RICCAR

Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region

Training Manual on the Use of GIS to Analyse Climate Change Data

THE LEAGUE OF ARAB STATES
THE ARAB CENTER FOR THE STUDIES OF ARID ZONES AND DRY LANDS
ACSAD
أكساد
1968

UNITED NATIONS
الاسكوا
ESCWA

Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region

RICCAR

Regional Initiative for the Assessment of
Climate Change Impacts on Water Resources and
Socio-Economic Vulnerability in the Arab Region

Training Manual on the Use of GIS to Analyse Climate Change Data

Regional Initiative for the Assessment of Climate Change Impacts on
Water Resources and Socio-Economic Vulnerability in the Arab Region (RICCAR)

Arab Center for the Studies
of Arid Zones and Dry Lands
(ACSAD)

United Nations Economic
and Social Commission for
Western Asia (ESCWA)

Email: publications-escwa@un.org
Website: www.unescwa.org; www.riccar.org

Available through:
United Nations Publication
E/ESCWA/SDPD/2019/RICCAR/Manual.2

United Nations Economic and Social Commission for Western Asia (ESCWA) and Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD). 2019. Training Manual on the Use of GIS to Analyse Climate Change Data. RICCAR Training Manual, Beirut, E/ESCWA/SDPD/2019/RICCAR/Manual.2

Authors:
United Nations Economic and Social Commission for Western Asia (ESCWA)
Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) of the League of Arab States

Layout: Ghazal Lababidi

PREFACE

The Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region (RICCAR) is a joint initiative of the United Nations and the League of Arab States launched in 2010.

RICCAR is implemented through a collaborative partnership involving 11 regional and specialized organizations, namely the United Nations Economic and Social Commission for Western Asia (ESCWA), the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD), Food and Agriculture Organization of the United Nations (FAO), Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), the League of Arab States, Swedish Meteorological and Hydrological Institute (SMHI), United Nations Environment Programme (UN Environment), United Nations Educational, Scientific and Cultural Organization (UNESCO) Office in Cairo, United Nations Office for Disaster Risk Reduction (UNISDR), United Nations University Institute for Water, Environment and Health (UNU-INWEH), and World Meteorological Organization (WMO). ESCWA coordinates the regional initiative. Funding for RICCAR is provided by the Government of Sweden and the Government of the Federal Republic of Germany.

RICCAR is implemented under the auspices of the Arab Ministerial Water Council and derives its mandate from resolutions adopted by this council as well as the Council of Arab Ministers Responsible for the Environment, the Arab Permanent Committee for Meteorology and the 25th ESCWA Ministerial Session.

Funding for this report was provided by the Swedish Government through the Swedish International Development Cooperation Agency.

This manual was prepared by ESCWA and ACSAD. An Arabic version of this report with supplementary exercises is available as E/ESCWA/SDPD/2019/GUIDE.4

CONTENTS

FIGURES

TABLES

ACRONYMS AND ABBREVIATIONS

ACSAD	Arab Center for the Studies of Arid Zones and Dry Lands
CNRM-CM5	Centre National de Recherches Météorologiques- Climate Model 5
CORDEX	Coordinated Regional Climate Downscaling Experiment
CORDEX-MENA	Coordinated Regional Climate Downscaling Experiment - Middle East North Africa
DJF	December-January-February
EC-EARTH	ECMWF-based Earth-system model
ESCWA	United Nations Economic and Social Commission for Western Asia
ESGF	Earth System Grid Federation
GCM	global climate model or general circulation model
GFDL-ESM2M	Geophysical Fluid Dynamics Laboratory-Earth System Model 2
GIS	Geographic Information Systems
JJA	June-July-August
MAM	March-April-May
mm	millimetres
MNA22	25-km resolution (MENA domain 0.22 degrees)
MNA44	50-km resolution (MENA domain 0.44 degrees)
NetCDF	Network Common Data Form
RCA4	Rossby Centre Regional Atmospheric Model 4
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
RICCAR	Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region
RKH	Regional Knowledge Hub
SMHI	Swedish Meteorological and Hydrological Institute
SON	September-October-November

1 INTRODUCTION

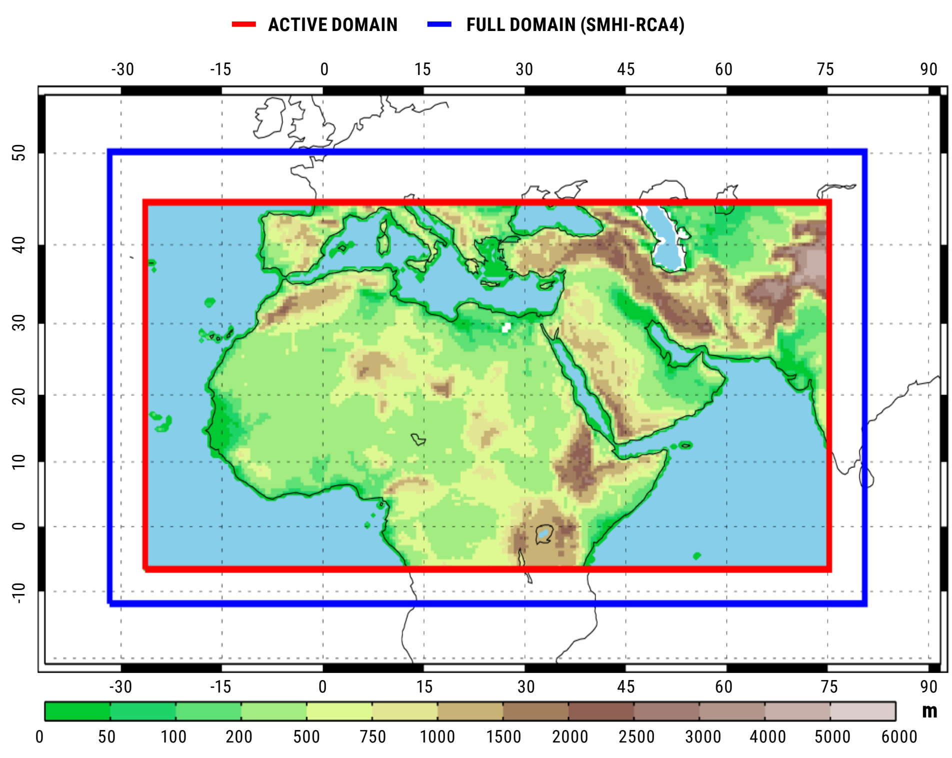
The present training manual serves as a guide that describes how users can download and utilise climate data developed within the framework of the Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region (RICCAR). Although climate data can be used on different platforms for analysis, evaluation using Geographic Information Systems (GIS) tools from ESRI ArcMap is solely considered in this manual.

2 SUMMARY OF RICCAR CLIMATE CHANGE DATA

Climate data outputs within the Arab Domain (figure 1) are described in the *Arab Climate Change Assessment Report – Main Report*. Data includes temperature, precipitation, and extreme events ensembles for three time periods (reference period, mid-century, and end-century), and according to two climate scenarios (RCP4.5 and RCP8.5). These ensembles were derived from bias-corrected regional climate modelling (RCM) outputs adapted from the Coordinated Regional Climate Downscaling Experiment (CORDEX). These outputs include modelled temperature and precipitation data from 1951-2100 with daily frequencies (table 1), and extreme events outputs from 1951-2100 with annual and seasonal frequencies (tables 2 and 3) for each of the studied driving global climate models (GCMs), namely CNRM-CM5, EC-EARTH, and GFDL-ESM2M. Results are available for different climate scenarios and at various spatial resolutions. Details regarding the modelling methodology can be found in the RICCAR Technical Note entitled *Regional Climate Modelling and Regional Hydrological Modelling Applications in the Arab Region*.[1]

Climate modelling outputs are accessible online. Users can download the bias-corrected RCM outputs from the Regional Knowledge Hub (RKH) data portal.[2] The raw RCM outputs (non-bias-corrected) adapted for RICCAR, other climate variables, and outputs from other domains can be obtained from CORDEX data available on the Earth System Grid Federation (ESGF) data portal.[3] More information on CORDEX and the ESGF is described in a RICCAR technical note entitled *Guidelines for Accessing CORDEX Regional Climate Projections*.[4] Users can obtain and use these datasets for institutional case studies and research. It is recommended to avoid mixing bias-corrected and raw RCM outputs.

FIGURE 1: Arab Domain (CORDEX- MENA Domain)



Source: ESCWA and others (2017). Arab Climate Change Assessment Report – Main Report., E/ESCWA/SDPD/2017/RICCAR/Report.

TABLE 1: Precipitation and temperature regional climate modelling outputs

Climate parameter	Abbreviation	Climate scenario	Driving Global Climate Model (GCM)	Data period	Spatial resolution
Precipitation	pr	RCP2.6	EC-EARTH	1951-2100	50 x 50 km
Precipitation	pr	RCP4.5	CNRM-CM5	1951-2100	50 x 50 km
Precipitation	pr	RCP4.5	EC-EARTH	1951-2100	50 x 50 km
Precipitation	pr	RCP4.5	GFDL-ESM2M	1951-2100	50 x 50 km
Precipitation	pr	RCP8.5	EC-EARTH	1951-2100	25 x 25 km
Precipitation	pr	RCP8.5	GFDL-ESM2M	1951-2100	25 x 25 km
Precipitation	pr	RCP8.5	CNRM-CM5	1951-2100	50 x 50 km
Precipitation	pr	RCP8.5	EC-EARTH	1951-2100	50 x 50 km
Precipitation	pr	RCP8.5	GFDL-ESM2M	1951-2100	50 x 50 km
Temperature	tas	RCP2.6	EC-EARTH	1951-2100	50 x 50 km
Temperature	tas	RCP4.5	CNRM-CM5	1951-2100	50 x 50 km
Temperature	tas	RCP4.5	EC-EARTH	1951-2100	50 x 50 km
Temperature	tas	RCP4.5	GFDL-ESM2M	1951-2100	50 x 50 km
Temperature	tas	RCP8.5	EC-EARTH	1951-2100	25 x 25 km
Temperature	tas	RCP8.5	GFDL-ESM2M	1951-2100	25 x 25 km
Temperature	tas	RCP8.5	CNRM-CM5	1951-2100	50 x 50 km
Temperature	tas	RCP8.5	EC-EARTH	1951-2100	50 x 50 km
Temperature	tas	RCP8.5	GFDL-ESM2M	1951-2100	50 x 50 km
Maximum temperature	tasmax	RCP2.6	EC-EARTH	1951-2100	50 x 50 km
Maximum temperature	tasmax	RCP4.5	CNRM-CM5	1951-2100	50 x 50 km
Maximum temperature	tasmax	RCP4.5	EC-EARTH	1951-2100	50 x 50 km
Maximum temperature	tasmax	RCP4.5	GFDL-ESM2M	1951-2100	50 x 50 km
Maximum temperature	tasmax	RCP8.5	EC-EARTH	1951-2100	25 x 25 km
Maximum temperature	tasmax	RCP8.5	GFDL-ESM2M	1951-2100	25 x 25 km
Maximum temperature	tasmax	RCP8.5	CNRM-CM5	1951-2100	50 x 50 km
Maximum temperature	tasmax	RCP8.5	EC-EARTH	1951-2100	50 x 50 km
Maximum temperature	tasmax	RCP8.5	GFDL-ESM2M	1951-2100	50 x 50 km
Minimum temperature	tasmin	RCP2.6	EC-EARTH	1951-2100	50 x 50 km
Minimum temperature	tasmin	RCP4.5	CNRM-CM5	1951-2100	50 x 50 km
Minimum temperature	tasmin	RCP4.5	EC-EARTH	1951-2100	50 x 50 km
Minimum temperature	tasmin	RCP4.5	GFDL-ESM2M	1951-2100	50 x 50 km
Minimum temperature	tasmin	RCP8.5	EC-EARTH	1951-2100	25 x 25 km
Minimum temperature	tasmin	RCP8.5	GFDL-ESM2M	1951-2100	25 x 25 km
Minimum temperature	tasmin	RCP8.5	CNRM-CM5	1951-2100	50 x 50 km
Minimum temperature	tasmin	RCP8.5	EC-EARTH	1951-2100	50 x 50 km
Minimum temperature	tasmin	RCP8.5	GFDL-ESM2M	1951-2100	50 x 50 km

TABLE 2: Extreme temperature indices climate modelling outputs

Index	Long name	Climate scenario	Driving Global Climate Model (GCM)	Data period	Spatial resolution
SU	Number of summer days	RCP4.5	CNRM-CM5	1951-2100	50 x 50 km
SU	Number of summer days	RCP4.5	EC-EARTH	1951-2100	50 x 50 km
SU	Number of summer days	RCP4.5	GFDL-ESM2M	1951-2100	50 x 50 km
SU	Number of summer days	RCP8.5	CNRM-CM5	1951-2100	50 x 50 km
SU	Number of summer days	RCP8.5	EC-EARTH	1951-2100	50 x 50 km
SU	Number of summer days	RCP8.5	GFDL-ESM2M	1951-2100	50 x 50 km
SU35	Number of hot days	RCP2.6	EC-EARTH	1951-2100	50 x 50 km
SU35	Number of hot days	RCP4.5	CNRM-CM5	1951-2100	50 x 50 km
SU35	Number of hot days	RCP4.5	EC-EARTH	1951-2100	50 x 50 km
SU35	Number of hot days	RCP4.5	GFDL-ESM2M	1951-2100	50 x 50 km
SU35	Number of hot days	RCP8.5	CNRM-CM5	1951-2100	50 x 50 km
SU35	Number of hot days	RCP8.5	EC-EARTH	1951-2100	50 x 50 km
SU35	Number of hot days	RCP8.5	GFDL-ESM2M	1951-2100	50 x 50 km
SU40	Number of very hot days	RCP2.6	EC-EARTH	1951-2100	50 x 50 km
SU40	Number of very hot days	RCP4.5	CNRM-CM5	1951-2100	50 x 50 km
SU40	Number of very hot days	RCP4.5	EC-EARTH	1951-2100	50 x 50 km
SU40	Number of very hot days	RCP4.5	GFDL-ESM2M	1951-2100	50 x 50 km
SU40	Number of very hot days	RCP8.5	CNRM-CM5	1951-2100	50 x 50 km
SU40	Number of very hot days	RCP8.5	EC-EARTH	1951-2100	50 x 50 km
SU40	Number of very hot days	RCP8.5	GFDL-ESM2M	1951-2100	50 x 50 km
TR	Number of tropical nights	RCP2.6	EC-EARTH	1951-2100	50 x 50 km
TR	Number of tropical nights	RCP4.5	CNRM-CM5	1951-2100	50 x 50 km
TR	Number of tropical nights	RCP4.5	EC-EARTH	1951-2100	50 x 50 km
TR	Number of tropical nights	RCP4.5	GFDL-ESM2M	1951-2100	50 x 50 km
TR	Number of tropical nights	RCP8.5	CNRM-CM5	1951-2100	50 x 50 km
TR	Number of tropical nights	RCP8.5	EC-EARTH	1951-2100	50 x 50 km
TR	Number of tropical nights	RCP8.5	GFDL-ESM2M	1951-2100	50 x 50 km

