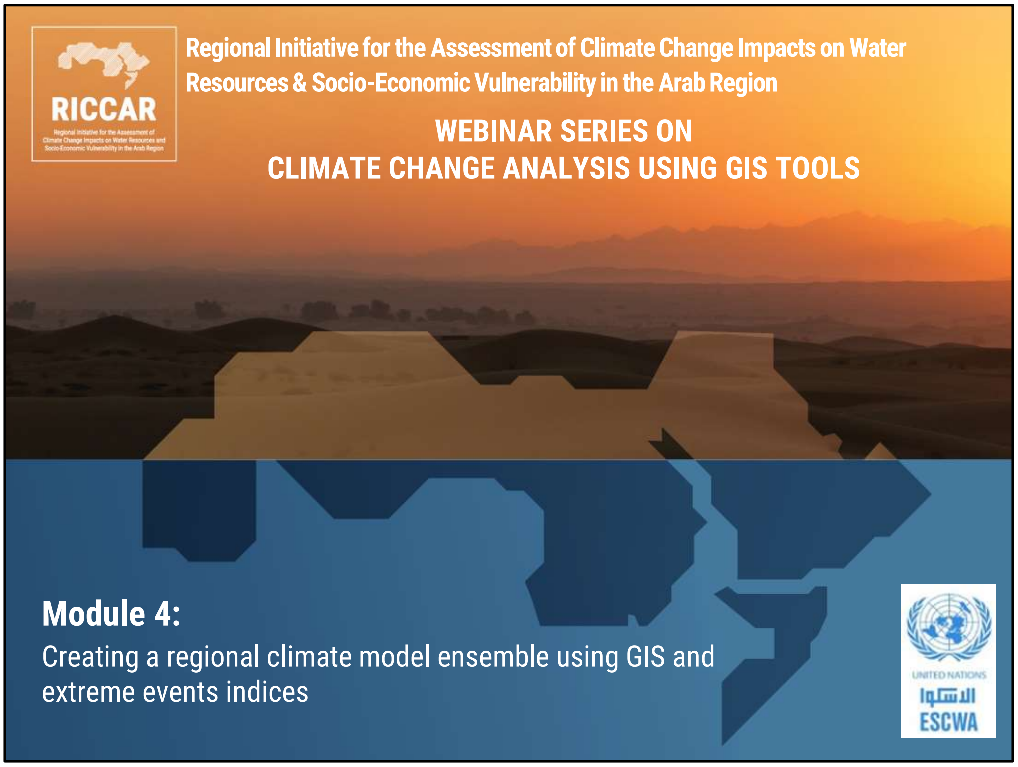
RICCAR
Regional Initiative for the Assessment of Climate Change Impacts on Water Resources & Socio-Economic Vulnerability in the Arab Region
WEBINAR SERIES ON
CLIMATE CHANGE ANALYSIS USING GIS TOOLS
Module 4:
Creating a regional climate model ensemble using GIS and extreme events indices
UNITED NATIONS
الاسكوا
ESCWA

RICCAR

Webinar Series

- **Module 1:** RICCAR regional climate modelling and hydrological modelling datasets: An introduction
- **Module 2:** Viewing NetCDF regional climate modeling datasets in GIS
- **Module 3:** Extracting tabular data from NetCDF climate files for use in other models and applications
- ✓ **Module 4:** Creating a regional climate model ensemble using GIS and extreme events indices
- **Module 5:** Accessing global and regional climate datasets and platforms
- **Module 6:** RICCAR integrated vulnerability assessment methodology

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RICCAR

Module 4: Contents

- Benefits of ensemble analysis
- How to create a regional climate model (RCM) ensemble in GIS
- RICCAR extreme events indices and applications

3

Driving CMIP5 GCMs used for RICCAR

Model Name	Modelling Centre	Country	GCM Resolution (lon x lat)
CNRM-CM5	Européen de Recherche et Formation Avancée en Calcul Scientifique (CERFACS)	France	1.41° × 1.40°
EC-EARTH	EC-EARTH consortium published at Irish Centre for High-End Computing	Netherlands / Ireland	1.13° × 1.13°
GFDL-ESM2M	NOAA Geophysical Fluid Dynamics Laboratory	USA	2.50° × 2.02°