TABLE 3: Extreme precipitation indices climate modelling outputs

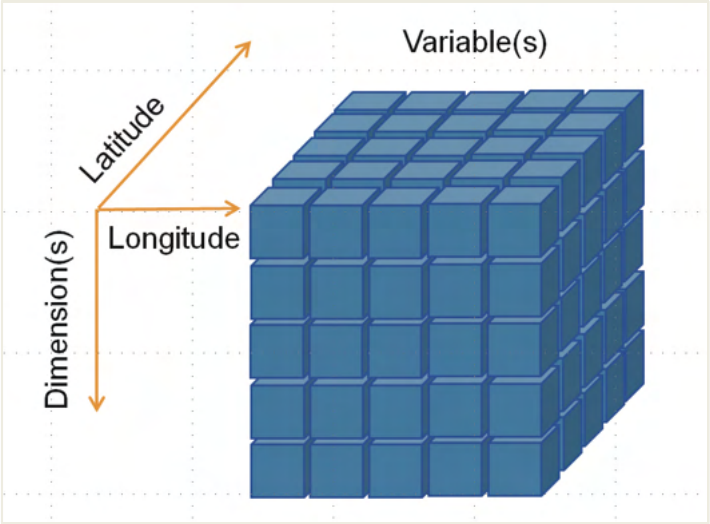
Index	Long name	Climate scenario	Driving Global Climate Model (GCM)	Data period	Spatial resolution
CDD	Maximum length of dry spell	RCP2.6	EC-EARTH	1951-2100	50 x 50 km
CDD	Maximum length of dry spell	RCP4.5	CNRM-CM5	1951-2100	50 x 50 km
CDD	Maximum length of dry spell	RCP4.5	EC-EARTH	1951-2100	50 x 50 km
CDD	Maximum length of dry spell	RCP4.5	GFDL-ESM2M	1951-2100	50 x 50 km
CDD	Maximum length of dry spell	RCP8.5	CNRM-CM5	1951-2100	50 x 50 km
CDD	Maximum length of dry spell	RCP8.5	EC-EARTH	1951-2100	50 x 50 km
CDD	Maximum length of dry spell	RCP8.5	GFDL-ESM2M	1951-2100	50 x 50 km
CWD	Maximum length of wet spell	RCP2.6	EC-EARTH	1951-2100	50 x 50 km
CWD	Maximum length of wet spell	RCP4.5	CNRM-CM5	1951-2100	50 x 50 km
CWD	Maximum length of wet spell	RCP4.5	EC-EARTH	1951-2100	50 x 50 km
CWD	Maximum length of wet spell	RCP4.5	GFDL-ESM2M	1951-2100	50 x 50 km
CWD	Maximum length of wet spell	RCP8.5	CNRM-CM5	1951-2100	50 x 50 km
CWD	Maximum length of wet spell	RCP8.5	EC-EARTH	1951-2100	50 x 50 km
CWD	Maximum length of wet spell	RCP8.5	GFDL-ESM2M	1951-2100	50 x 50 km
R10	Count of 10 mm precipitation days	RCP2.6	EC-EARTH	1951-2100	50 x 50 km
R10	Count of 10 mm precipitation days	RCP4.5	CNRM-CM5	1951-2100	50 x 50 km
R10	Count of 10 mm precipitation days	RCP4.5	EC-EARTH	1951-2100	50 x 50 km
R10	Count of 10 mm precipitation days	RCP4.5	GFDL-ESM2M	1951-2100	50 x 50 km
R10	Count of 10 mm precipitation days	RCP8.5	CNRM-CM5	1951-2100	50 x 50 km
R10	Count of 10 mm precipitation days	RCP8.5	EC-EARTH	1951-2100	50 x 50 km
R10	Count of 10 mm precipitation days	RCP8.5	GFDL-ESM2M	1951-2100	50 x 50 km
R20	Count of 20 mm precipitation days	RCP2.6	EC-EARTH	1951-2100	50 x 50 km
R20	Count of 20 mm precipitation days	RCP4.5	CNRM-CM5	1951-2100	50 x 50 km
R20	Count of 20 mm precipitation days	RCP4.5	EC-EARTH	1951-2100	50 x 50 km
R20	Count of 20 mm precipitation days	RCP4.5	GFDL-ESM2M	1951-2100	50 x 50 km
R20	Count of 20 mm precipitation days	RCP8.5	CNRM-CM5	1951-2100	50 x 50 km
R20	Count of 20 mm precipitation days	RCP8.5	EC-EARTH	1951-2100	50 x 50 km
R20	Count of 20 mm precipitation days	RCP8.5	GFDL-ESM2M	1951-2100	50 x 50 km
SDII	Simple precipitation intensity index	RCP2.6	EC-EARTH	1951-2100	50 x 50 km
SDII	Simple precipitation intensity index	RCP4.5	CNRM-CM5	1951-2100	50 x 50 km
SDII	Simple precipitation intensity index	RCP4.5	EC-EARTH	1951-2100	50 x 50 km
SDII	Simple precipitation intensity index	RCP4.5	GFDL-ESM2M	1951-2100	50 x 50 km
SDII	Simple precipitation intensity index	RCP8.5	CNRM-CM5	1951-2100	50 x 50 km
SDII	Simple precipitation intensity index	RCP8.5	EC-EARTH	1951-2100	50 x 50 km
SDII	Simple precipitation intensity index	RCP8.5	GFDL-ESM2M	1951-2100	50 x 50 km

3 ARCMAP MULTIDIMENSION TOOL

3.1 Introduction to NetCDF format

Regional climate modelling outputs are available in Network Common Data Form (NetCDF) format (.nc). NetCDF files enable storage of multidimensional datasets (figure 2). Each variable can be displayed through a dimension, such as time. They can be used on different software platforms, including MATLAB, Python, and R, but only ArcMap GIS will be discussed in the present training manual.

FIGURE 2: Three-dimensional NetCDF array



The RICCAR Arab Domain climate data files have a naming convention similar to the following:

pr_MNA-44_CNRM-CERFACS-CNRM-CM5_historicalandrcp45_r1i1p1_SMHI-RCA4_v1-bc-dbs-wfdei_day_19510101-21001231_2046_2046.nc

where:

- **pr** is the climate variable
- **MNA-44** is the CORDEX domain and spatial resolution
- **CNRM-CERFACS-CNRM-CM5** is the global climate model
- **historicalandrcp45** is the climate scenario
- **r1i1p1** is the experimental ensemble calculation
- **SMHI-RCA4** is the regional climate model
- **v1-bc-dbs-wfdei** is the bias-correction method
- **day** is the temporal resolution
- **19510101-21001231** is the period of the entire dataset
- **2046_2046** is the year of this NetCDF file.

Each file has 365 dimensions, representing each day of the year (for leap years, there are 366 dimensions).

For the extreme event indices, files are available both annually (ANN) or seasonally: DJF for December- January-February; MAM for March-April-May; JJA for June-July-August; and SON for September-October-November. Each file contains 150 dimensions, one for each year within the dataset. The file naming convention is described in the following example:

su35_MNA-44_ICHEC-EC-EARTH_rcp45_r12i1p1_SMHI-RCA4-DBS43-WFDEI-1980-2009_v1_day_1951-2100_SON.nc

where:

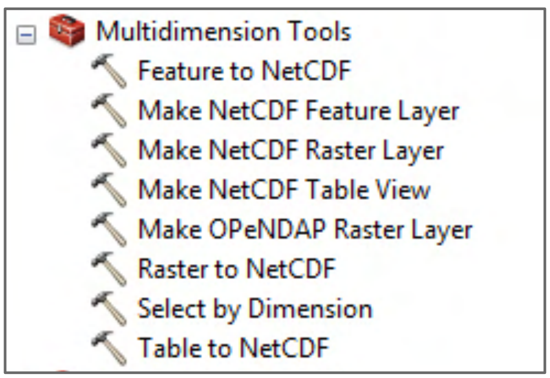
- **su35** is the climate variable
- **MNA-44** is the CORDEX domain and spatial resolution,
- **ICHEC-EC-EARTH** is the global climate model
- **rcp45** is the climate scenario
- **r12i1p1** is the experimental ensemble calculation
- **SMHI-RCA4** is the regional climate model
- **DBS43-WFDEI-1980-2009_v1_day** is the bias-correction method
- **1951-2100** is the period of the dataset
- **SON** is the season represented.

3.2 Creating raster files from NetCDF files

3.2.1 Creating raster layer files

NetCDF files cannot be added directly into ArcMap using the Add Data tool ( ). Instead, users must use a set of functions denoted as Multidimension Tools (figure 3).

FIGURE 3: List of Multidimension Tools in ArcMap



To visualize NetCDF files in ArcMap, select *Make NetCDF Raster Layer* (figure 4). Choose the NetCDF file and using the drop-down boxes, choose the relevant climate variable, X dimension, and Y dimension. The X- and Y-dimensions should be lon and lat, respectively, denoting longitude and latitude. This will direct the raster layer to be projected into a standardized coordinate system, facilitating a match with useful shapefiles, such as cities, country borders, and landmarks. For *Output Raster Layer*, users can leave the default name or designate a different file name.

The resultant raster layer in ArcMap (figure 5) will represent the first-time band in the NetCDF file, which will be 1 January for the temperature and precipitation files or the first year for each of the extreme events indices.

FIGURE 4: *Make NetCDF Raster Layer* tool

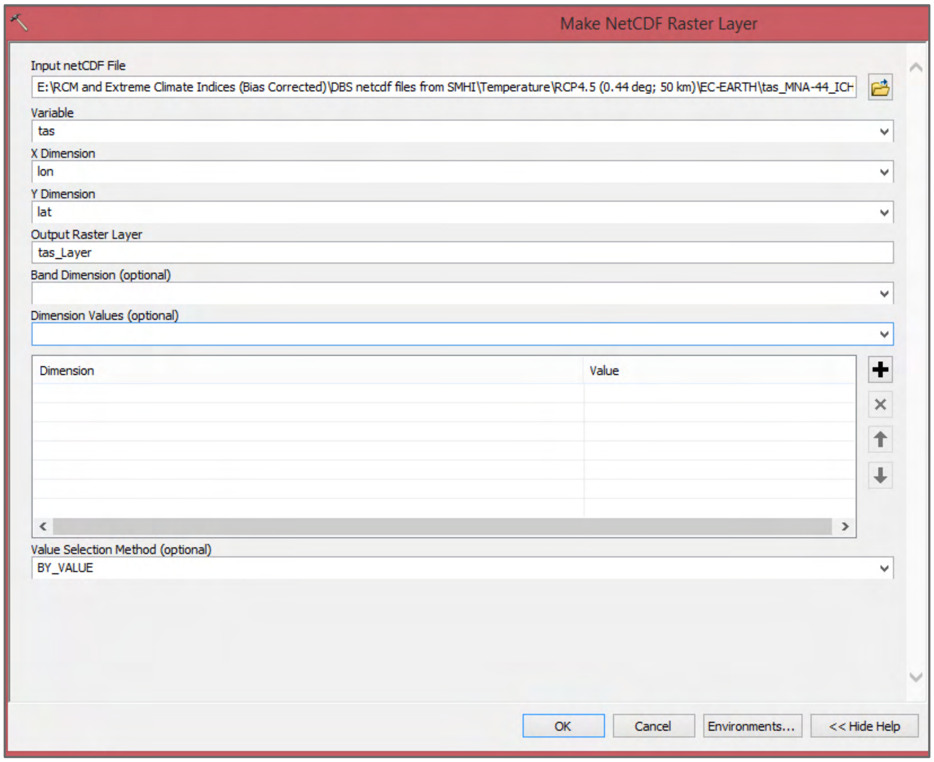
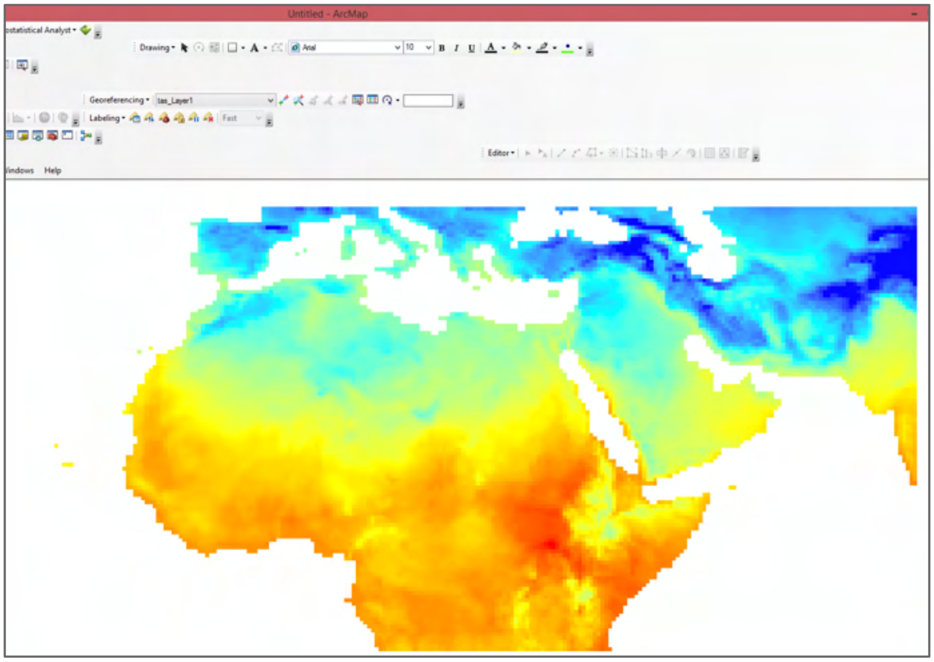


FIGURE 5: Raster Layer from NetCDF file



To visualize other time bands, choose *Layer Properties* from the raster layer *file* in the Table of Contents. Select the tab denoted as NetCDF. There, users can see the different time bands available in the file and can choose one accordingly (figure 6).

It is worthy to note that the raster layer is only temporarily stored in the computer memory. Users can either save the raster layer or export the time band shown to a raster file by right-clicking on the file in the Table of Contents, and selecting Data > Export Data.

Users may notice that in cases of some coastal areas, no raster is shown (figure 7). This is because during the bias-correction process, grid cells which comprised less than 50 per cent as a water body were eliminated. To obtain RCM outputs at these locations, it is recommended to either select the nearest grid value or to extrapolate values (see section 5 of the present manual).

FIGURE 6: NetCDF Raster Layer properties

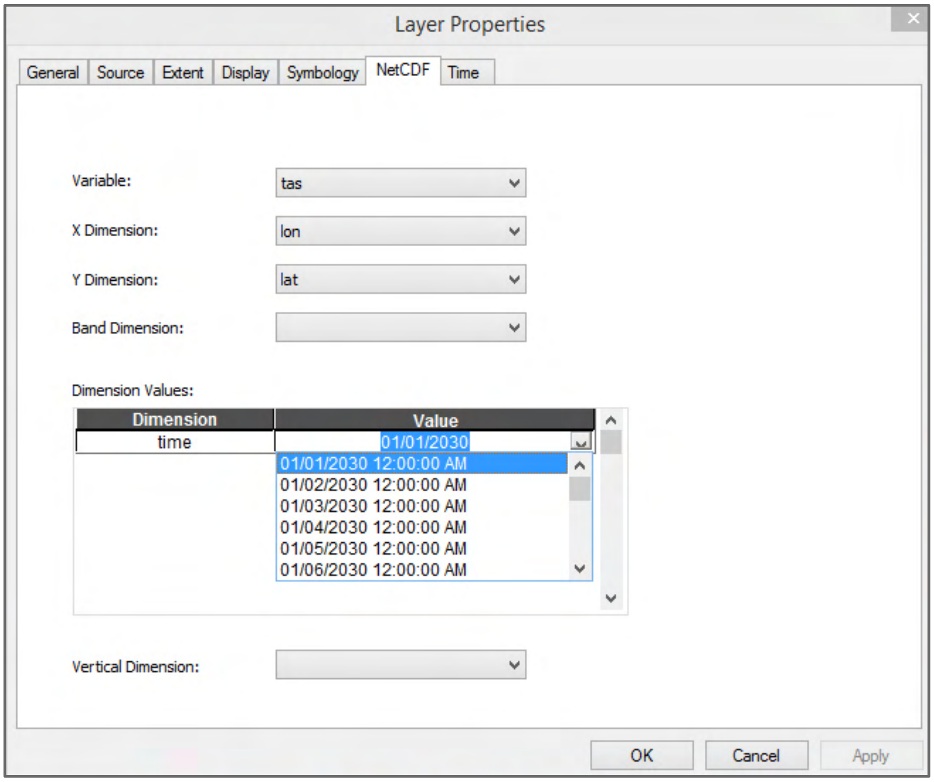
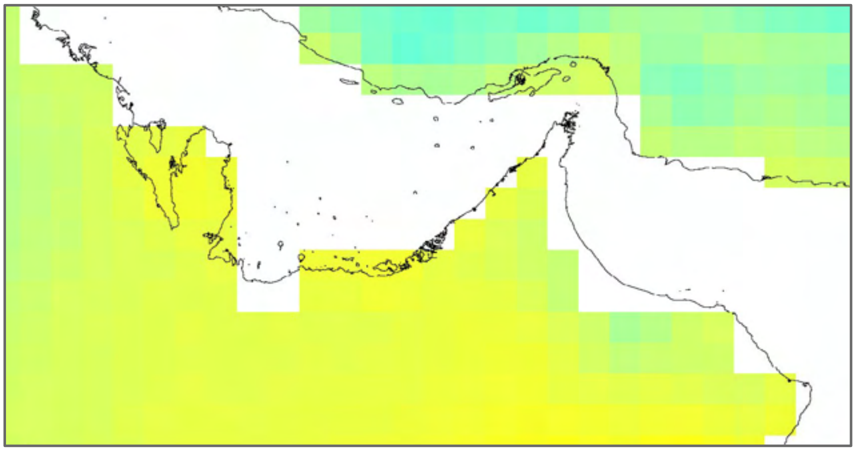


FIGURE 7: NetCDF Raster Layer zoomed in to shown gapped coastal areas

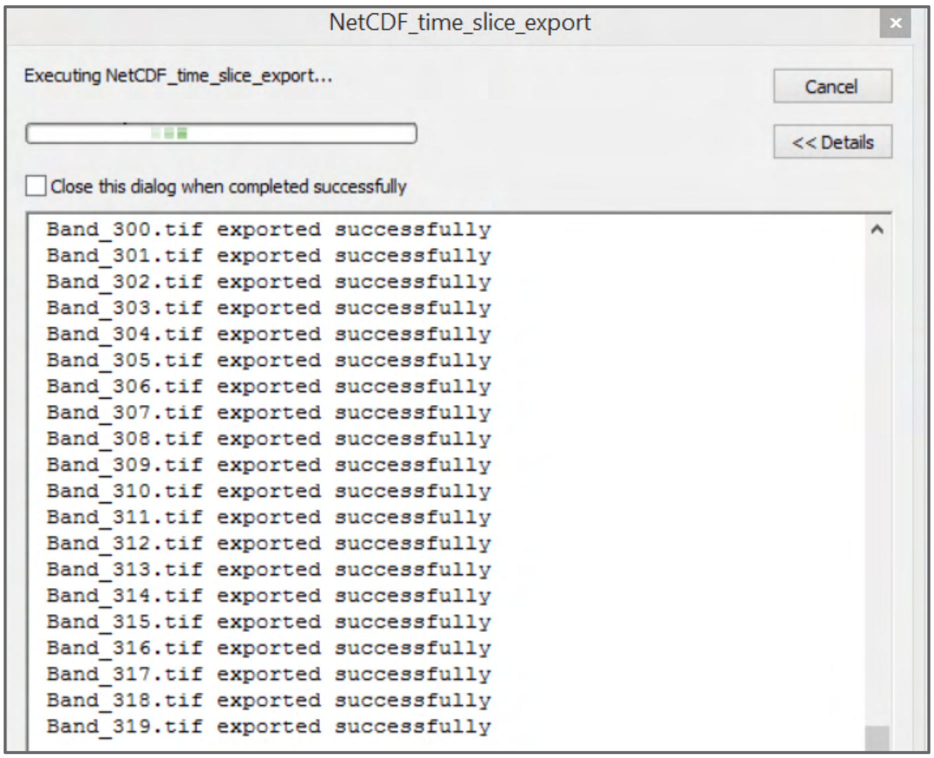


3.2.2 Extracting multiple time slices from raster layer files

Rather than exporting each individual time slice from NetCDF raster layers, a dedicated tool that automates the process is available for download[5] from ESRI. Exporting multiple NetCDF files to rasters will help users to develop ensembles (see section 5 of the present manual).

When using the *NetCDF time slice export* tool, it is recommended to use a unique folder for each NetCDF file. By default, the individual time band rasters will be named Band_n, where n varies (figure 8). For temperature and precipitation NetCDF files, the numbers correspond to the day of the year according to a Gregorian calendar. For example, Band_1 represents 1 January, Band_2 represents 2 January, and Band_365 represents 31 December. The RICCAR NetCDF files do consider leap years, whereby every four years an extra calendar day is added. In such cases, Band_366 represents 31 December. For the extreme events indices, each of the bands represent a single year such that Band_1 is 1951 and Band_150 is 2100.

FIGURE 8: NetCDF time slice export tool in process



3.2.3 Using model builder to extract rasters for subareas of interest

The model builder can help expedite creating raster layers from multiple NetCDF files, which can be clipped to a specific area of interest. The area of interest should be defined by a shapefile.

Begin by dragging the *Make NetCDF Raster Layer* tool over to the Model Builder (figure 9). The Model Builder will perform the same action multiple times by iteration. To do this, select Insert>Iterators>Files. To instruct the model to use the file as input, connect *File* to *Make NetCDF Raster Layer*. Then, right click on the *File* icon and select Rename. Add .nc to the File name to instruct the model to only select NetCDF files (figure 10). The NetCDF files should all be in a single folder (Note that the entire folder name, including parent folders, should be kept to a minimum otherwise there may be problems with running the model). Avoid mixing different climate parameters, GCMs, and RCPs to minimize confusion. Select Insert>Create Variable>Folder and connect the *Folder* icon to *Iterate Files* (figure 11).

FIGURE 9: Model Builder: Add *Make NetCDF Raster Layer*

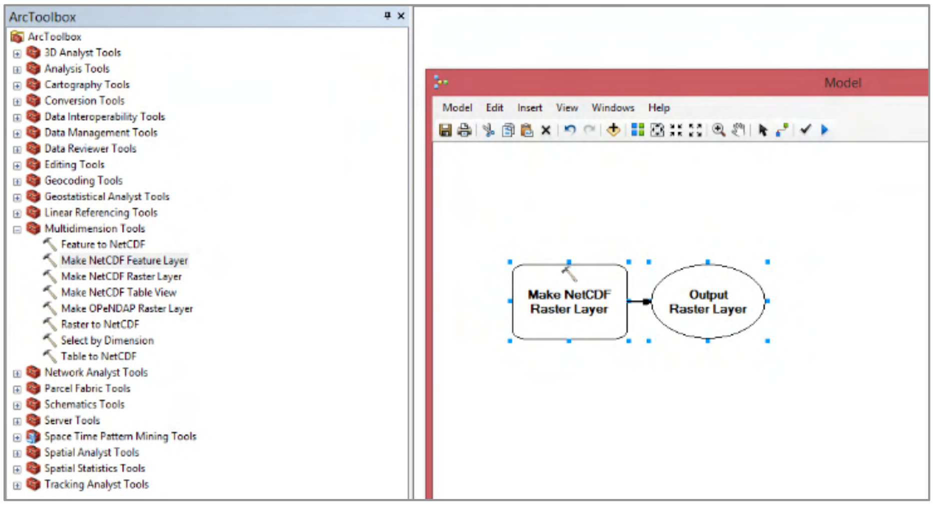


FIGURE 10: Model Builder: Iterate files

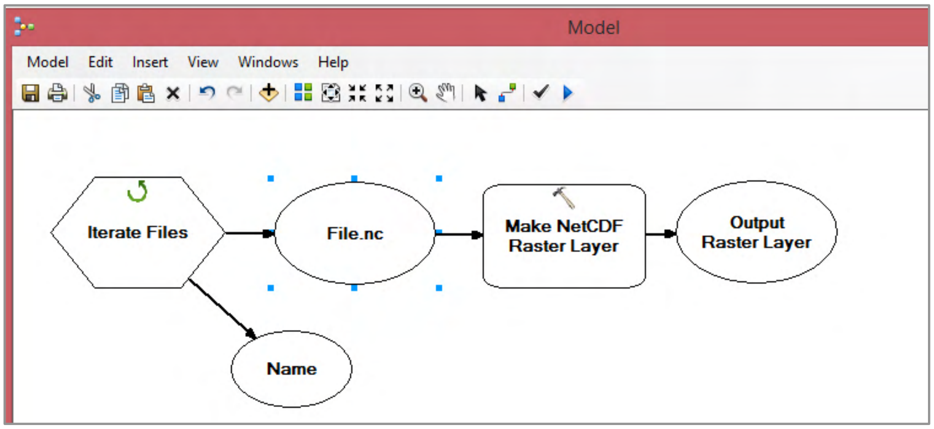
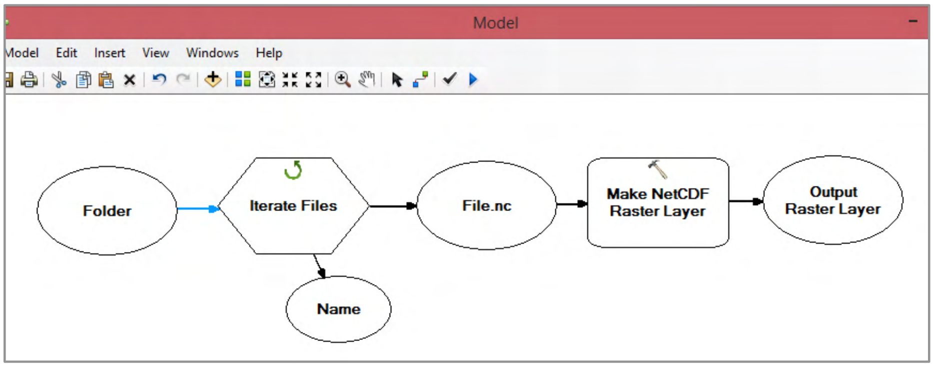


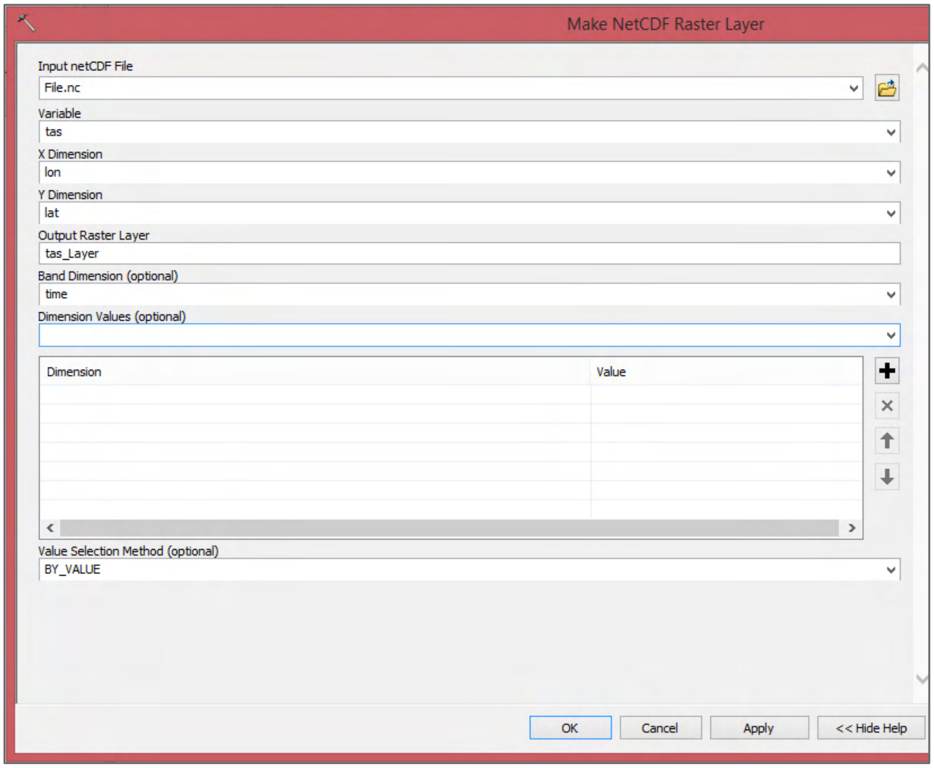
FIGURE 11: Model Builder: Create variable as folder



Double-click on the *Folder* icon and select the specific folder holding the NetCDF files. Icon elements in the model will then change to coloured, indicating that the model step is set up correctly. The *Make NetCDF Raster Layer* and *Output Raster Layer* icons remain blank because those elements have not been set up yet.