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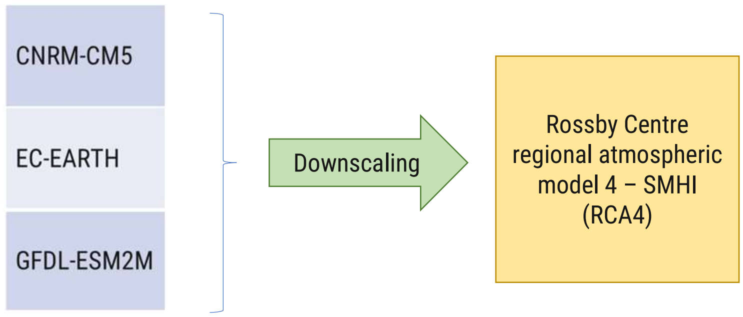
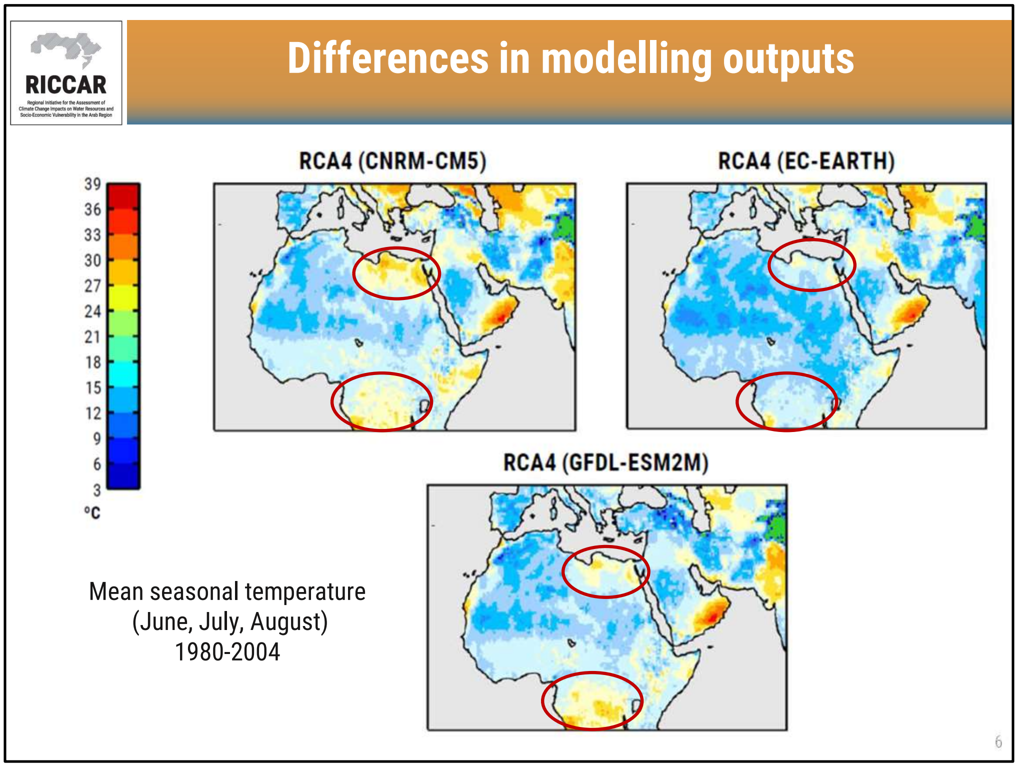
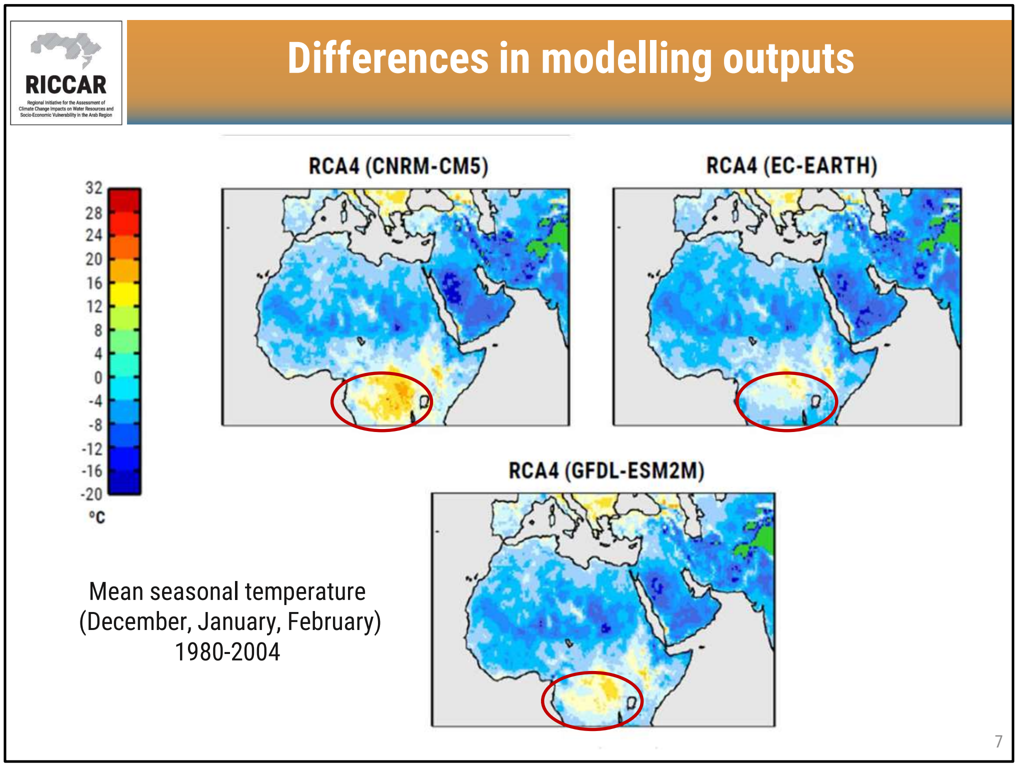
Driving GCMs to RCM (RICCAR)





- Maps show differences in modelling outputs based on 3 different driving GCMs (CNRM-CM5, EC-EARTH, and GFDL-ESM2M) downscaled using the same RCM (RCA4).
- Differences are most apparent in eastern North Africa and Sub-Saharan Africa
- More information is found in the RICCAR Technical Note from the Swedish Meteorological and Hydrological Institute (SMHI). Regional Climate Modelling and Regional Hydrological Modelling Applications in the Arab Region.



- Maps show differences in modelling outputs based on 3 different driving GCMs (CNRM-CM5, EC-EARTH, and GFDL-ESM2M) downscaled using the same RCM (RCA4).
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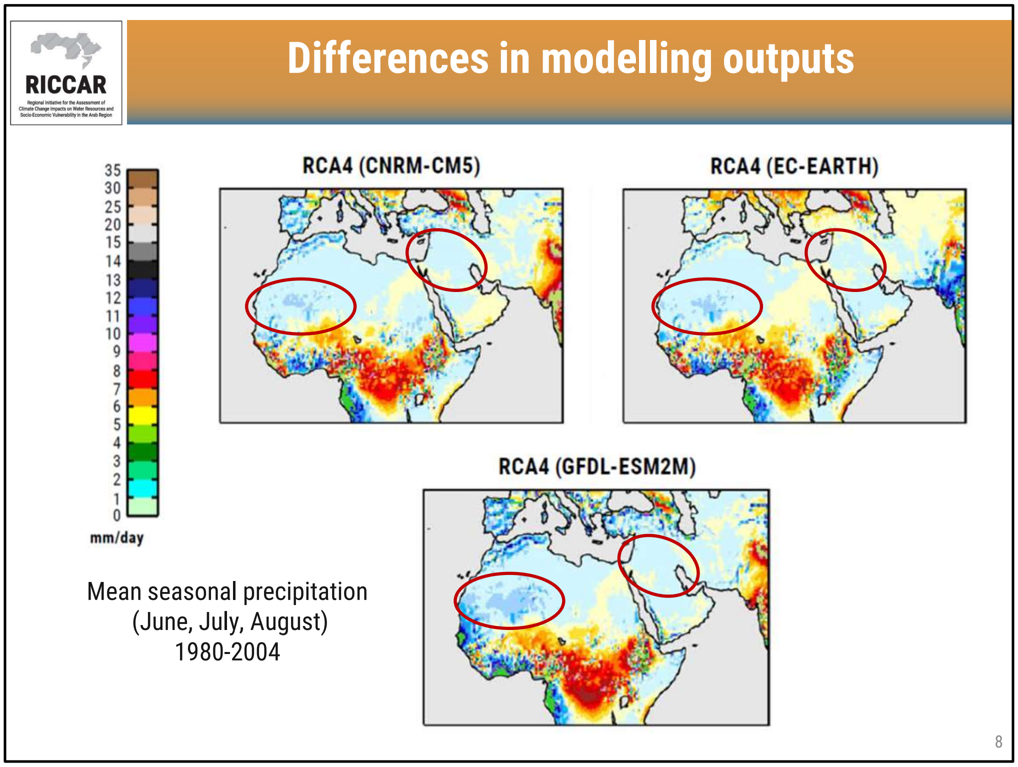
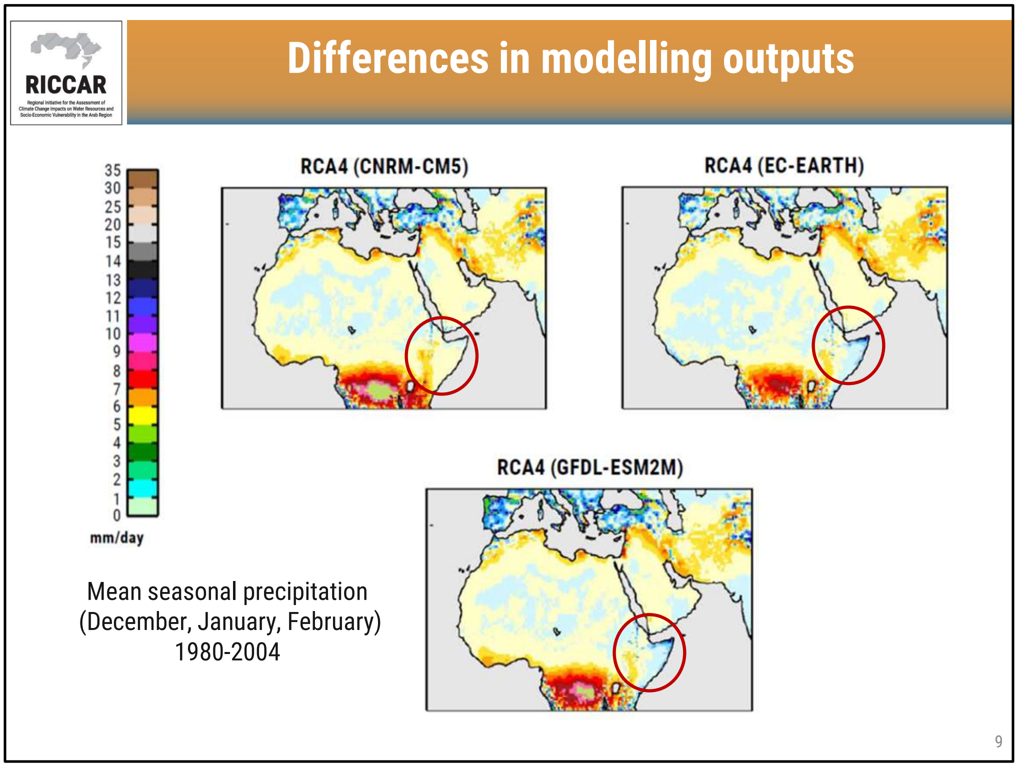
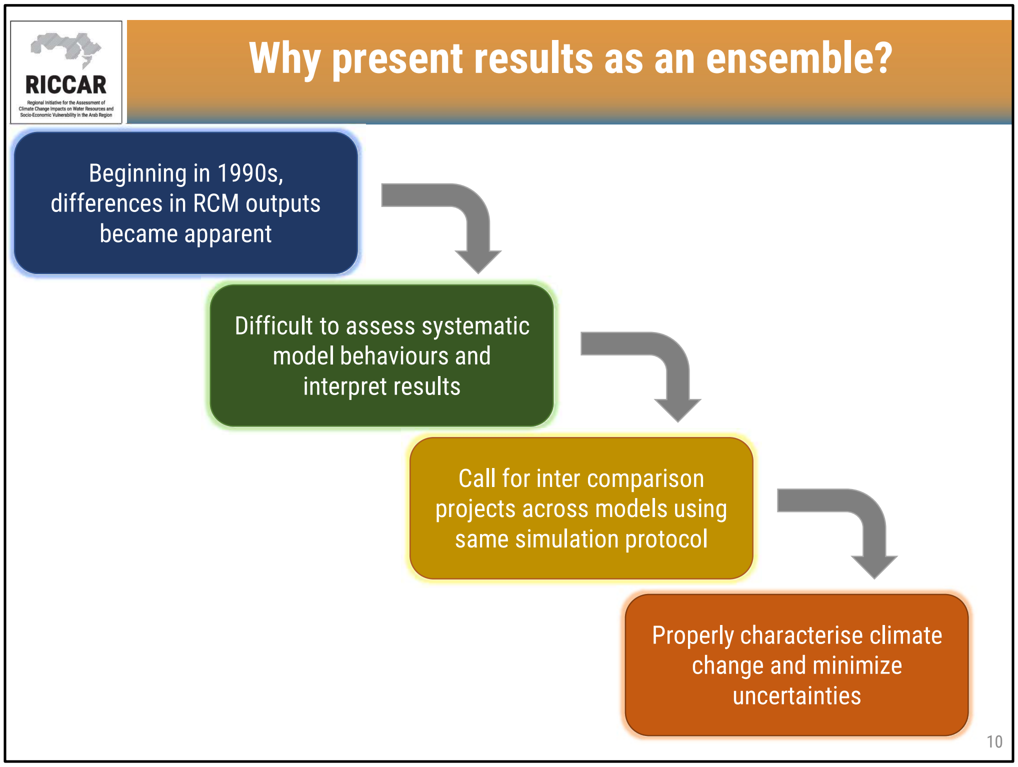