Double-click on the *Make NetCDF Raster Layer* icon. The default will show File.nc for *Input NetCDF File* and the only available variable will be called Name. To set up the tool correctly, select the first NetCDF file from the folder that will be modelled, along with the variables, just as would be done to create a single raster file. The Output Raster Layer name can be left as the default. Under Band Dimension, time should be selected to instruct the model to create a multiband raster layer (figure 12).

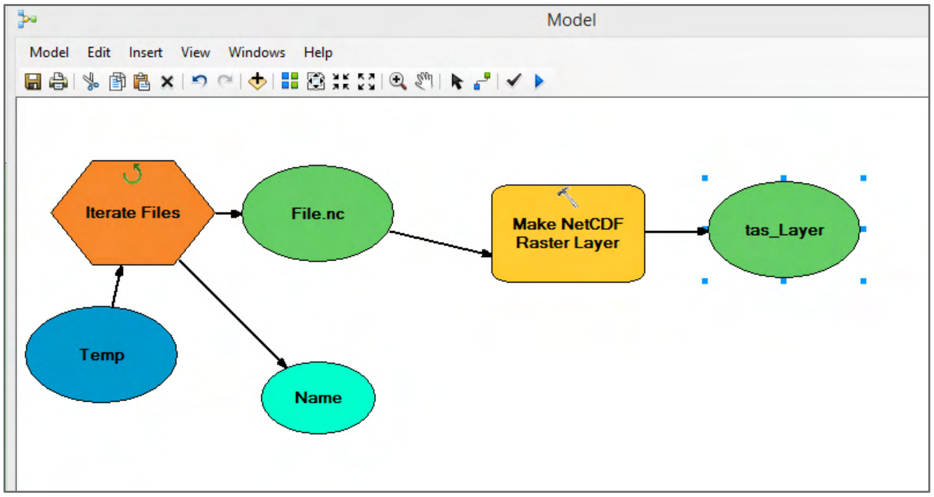
FIGURE 12: Enter data into *Make NetCDF Raster Layer*



A blue oval indicating at the NetCDF file will overlap the green oval for File.nc. The blue oval is now considered unneeded input and can simply be deleted (the *Make NetCDF Raster Layer* and *Output Raster Layer* icons will change back to white). Double-click on the *Make NetCDF Raster Layer* icon and confirm that the variable and x- and y-dimensions are correct.

Connect File.nc to *Make NetCDF Raster Layer* to instruct the model to perform the function on all NetCDF files in the selected folder (figure 13).

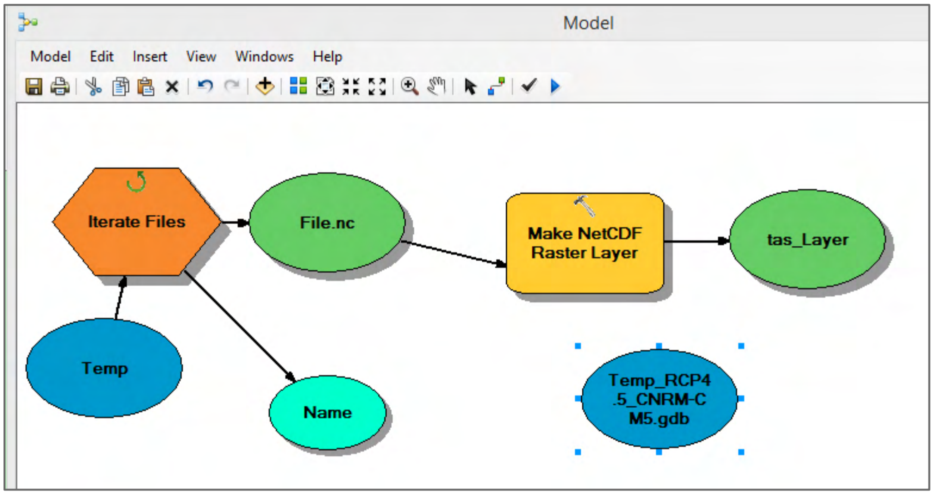
FIGURE 13: Model Builder: Perform process on all files in folder



At this point, run the model to confirm is it is operating correctly.

To visualize the output, select Insert>Create Variable>Workspace. Double-click on workspace and create a new geodatabase (.gdb) in the working folder. In this example, the geodatabase is named Temp_RCP4.5_CNRM-CM5.gdb (figure 14).

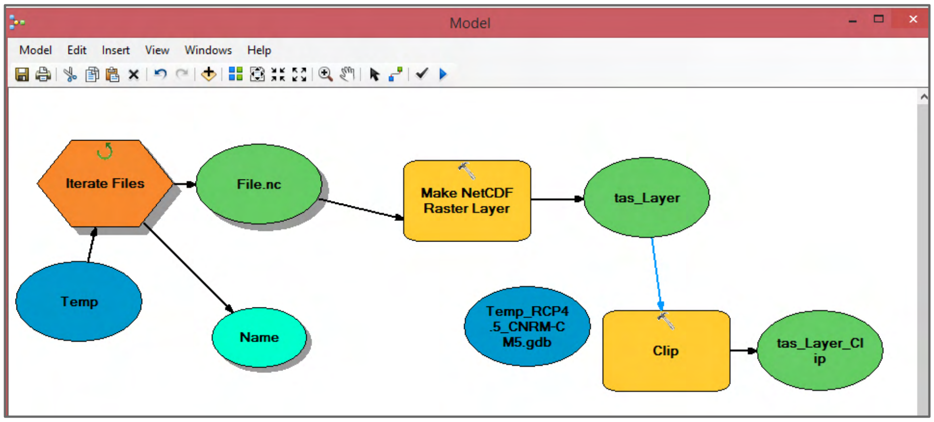
FIGURE 14: Model Builder: Add variable as workspace and create a geodatabase



It is not necessary at this point to connect the blue geodatabase oval to the rest of the model elements.

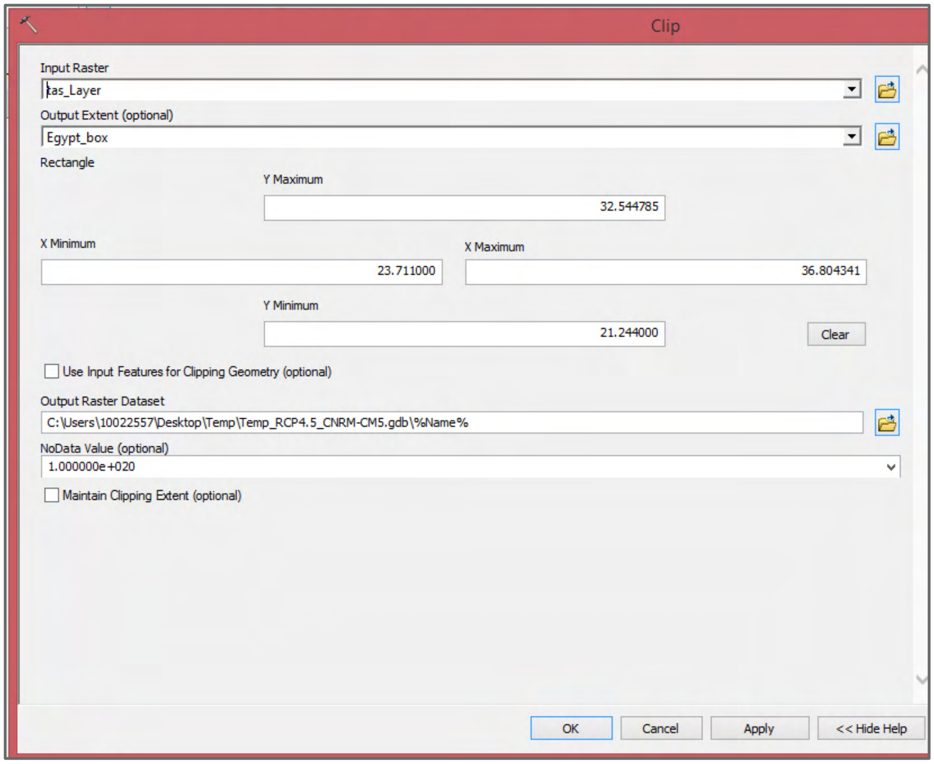
The final step is to clip the NetCDF raster files. Add the Clip tool to the model found under Data Management Tools>Raster>Raster Processing and connect it to the raster layer output (green oval) (figure 15).

FIGURE 15: Model Builder: Clip NetCDF rasters to area of interest



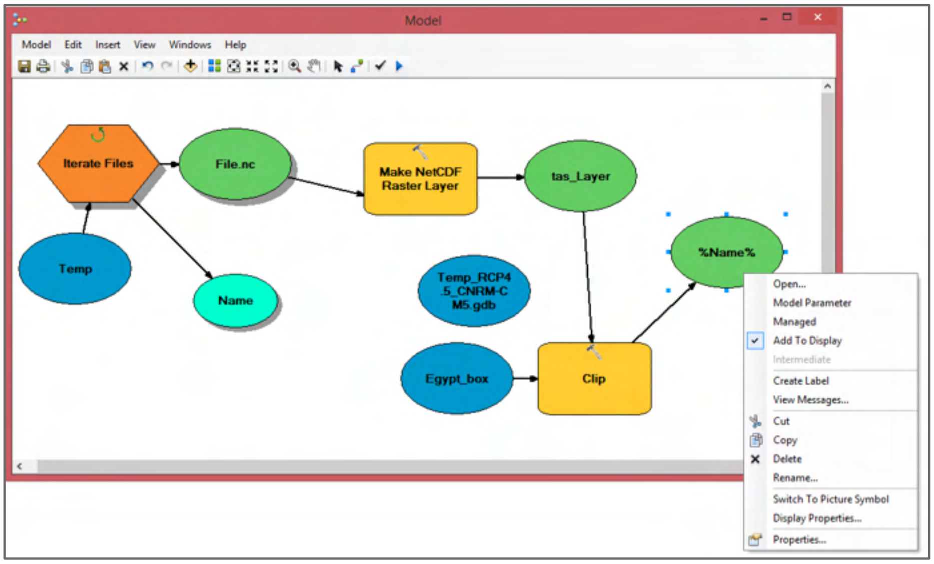
Double-click on the *Clip* icon. Under *Output Extent*, select the shapefile for the area of interest. The box for *Use Input Features for Clipping Geometry* should be selected. Under *Output Raster Dataset*, select the geodatabase created (for this example, Temp_RCP4.5_CNRM-CM5.gdb) and name the output (i.e. %Name%). This naming convention will name the files the same way as the original NetCDF files. For this to function, the original NetCDF files in the folder should have names of less than 13 characters, such as tas_2000, tas_2001, etc, representing the climate variable and year (figure 16).

FIGURE 16: Model Builder: Clip rasters



Right-click on the output icon and select Add to Display to view the raster files in ArcMap (figure 17). Run the model.

FIGURE 17: Model Builder: Add clipped rasters to display



The result will be one multiband raster file for each of the NetCDF files, clipped to the area of interest, which in this example is a box around Egypt (figure 18). By default, the first three-time bands are divided into three colour bands. Properties for each of the time bands can be viewed by right-clicking on the layer file in the Table of Contents and selecting Layer Properties (figure 19). Details for each of the time bands, including a preview of the individual raster band, can be obtained from the ArcCatalog (figure 20).