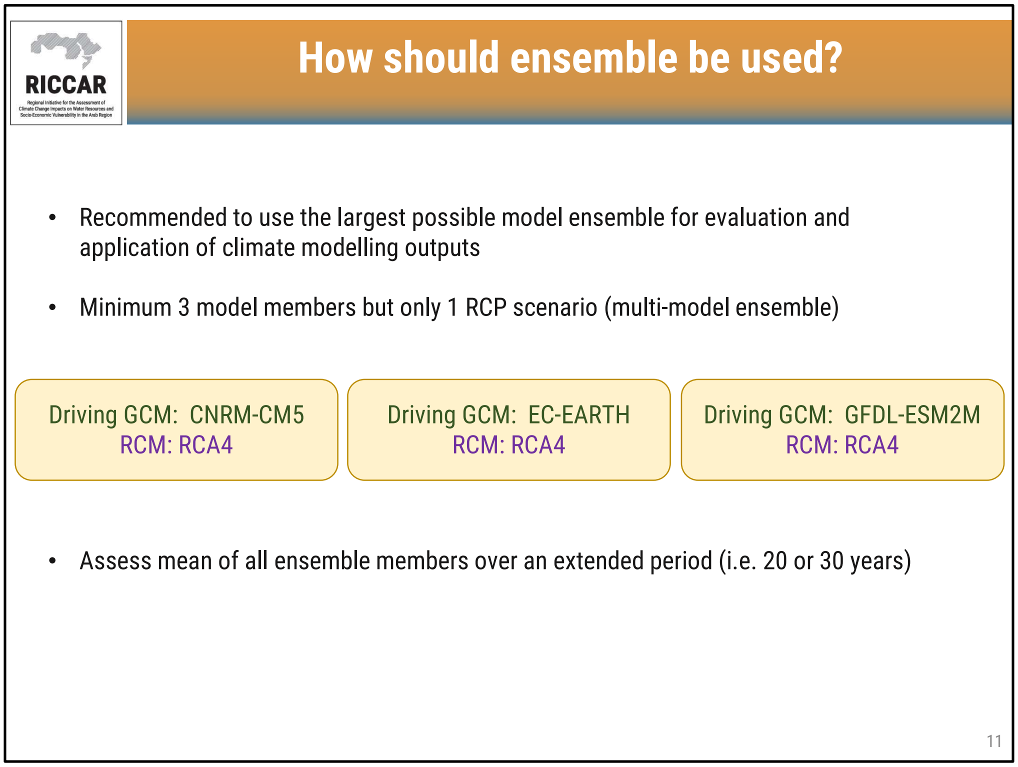
- Maps show differences in modelling outputs based on 3 different driving GCMs (CNRM-CM5, EC-EARTH, and GFDL-ESM2M) downscaled using the same RCM (RCA4).
- Differences are most apparent in Mashreq and western Sahel.
- More information is found in the RICCAR Technical Note from the Swedish Meteorological and Hydrological Institute (SMHI). Regional Climate Modelling and Regional Hydrological Modelling Applications in the Arab Region.



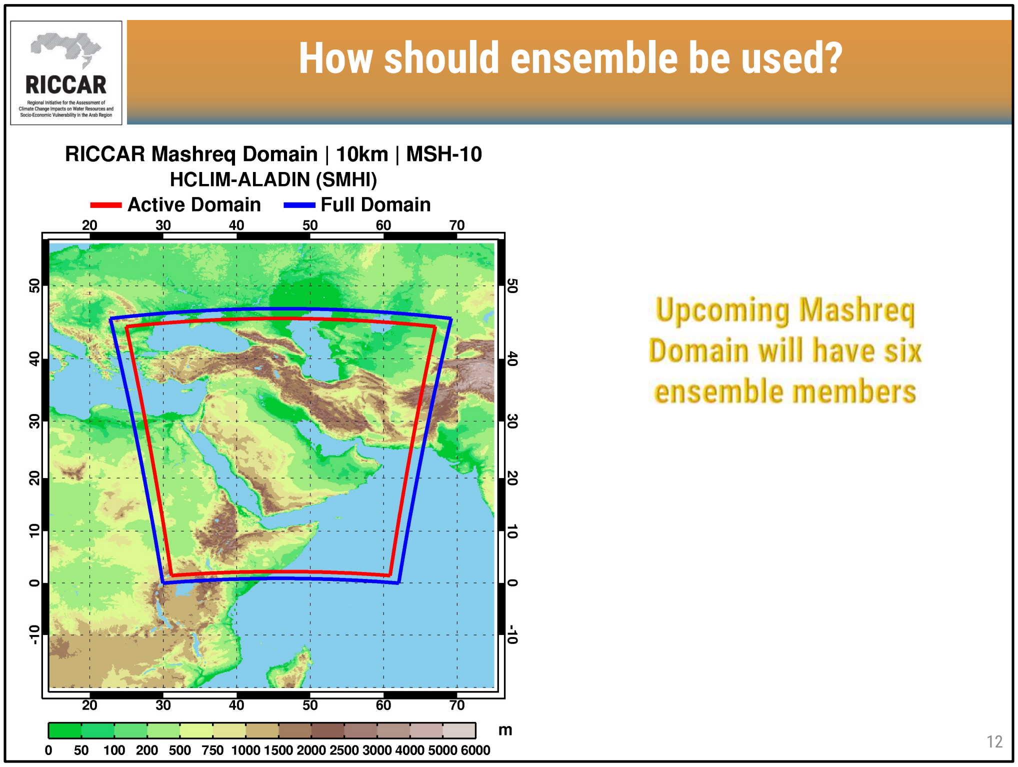
- Maps show differences in modelling outputs based on 3 different driving GCMs (CNRM-CM5, EC-EARTH, and GFDL-ESM2M) downscaled using the same RCM (RCA4).
- Differences are most apparent in the Horn of Africa
- More information is found in the RICCAR Technical Note from the Swedish Meteorological and Hydrological Institute (SMHI). Regional Climate Modelling and Regional Hydrological Modelling Applications in the Arab Region.



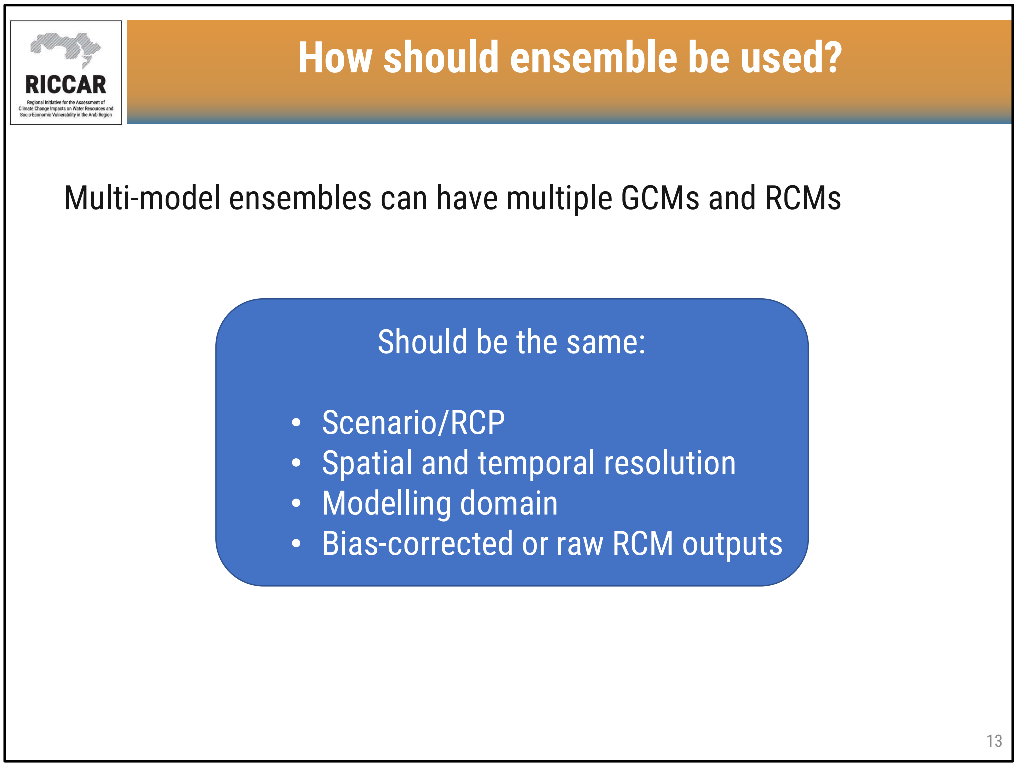
- Uncertainties in modelling outputs can include scenario uncertainties (RCPs), internal climate variabilities, and differing model assumptions.



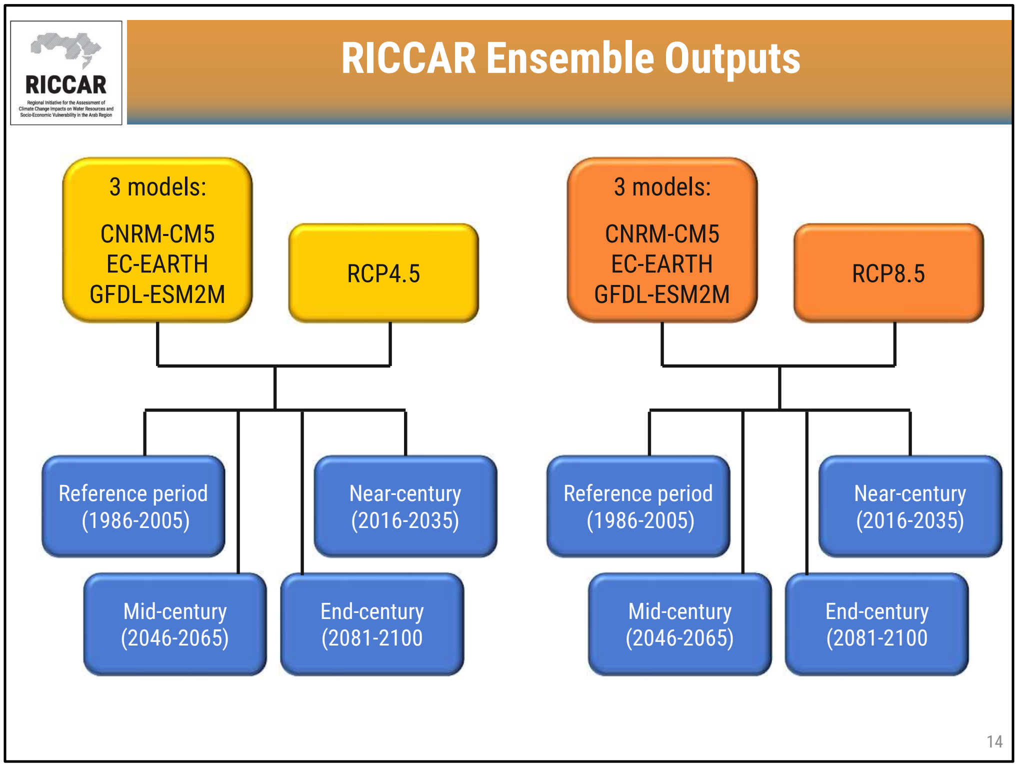
- RICCAR climate modelling output ensembles are based on 3 members as shown.
- RICCAR ensembles represent a 20-year mean. Results can either be annual or seasonal.