FIGURE 18: Model Builder: Clip NetCDF rasters to area of interest result

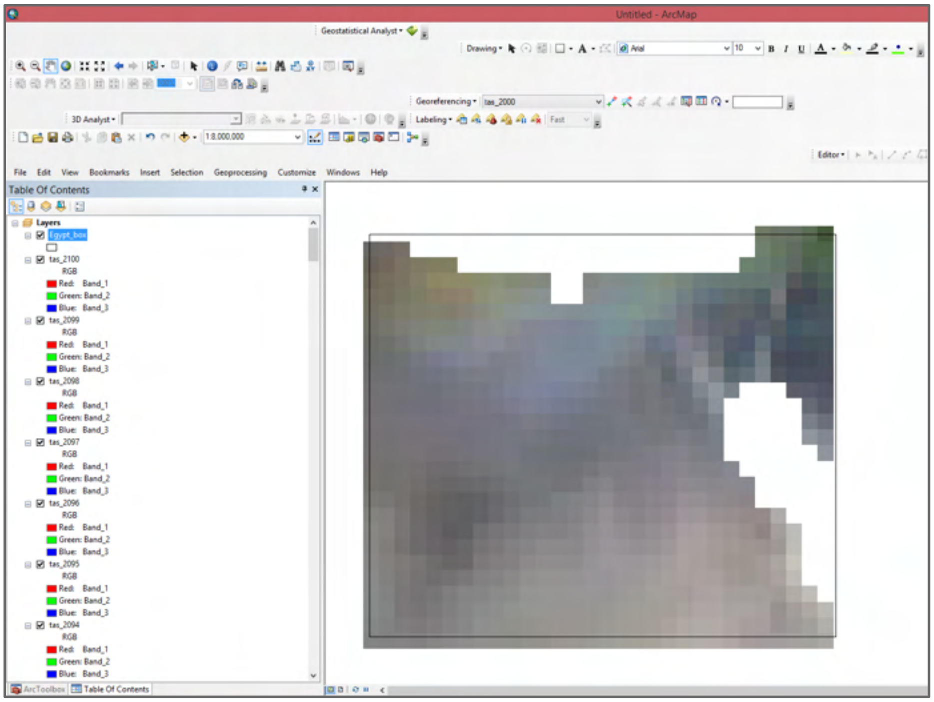


FIGURE 19: Multiband raster layer properties

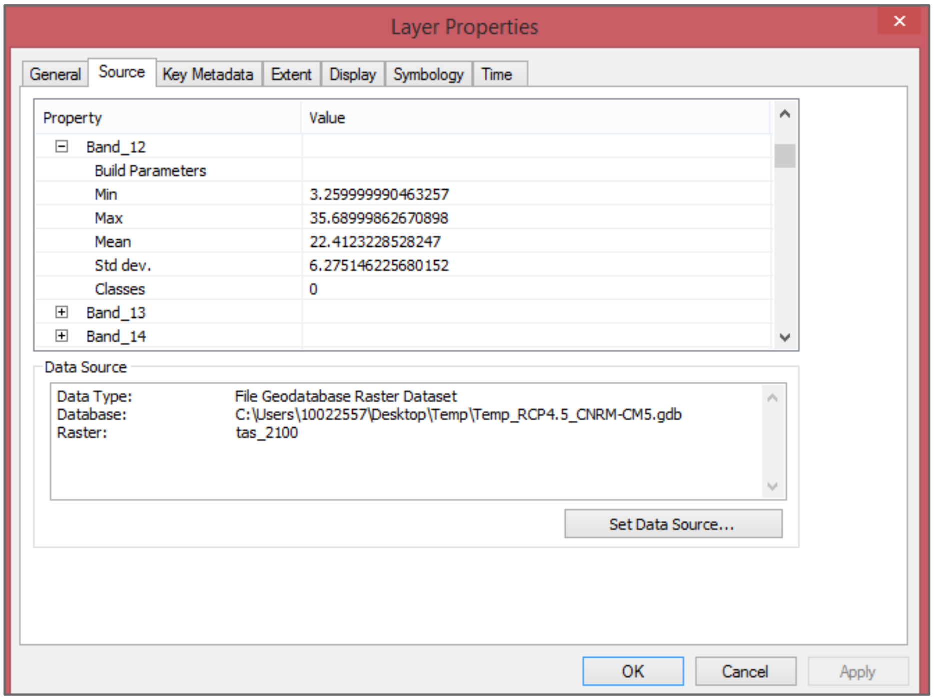
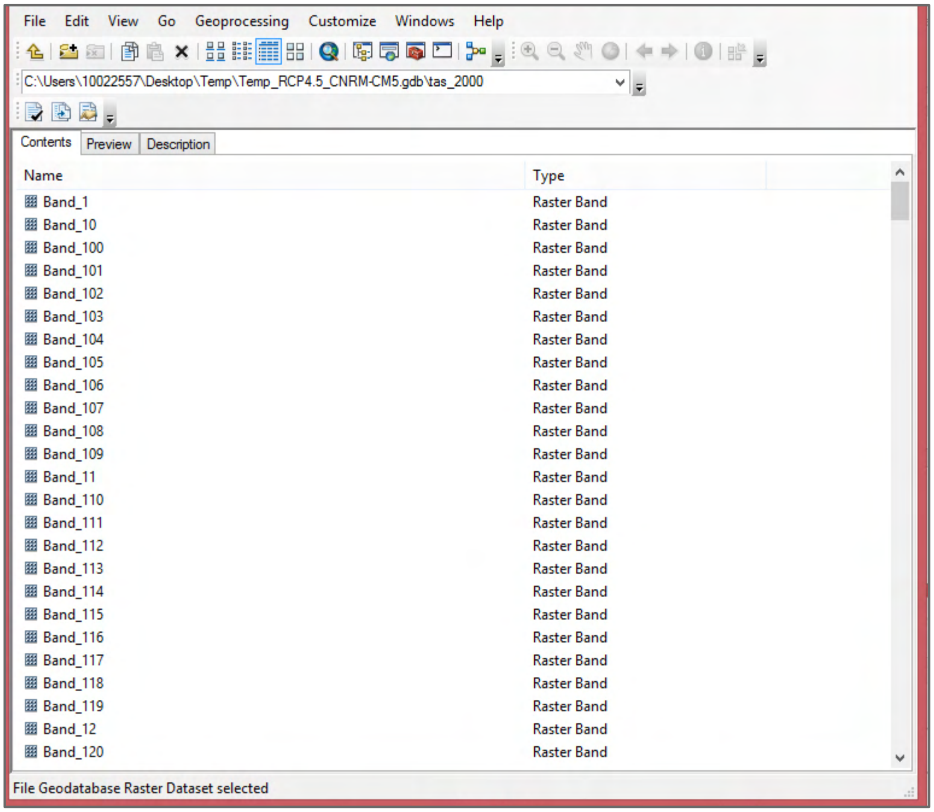


FIGURE 20: Multiband raster files in ArcCatalog

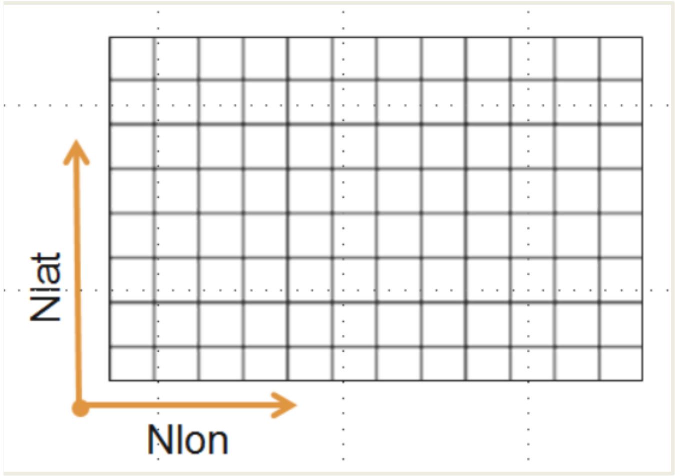


3.3 Creating tables from NetCDF files

3.3.1 Introduction to nlon and nlat

When creating raster files from NetCDF files, it is recommended to work in standard cartesian coordinates, designated as lon (longitude) and lat (latitude). When creating tabular data from the MNA-44 domain (50 x 50 km), users must work in nlon and nlat. In the case of nlat and nlon, coordinates are determined by the number of grid cells in the vertical and horizontal directions, respectively, originating at the bottom left corner (figure 21).

FIGURE 21: Grid system for nlat and nlon



For the MNA-44 domain (50 x 50 km), there are 232 horizontal cells and 118 vertical cells. For the MNA-22 domain (25 x 25 km), the number of cells doubles owing to the finer resolution, resulting in 464 horizontal cells and 236 vertical cells. For other domains, the number of cells will depend on the size of the domain and the spatial resolution.

Users can convert coordinates from conventional to nlon and nlat using equations 1 and 2 for MNA-44 and equations 3 and 4 for MNA-22.

$$\text{Nlat} = \frac{\text{lat} - (-6.82)}{0.44} \quad (1)$$

$$\text{Nlon} = \frac{\text{lon} - (-26.62)}{0.44} \quad (2)$$

$$\text{Nlat} = \frac{\text{lat} - (-6.82)}{0.22} \quad (3)$$

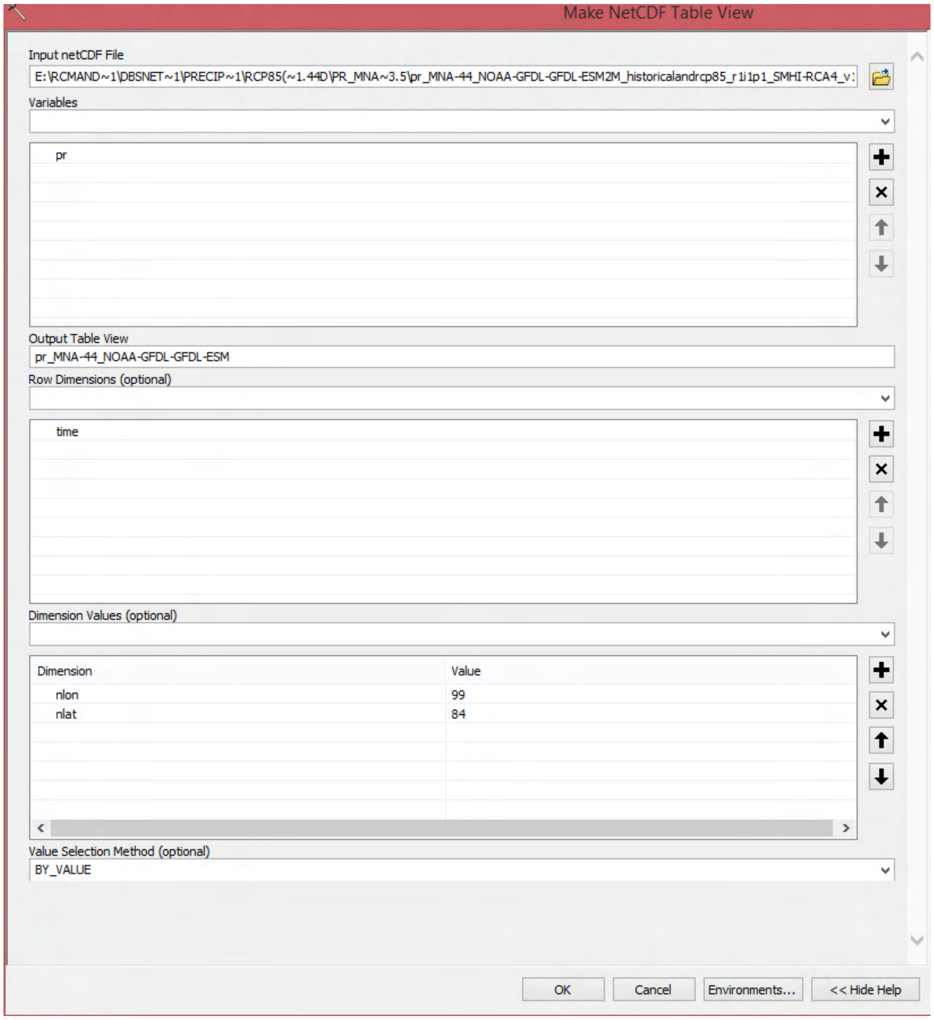
$$\text{Nlon} = \frac{\text{lon} - (-26.62)}{0.22} \quad (4)$$

Round the resultant nlon and nlat values to the nearest integer value, as the cell values are also integers. Smaller domains would likely require adjustments to the equations.

3.3.2 Creating table of climate data for a given location

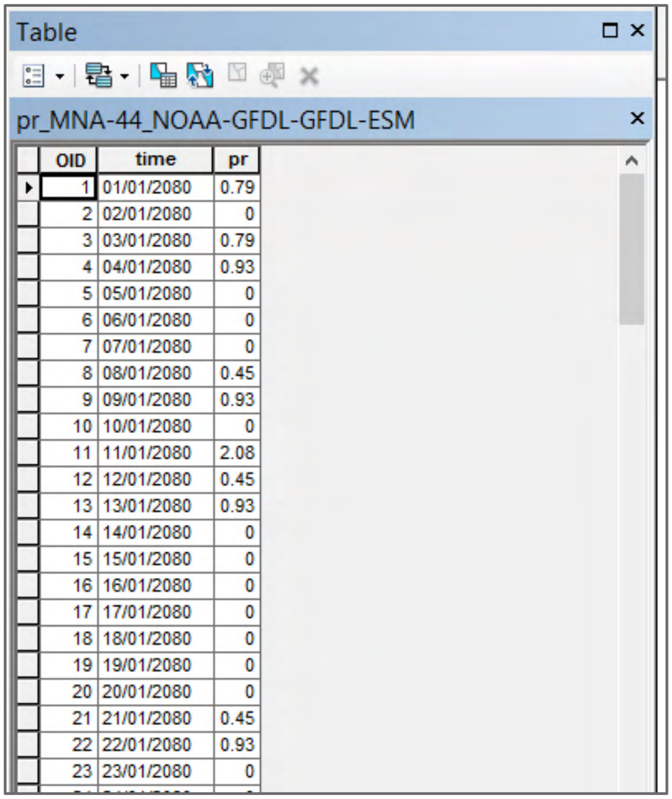
The *Make NetCDF Table View* tool found under the *Multidimension Tools* can generate a table of all values from a NetCDF file at a single location. Upon opening the tool, select the appropriate NetCDF file, select the applicable climate variable, enter time under row dimensions, and select nlon and nlat for the dimension values. Enter the appropriate nlon and nlat coordinates for the selected location (figure 22). In the example, Tunis is selected. Note that MNA-22 (25 x 25 km) data does not include nlon and nlat; instead, users select conventional longitude and latitude coordinates based on the centroid of the grid pixel. Shapefiles to help users determine nlon and nlat coordinates (for MNA-44) and centroid longitude and latitude coordinates (for MNA-22) are available upon request.

FIGURE 22: *Make NetCDF Table View* tool



The result will generate a table of values for a specified location (figure 23). Note the temporal resolution of the NetCDF file to obtain the correct units of measurement for the climate variable. For example, since precipitation is daily data, the resultant table values are in mm/day. Similarly, for seasonal extreme climate indices, units are days/season/year.

FIGURE 23: *Make NetCDF Table View* result



Table

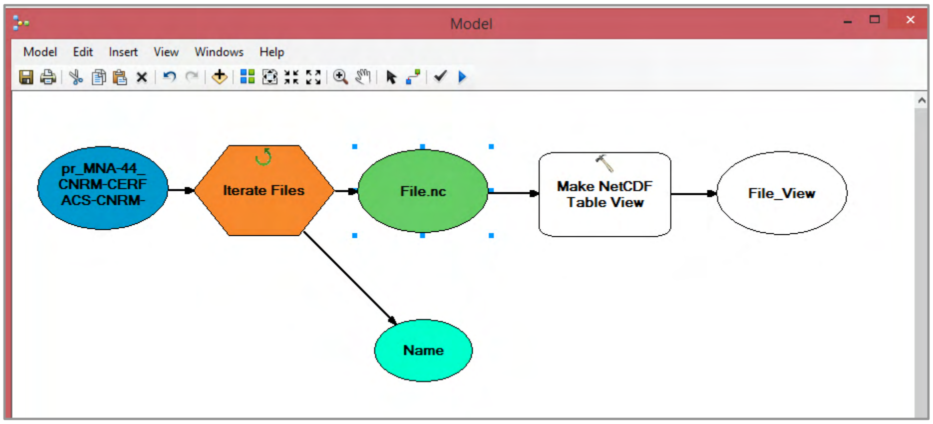
pr_MNA-44_NOAA-GFDL-GFDL-ESM

OID	time	pr
1	01/01/2080	0.79
2	02/01/2080	0
3	03/01/2080	0.79
4	04/01/2080	0.93
5	05/01/2080	0
6	06/01/2080	0
7	07/01/2080	0
8	08/01/2080	0.45
9	09/01/2080	0.93
10	10/01/2080	0
11	11/01/2080	2.08
12	12/01/2080	0.45
13	13/01/2080	0.93
14	14/01/2080	0
15	15/01/2080	0
16	16/01/2080	0
17	17/01/2080	0
18	18/01/2080	0
19	19/01/2080	0
20	20/01/2080	0
21	21/01/2080	0.45
22	22/01/2080	0.93
23	23/01/2080	0