- Mashreq Domain modelling outputs expected starting in early 2021
- Driving GCMs are to be determined. One of them will be EC-EARTH.
- RCM to be used will be ALADIN (Aire Limitée Adaptation dynamique Développement InterNational) developed by CNRM. ALADIN is currently used by institutes from the ALADIN-HIRLAM consortium under the name HCLIM-ALADIN (SMHI).



- Multiple GCMs and RCMs can be used. For example for the MNA (Arab) Domain, there are raw RCM output projections available from CORDEX/ESGF that include (shown by GCM/RCM): (a) CNRM-CM5/RCA4, (b) EC-EARTH/RCA4, (c) GFDL-ESM2M/RCA4, (d) MPI-ESM-MR/RegCM4.3, and (e) HadGEM2-ES/RegCM4.3. All 5 modelling outputs can be used to create an ensemble.
- Spatial resolution of all ensemble members should be the same (i.e. all from 50 km / 0.44°)
- Temporal resolution of all ensemble members should be the same (i.e. all daily or all monthly)
- The modelling domain should be the same (i.e. all from Arab Domain) so that boundary conditions are identical
- Do not mix bias-corrected data with raw RCM outputs (not bias-corrected)



- Ensembles for RICCAR are based on the mean output of 3 modelling outputs for 4 different 20-year time periods for 2 different RCP scenarios.
- Available in raster format from the RICCAR Regional Knowledge Hub data portal

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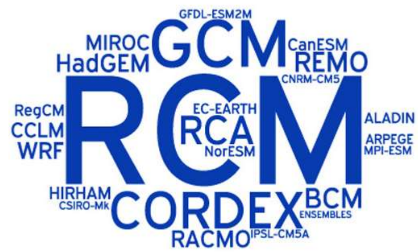
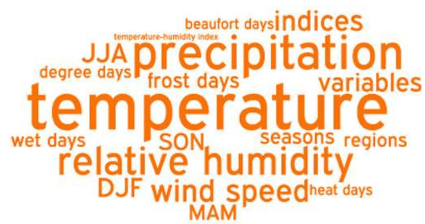
Creating an ensemble

- Ensembles not available on the RICCAR Regional Knowledge Hub must be created manually
- Based on annual or seasonal data
- Minimum 3 model outputs, 20-year period (i.e. "2030", based on 2021-2040)





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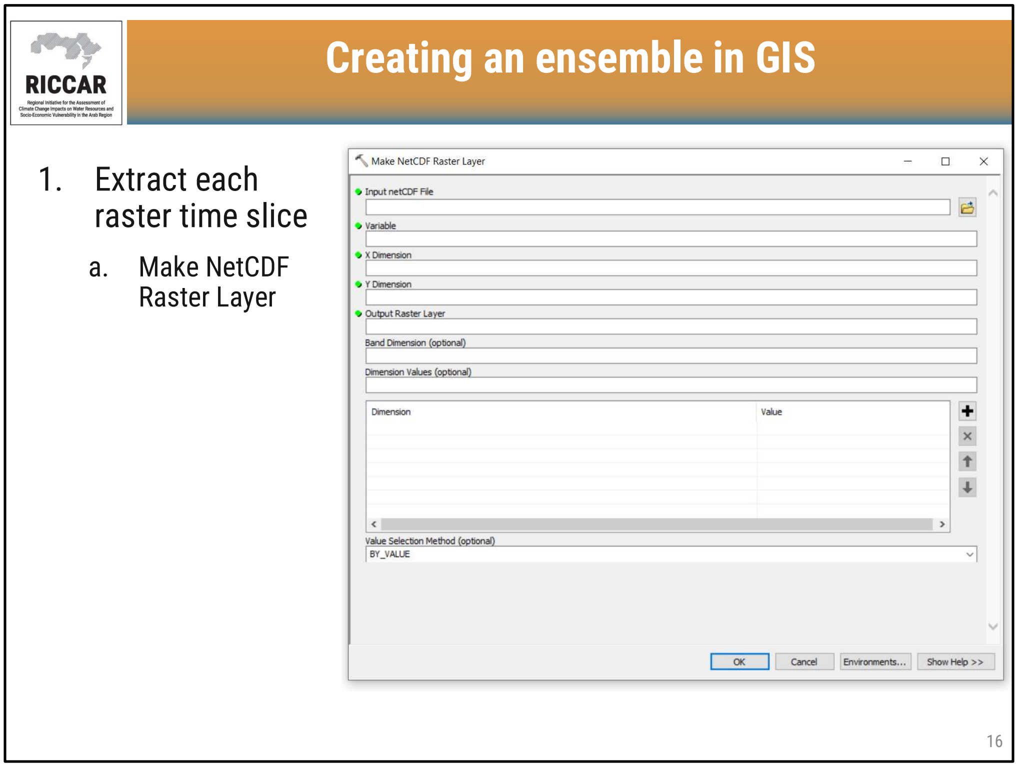
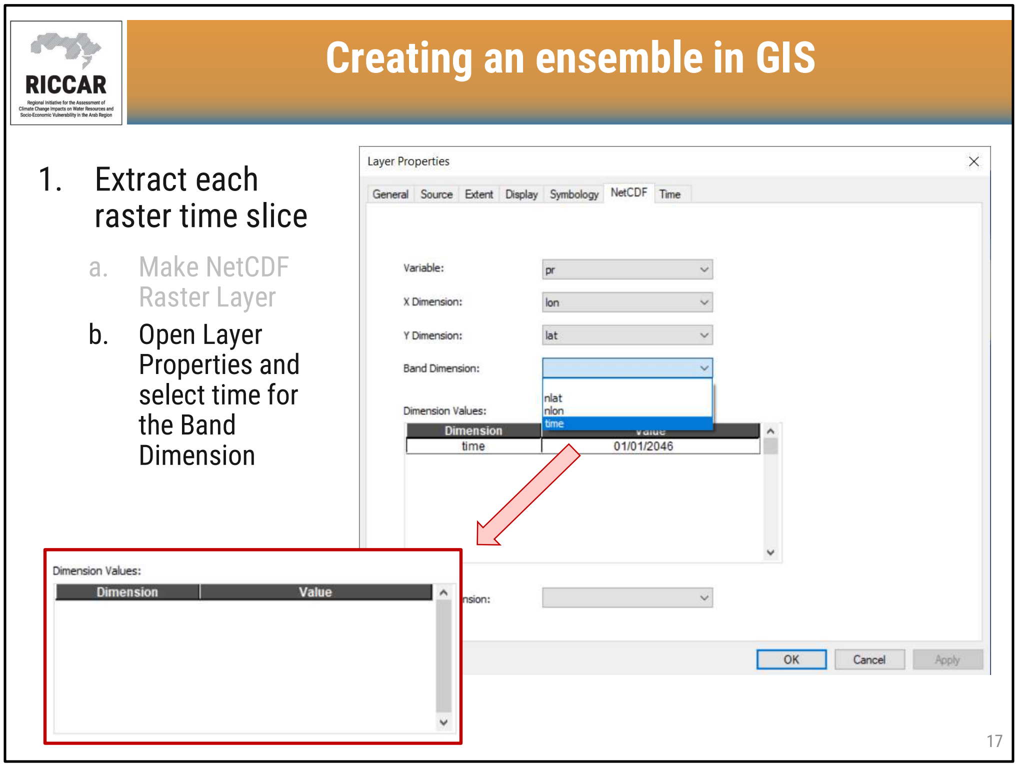