3.3.3 Using the model builder to create a climate data table for multiple years

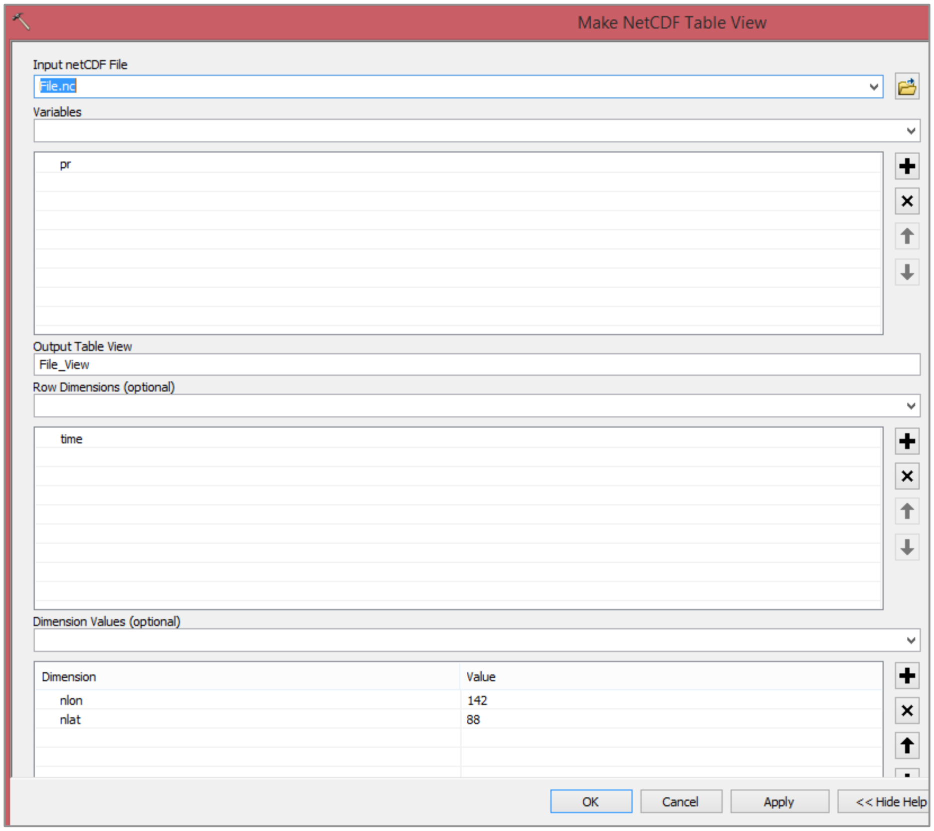
The Model Builder can be used to create a table containing values for a given climate parameter at a single point over multiple years, such as 1980-2100. The initial steps are identical as the ones to create multiple clipped rasters, except that the tool to use is *Make NetCDF Table View* (figure 24).

FIGURE 24: Model Builder: *Make NetCDF Table View* initial steps



In this example, precipitation data for Amman is evaluated. The location coordinates must be converted to nlon and nlat. Enter the information in the *Make NetCDF Table View* tool using one of the NetCDF files from the folder (figure 25). Remember to delete the blue oval representing the NetCDF file and connect the green File.nc oval to the tool. Next, run the model.

FIGURE 25: Model Builder: *Make NetCDF Table View* entering data



Add the *Table to Table* tool to the Model Builder found under Conversion Tools>To Geodatabase (figure 26). This will convert the output file from *Make NetCDF Table View* to a geodatabase.

Double-click on the *Table to Table* icon to enter information. The Input Rows should be the output from *Make NetCDF Table View*, which is called File View in this example. The Output Location will be a folder specified by the user. The Output Table should be named by the user and include %n% to add a unique number to each table, starting from 0 (figure 27).

FIGURE 26: Model Builder: *Make NetCDF Table View* Table to Table

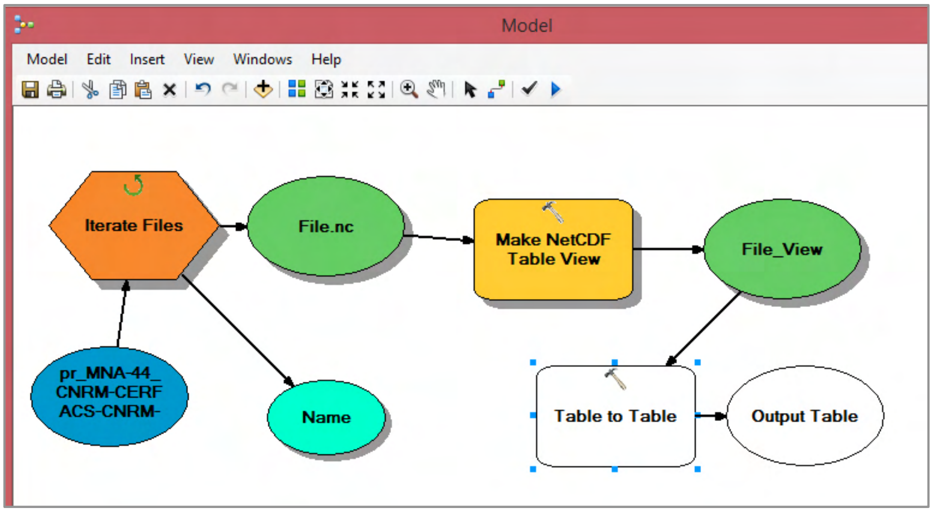
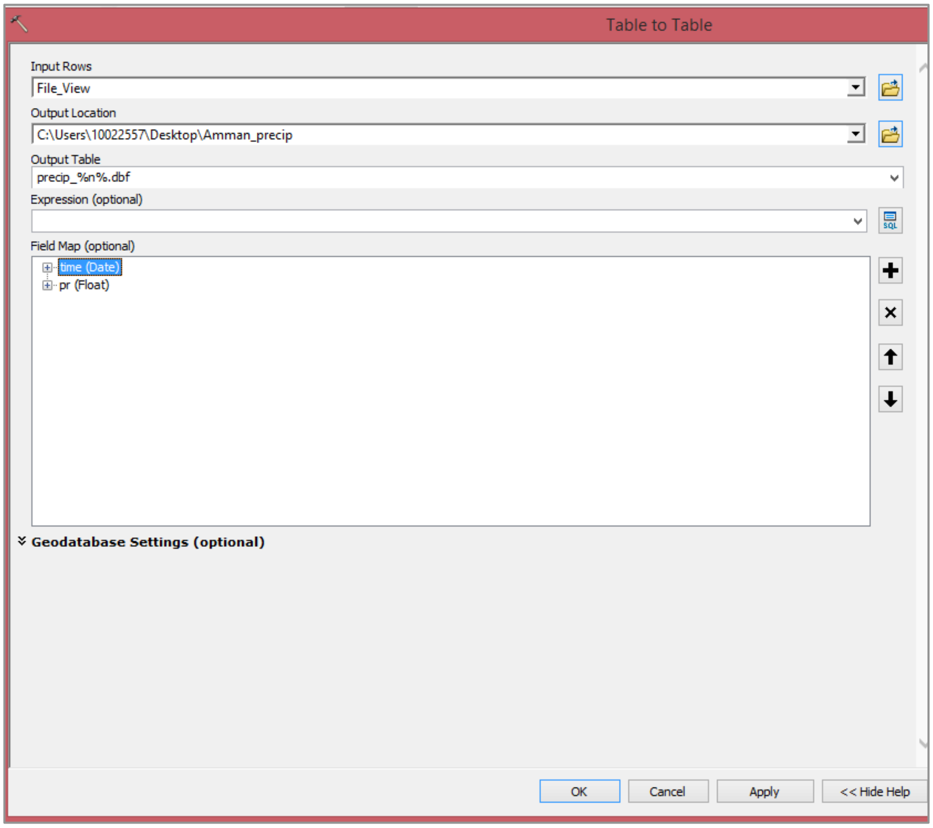
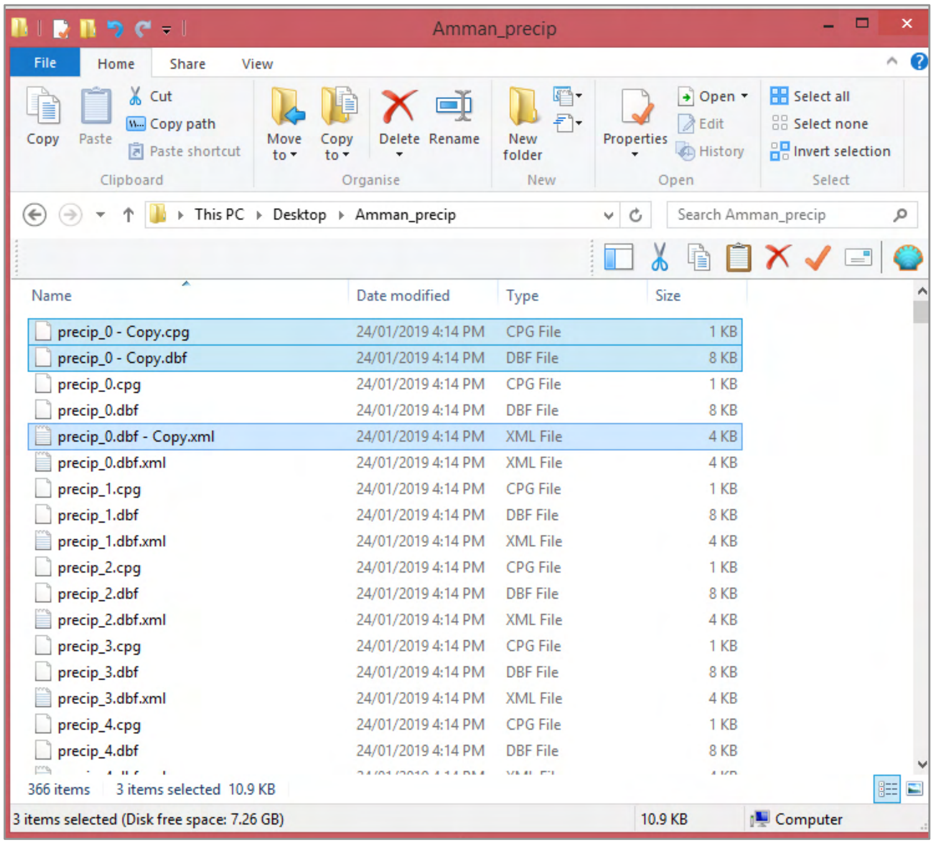


FIGURE 27: Model Builder: Enter Table to Table information



Run the entire model. After completion, the user can open up the folder that was created. Three files (cpg, .dbf, and .dbf.xml) comprise a single table. Copy and paste the first table (all 3 files), which is the output table name followed by 0 (figure 28).

FIGURE 28: Model Builder: View output in file folder and copy first table



To merge all the results into a single table, the *Append* tool must be added to the Model Builder, found under Data Management Tools>General. Connect to the *Table to Table* output (i.e. precip_%n%.dbf) (figure 29).

Double-click on the *Append* tool. The Input Dataset will be automatically entered by the connection in the Model Builder (i.e. precip_%n%.dbf). Select the copied .dbf file (i.e. precip_0-Copy.dbf) from the output folder saved to the computer and add it to the Target Dataset (figure 30).

FIGURE 29: Model Builder: Merge output into single table

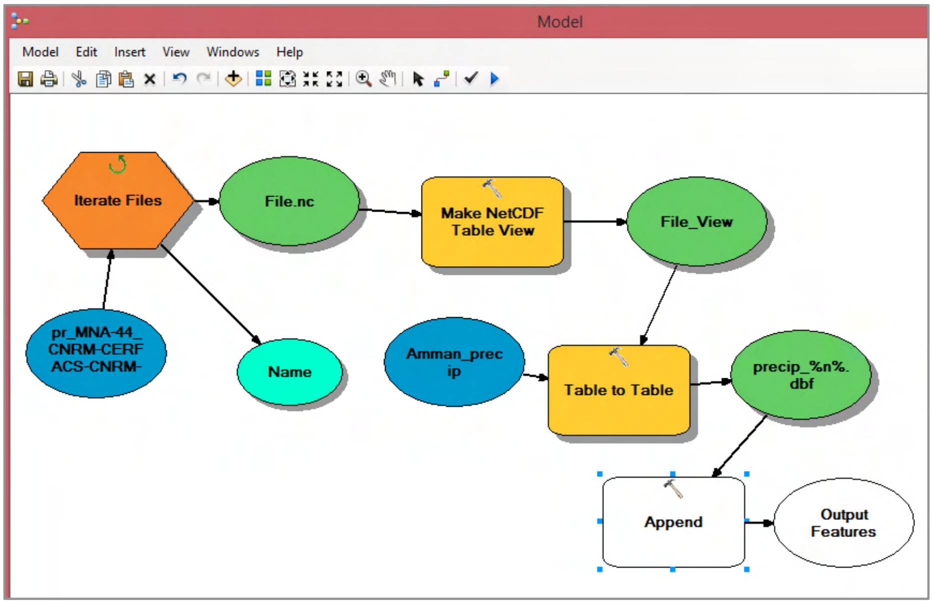
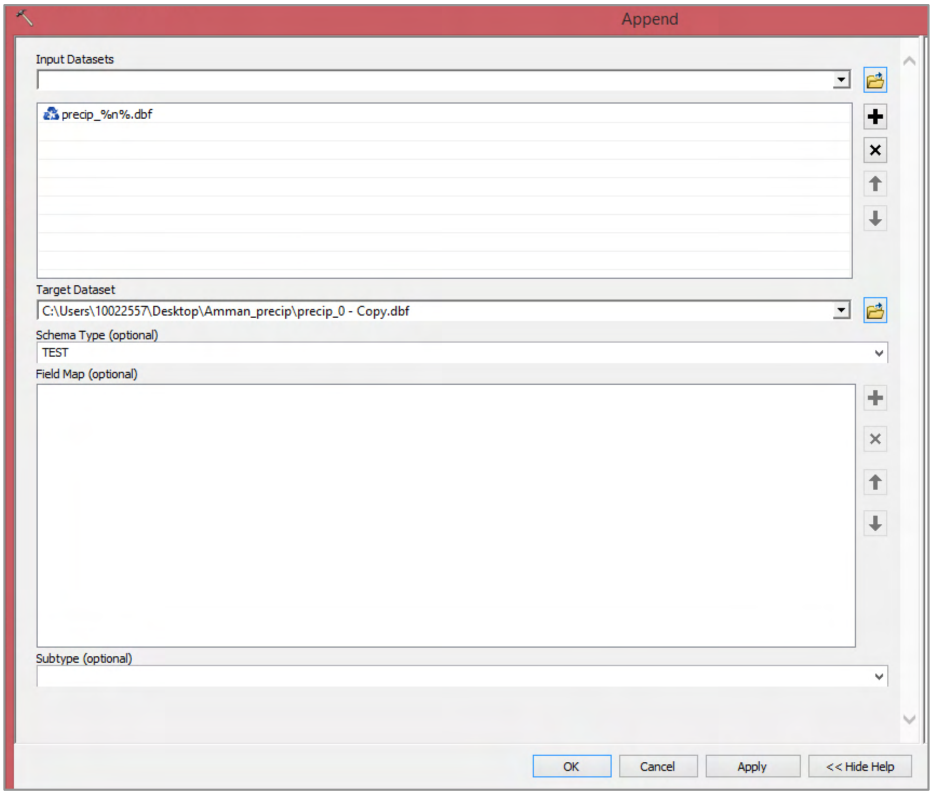
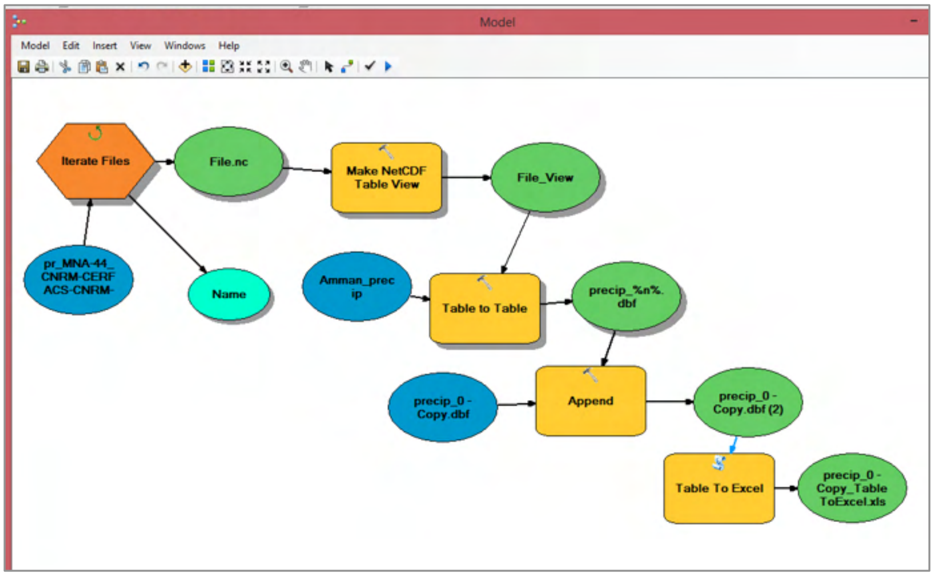