- Make NetCDF Raster Layer was discussed during webinar module 2.
- RICCAR Training Manual on the Use of GIS to Analyse Climate Change Data Section 3.2.2.

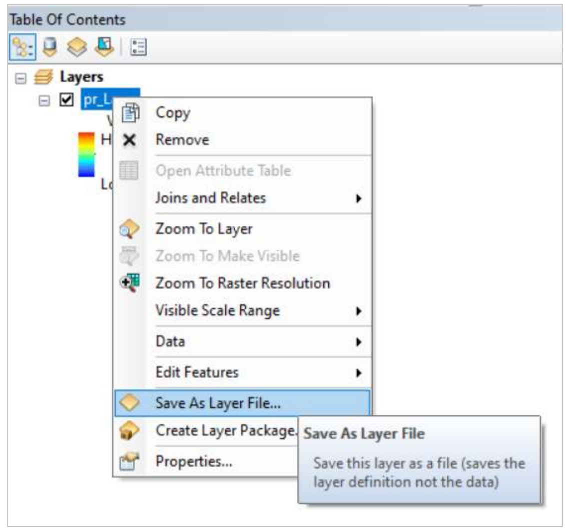


- After selecting time as the Band Dimension, the Dimension Values field will turn blank.

RICCAR

Creating an ensemble in GIS

1. Extract each raster time slice
   a. Make NetCDF Raster Layer
   b. Open Layer Properties and select time for the Band Dimension
   c. Save as Layer File



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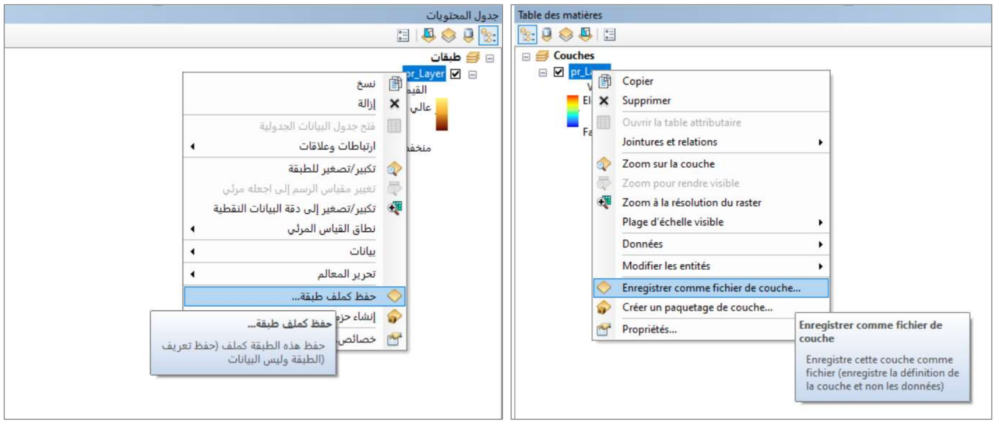
- Save layer file in user-defined location.