FIGURE 30: Model Builder: Enter data into *Append* tool



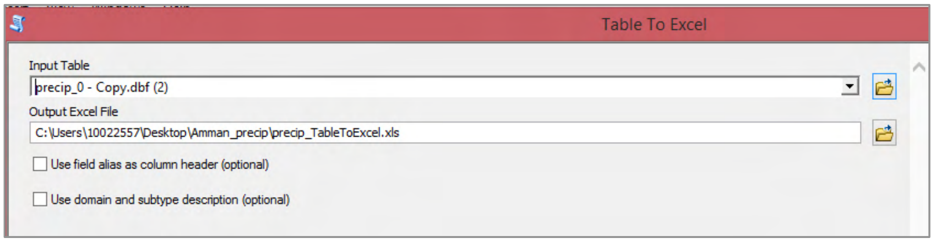
Add the *Table to Excel* tool to the Model Builder found under Conversion Tools > Excel and connect to the output to consolidate all files into Excel format (figure 31).

FIGURE 31: Model Builder: *Table to Excel* tool



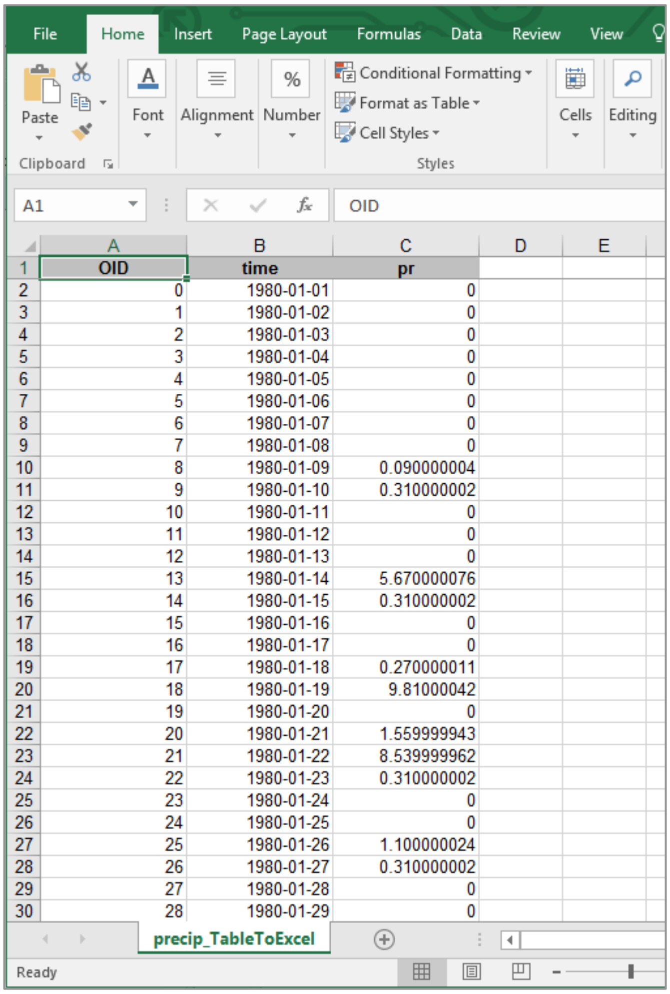
Double-click on the Table to Excel tool. The Input Table will be the default from the Model Builder. Users will need to specify an output location and file name, keeping the .xls extension for an Excel file (figure 32).

FIGURE 32: Model Builder: Enter data into *Table to Excel* tool



Save and run the entire model. The result will be an Excel spreadsheet containing daily precipitation values (in mm/day) for each NetCDF file at the selected location (figure 33).

FIGURE 33: Model Builder: *Make NetCDF Table View* Excel output



	OID	time	pr
2	0	1980-01-01	0
3	1	1980-01-02	0
4	2	1980-01-03	0
5	3	1980-01-04	0
6	4	1980-01-05	0
7	5	1980-01-06	0
8	6	1980-01-07	0
9	7	1980-01-08	0
10	8	1980-01-09	0.090000004
11	9	1980-01-10	0.310000002
12	10	1980-01-11	0
13	11	1980-01-12	0
14	12	1980-01-13	0
15	13	1980-01-14	5.670000076
16	14	1980-01-15	0.310000002
17	15	1980-01-16	0
18	16	1980-01-17	0
19	17	1980-01-18	0.270000011
20	18	1980-01-19	9.81000042
21	19	1980-01-20	0
22	20	1980-01-21	1.559999943
23	21	1980-01-22	8.539999962
24	22	1980-01-23	0.310000002
25	23	1980-01-24	0
26	24	1980-01-25	0
27	25	1980-01-26	1.100000024
28	26	1980-01-27	0.310000002
29	27	1980-01-28	0
30	28	1980-01-29	0

4 CREATING ENSEMBLES USING SPATIAL ANALYST TOOLS

4.1 Calculating annual and seasonal projections

To derive the best possible projected estimate from the different climate models, ensemble analysis is recommended. All model simulations based on the same climate scenario and which have the same spatial resolution are grouped and presented as an ensemble mean. Moreover, the ensemble mean should represent results from several years. For RICCAR, three different time periods were selected to present data as an ensemble mean:

- Reference period, representing 1986-2005
- Mid-century, representing 2046-2065
- End-century, representing 2081-2100.

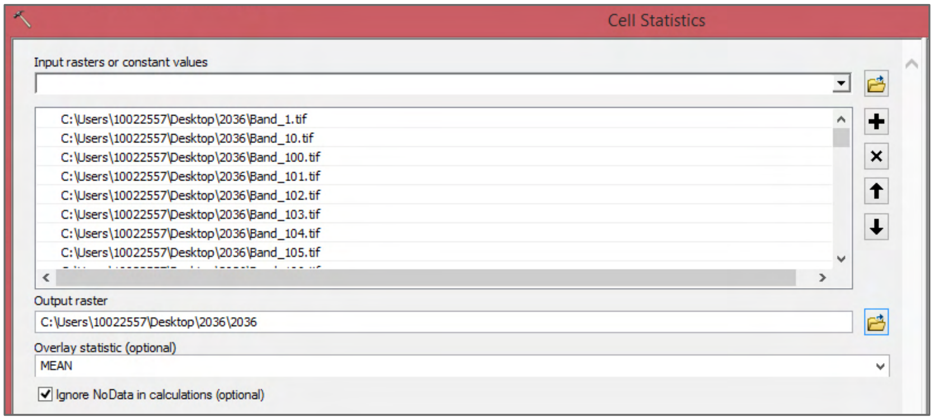
Outputs from these time periods are available on the RKH data portal in addition to the near-century data, representing 2016-2035.

Users may elect to evaluate different periods, such as 10-year climate projections, or may wish to evaluate data seasonally. These cases require developing an ensemble.

The first steps are to create a NetCDF raster file (see section 3.2.1) and to extract multiple time slices from the raster layer file (see section 3.2.2).

The *Cell Statistics* tool, found under Spatial Analyst Tools > Local, can calculate the sum, mean, or other statistics from multiple raster files (figure 34).

FIGURE 34: *Cell Statistics* tool



The default statistic is mean. This is typically used for climate parameters such as temperature. However, for precipitation, typically average annual values are reported as mm/month or mm/year instead of mm/day. In these cases, users must first sum each of the daily raster bands, and then average the summed values. Users may find it helpful to create a model using Model Builder to expedite this process and minimize errors in selecting the relevant time bands.

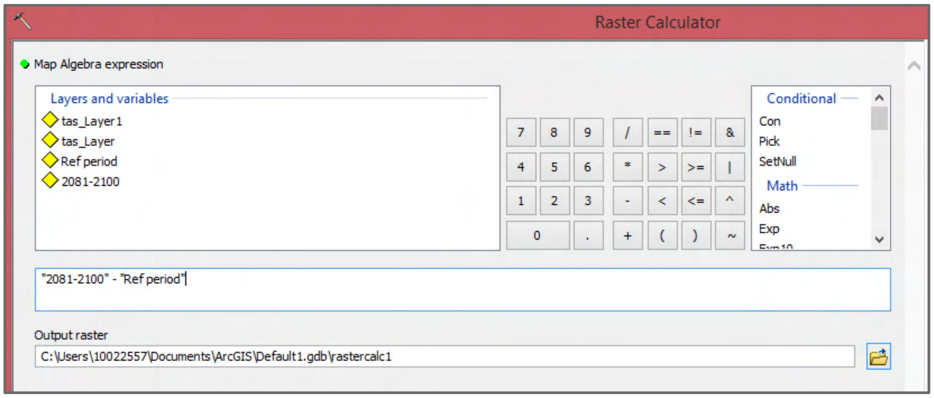
The Cell Statistics tool is repeated to average results obtained from multiple years, and then again to average results from each of the climate models, to finally obtain the ensemble result.

4.2 Comparing projections using the raster calculator

Rather than report actual values obtained from future projections, it is common to report the change in values compared with a designated reference period. For example, for RICCAR, mid-century (2046-2065) results reflected a change in the different climate parameters compared to the reference period (1986-2005).

Change in values can be determined by using the Raster Calculator, found under Spatial Analyst Tools > Math Algebra (figure 35). The Raster Calculator can perform many mathematical functions. In this case, users simply subtract the reference period values from the projected values.

FIGURE 35: Raster calculator



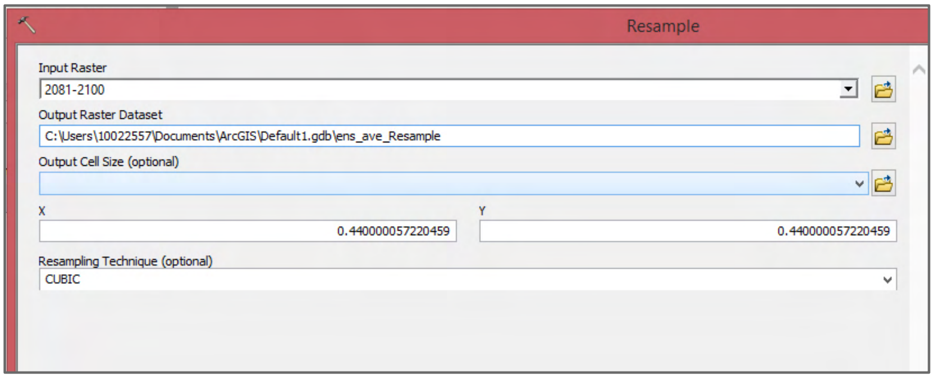
5 CLIMATE DATA INTERPOLATION

5.1 Data resampling and interpolation

As previously described, the climate data spatial resolution is 50 x 50 km (or in limited cases, 25 x 25 km). In addition, data is gapped in some coastal areas due to the bias-correction process. Users may elect to change the data to a different spatial resolution to allow for easier compatibility with other raster files or to extrapolate values to include coastal areas.

The *Resample* tool, found under Data Management Tools > Raster > Raster Processing, enables users to convert rasters to a different spatial resolution (figure 36). By default, the 50 x 50 km climate data will appear with a grid cell size of 0.44 x 0.44, representing degrees (similarly, the 25 x 25 km data will show 0.22 x 0.22 degrees).

FIGURE 36: *Resample* tool



To convert 50 x 50 km to 1 x 1 km, equation 5 needs to be used, which divides the size in degrees by the size in kilometres, where x = 1 km. A similar approach should be applied for differing grid cell sizes.

$$50x = 0.44$$

There are four different resampling techniques to select from: nearest, majority, bilinear, and cubic. The first two are best suited for discrete data that have distinct boundaries or limits such as building or roadway data. The last two are suited for continuous data, such as climate data. The bilinear method averages values from the surrounding four pixels, whereas the cubic method averages from the nearest 16 pixels and results in a smoother image.

Resampling changes only the grid square size with some smoothing. The data extent is the same as the original dataset. In some cases, users may elect to extrapolate data to areas that may be gapped, such as coastal areas. This is performed using a multistep process:

1. Conduct interpolation using Geostatistical Analyst
2. Convert interpolated result to raster
3. Extract raster to desired shape.

Interpolation tools can be found under the Geostatistical Analyst and Spatial Analyst Tools > Interpolation. The latter will not work for raster data. To use Geostatistical Analyst, the applicable extension must be turned on, found under Customize in ArcMap (figure 37). The Geostatistical Analyst toolbar can then be activated. Interpolation can be facilitated using the *Geostatistical Wizard* (figure 38).

Multiple interpolation methods are available for use. Inverse Distance Weighting (IDW) is fastest and most appropriate because the data is continuous. Users can then either select “Finish” directly or view the intermediate interpolation steps by pressing “Next”. A review of intermediate results is needed when applying more advanced interpolation methods, such as kriging. The interpolated result using IDW will resemble figure 39 comprising climate data for the entire domain including water bodies. Note that this interpolated result is not saved and is solely available in the computer memory.

FIGURE 37: Option to activate Extensions in ArcMap

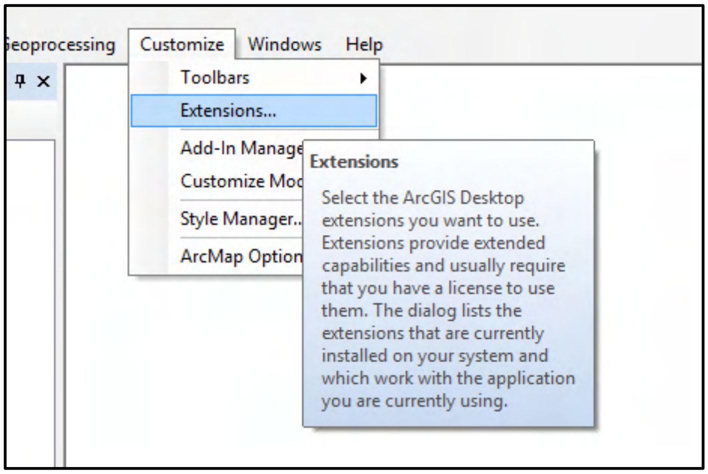


FIGURE 38: *Geostatistical Wizard* tool

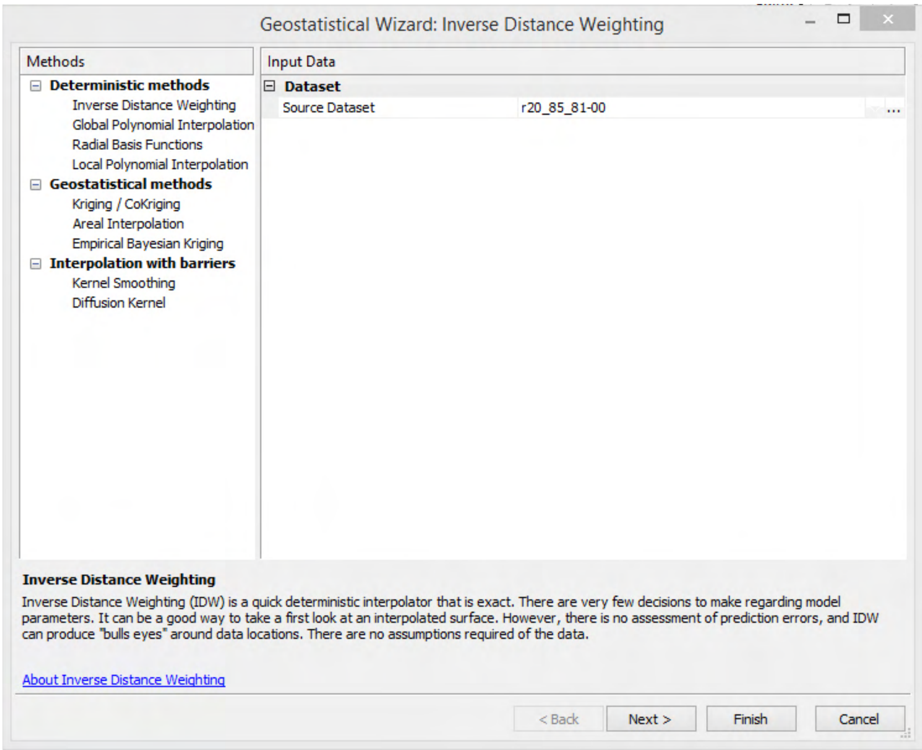
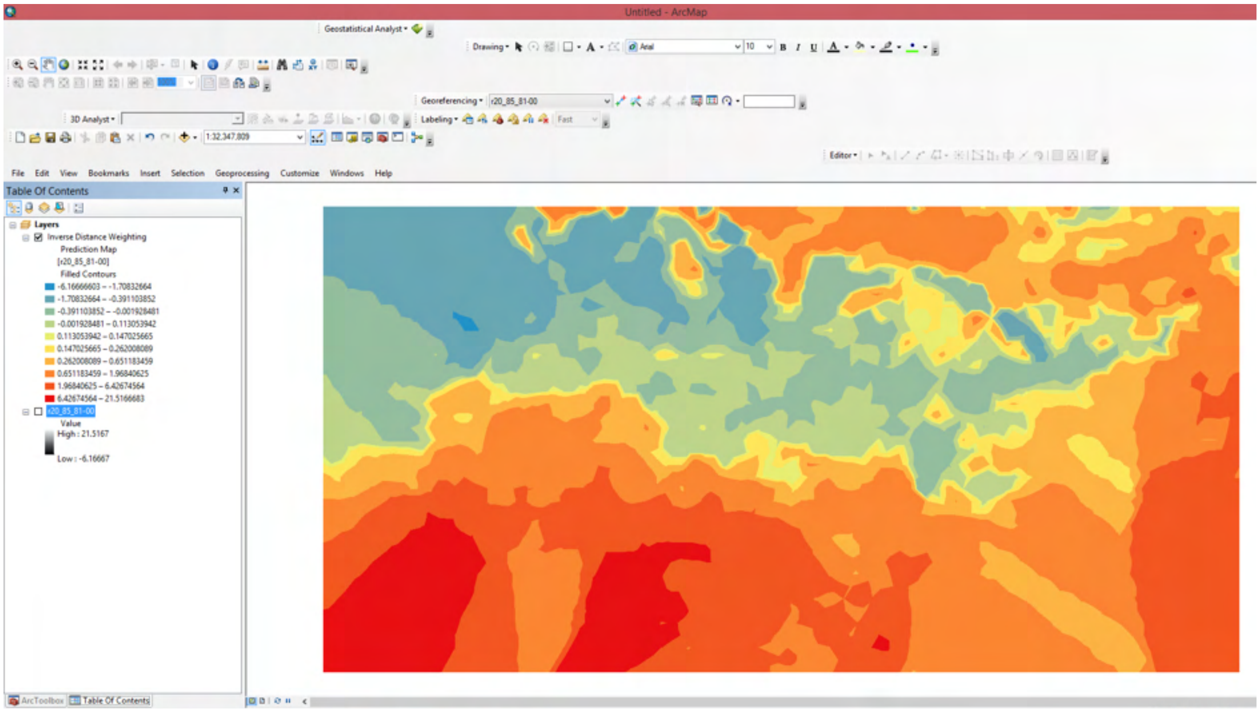
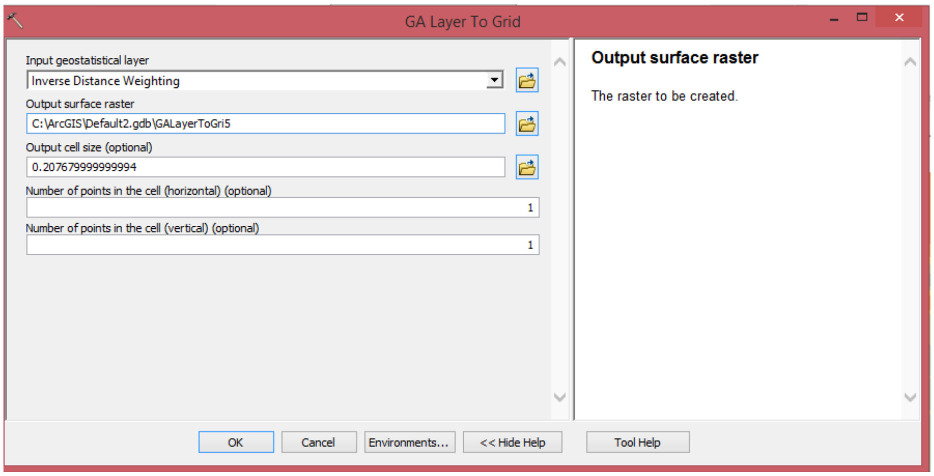


FIGURE 39: Example of IDW interpolation result



The interpolated result must be converted to raster by using the *GA Layer to Grid* tool (figure 40). This tool is activated by right clicking on the Inverse Distance Weighting layer in the Table of Contents, selecting *Data*, and *Export to Raster*. It is recommended to leave the default name as the Output surface raster; otherwise, users may encounter errors using the tool. The output cell size should be the same as the resampled cell size. The number of horizontal and vertical points in the cell is 1, which should be the default value. The result will be shown in the Table of Contents.

FIGURE 40: *GA Layer to Grid* tool

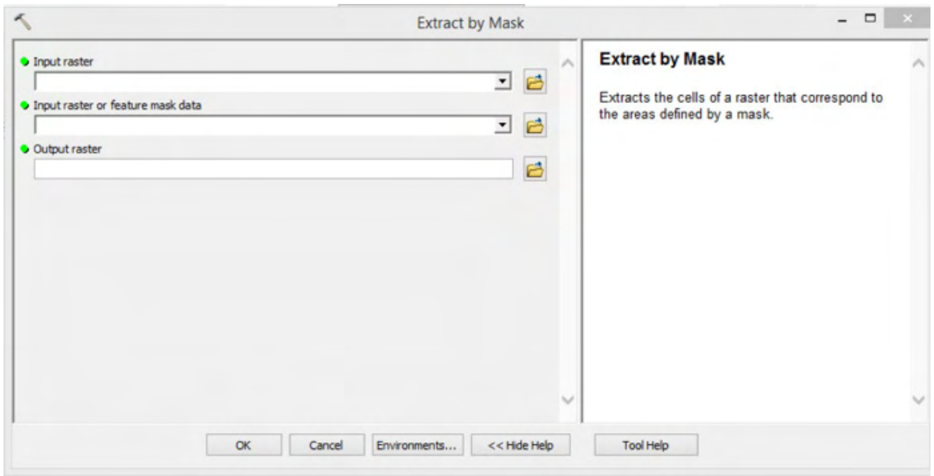


The *GA Layer to Grid* raster can be cut to a desired shape (i.e. watershed, country border) using the *Extract by Mask* tool, found under Spatial Analyst Tools/Extraction (figure 41). Select the *GA Layer to Grid* raster and the desired shape (either a raster or a shapefile). Users may find extraneous data with the result or may encounter errors naming the output raster something other than the default. In such cases, the extraneous data can be removed, or the file renamed and saved using the *Extract by Rectangle* tool. The result will be a raster dataset with the desired grid cell size and extent.

Note that interpolation cannot be done using the *Fill* tool, found under Spatial Analyst Tools > Hydrology. This tool is intended to remove small imperfections in raster datasets for hydrological applications. It will not sufficiently extrapolate data.

These processes should only be applied in certain cases, such as vulnerability studies, whereby contributing datasets should be of the same spatial resolution and extent. It is not intended to imply a finer spatial resolution or accuracy of data.

FIGURE 41: *Extract by Mask* tool



5.2 Differentiating between interpolation and downscaling

Regional climate modelling provides smaller scale projections than what is traditionally available through global climate models. Regional climate models can account for details, such as topography, and simulate the climate in greater spatial detail than global climate models. However, the scale of the projection determines its suitability and accuracy for use in different studies. For smaller scale analysis, users may be tempted to resample and extrapolate data as described in section 5.1 of the present manual. However, interpolation methods such as kriging (or co-kriging) should not be used with modelled climate data, such as reanalysis data or projections. Kriging can be applied when interpolating historical meteorological data as these are observed datasets. Further information can be found in Venäläinen and Heikinheimo (2002), Jeffrey and others (2001), and Spadavecchia and Williams (2009), and others.

To correctly convert climate modelling outputs to a smaller spatial or temporal scale, users must perform downscaling. Downscaling can be pursued through dynamic or statistical techniques. Dynamic downscaling runs a regional climate model over a sub-domain using observational datasets and draws on other climate modelling outputs to prescribe boundary conditions based on physical principles. This method can be considered computationally intensive. Statistical downscaling considers the statistical relationships between local climate variables and large-scale predictors such as pressure fields coupled with the application of these relationships to modelling outputs. For more information, refer to Teutschbein and Seibert (2010).

ENDNOTES

1. Swedish Meteorological and Hydrological Institute, 2017.
2. The RKH data portal is available at https://rkh.apps.fao.org/.
3. CORDEX data on the ESGF data portal is available at https://esg- dn1.nsc.liu.se/projects/esgf-liu/.
4. ESCWA and ACSAD, 2019.
5. The tool is available at https://suppor t.esri.com/en/technical-ar ticle/000011318 and includes instructions.

REFERENCES

ESCWA et. al. (2017). Arab Climate Change Assessment Report – Main Report. Beirut, E/ESCWA/SDPD/2017/RICCAR/Report.

ESCWA and ACSAD (2019). Guidelines for Accessing CORDEX Regional Climate Projections. *RICCAR Technical Note*, Beirut, E/ESCWA/SDPD/2019/RICCAR/TechnicalNote.3.

Jeffrey, S. J. and others (2001). Using spatial interpolation to construct a comprehensive archive of Australian climate data, *Environmental Modelling & Software*, Volume 16, Issue 4, Pages 309-330, ISSN 1364-8152.

Swedish Meteorological and Hydrological Institute (2017). Regional Climate Modelling and Regional Hydrological Modelling Applications in the Arab Region. *RICCAR Technical Note*, Beirut, E/ESCWA/SDPD/2017/RICCAR/TechnicalNote.1. Available at: www.riccar.org

Spadavecchia, L. and Williams, M. (2009). Can Spatio-temporal Geostatistical Methods Improve High Resolution Regionalisation of Meteorological Variables? *Agricultural and Forest Meteorology*, Volume 149, Issues 6–7, Pages 1105-1117, ISSN 0168-1923, https://doi.org/10.1016/j.agrformet.2009.01.008.

Teutschbein, C. and Seibert, J. (2010). Regional Climate Models for Hydrological Impact Studies at the Catchment Scale: A Review of Recent Modeling Strategies. *Geography Compass*, 4: 834-860. doi:10.1111/j.1749-8198.2010.00357.x

Venäläinen, A. and Heikinheimo, M. (2002). Meteorological Data For Agricultural Applications, *Physics and Chemistry of the Earth*, Parts A/B/C, Volume 27, Issues 23–24, Pages 1045-1050, ISSN 1474-7065, https://doi.org/10.1016/S1474-7065(02)00140-7.