جدول المحتويات
طبقات
pr_Layer
نسخ
إزالة
فتح جدول البيانات الجدولية
ارتباطات وعلاقات
تكبير/تصغير للطبقة
تغيير مقياس الرسم إلى اجعله مرئي
تكبير/تصغير إلى دقة البيانات النقطية
نطاق القياس المرئي
بيانات
تحرير المعالم
حفظ كملف طبقة...
حفظ كملف طبقة...
حفظ هذه الطبقة كملف (حفظ تعريف الطبقة وليس البيانات)
Table des matières
Couches
Copier
Supprimer
Ouvrir la table attributaire
Jointures et relations
Zoom sur la couche
Zoom pour rendre visible
Zoom à la résolution du raster
Plage d'échelle visible
Données
Modifier les entités
Enregistrer comme fichier de couche...
Créer un paquetage de couche...
Propriétés...
Enregistrer comme fichier de couche
Enregistre cette couche comme fichier (enregistre la définition de la couche et non les données)

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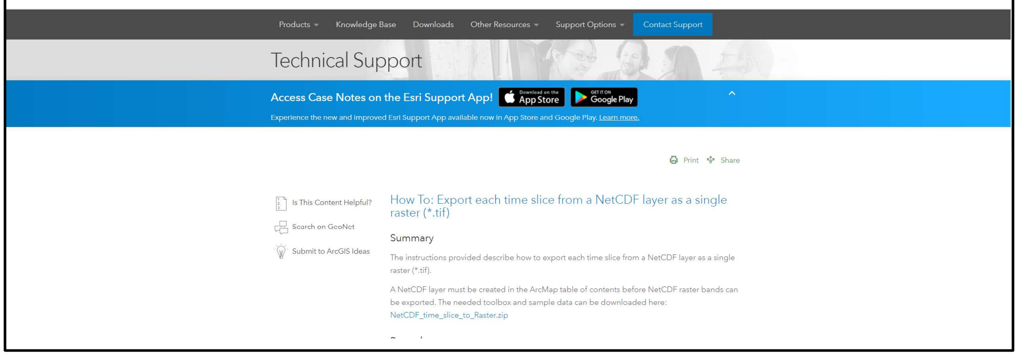
Creating an ensemble in GIS

1. Extract each raster time slice
   a. Make NetCDF Raster Layer
   b. Open Layer Properties and select time for the Band Dimension
   c. Save as Layer File
   d. Download and use NetCDF Time Slice to Raster tool available from https://support.esri.com/en/technical-article/000011318

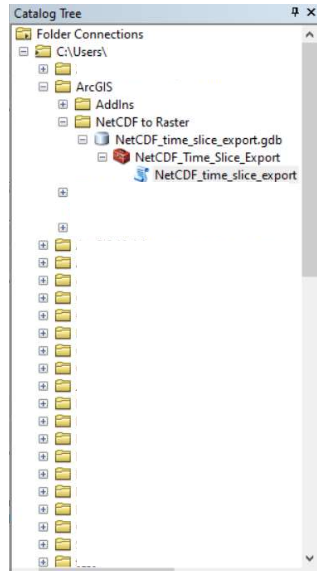


- Using the NetCDF_time_slice_to_Raster will automatically export each time slice from the NetCDF layer file as a single raster (.tif).
- Save the tool in a user-defined location.

RICCAR

Creating an ensemble in GIS

1. Extract each raster time slice
   a. Make NetCDF Raster Layer
   b. Open Layer Properties and select time for the Band Dimension
   c. Save as Layer File
   d. Download and use NetCDF Time Slice to Raster tool
   e. Open tool from user-defined location in ArcCatalog



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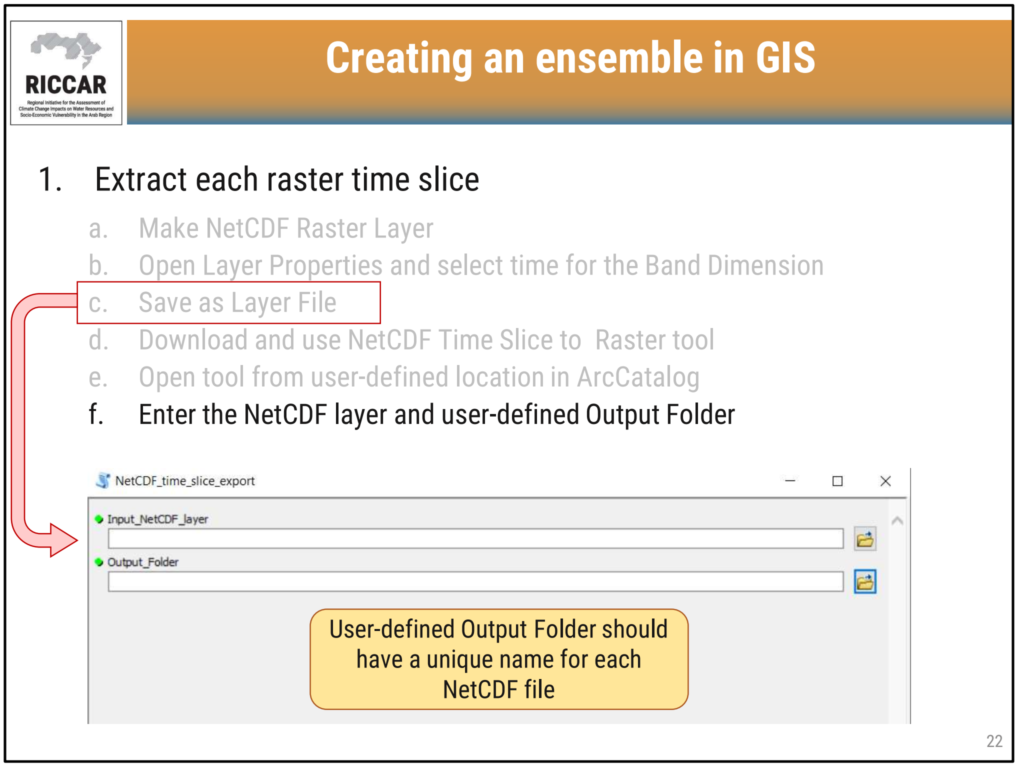
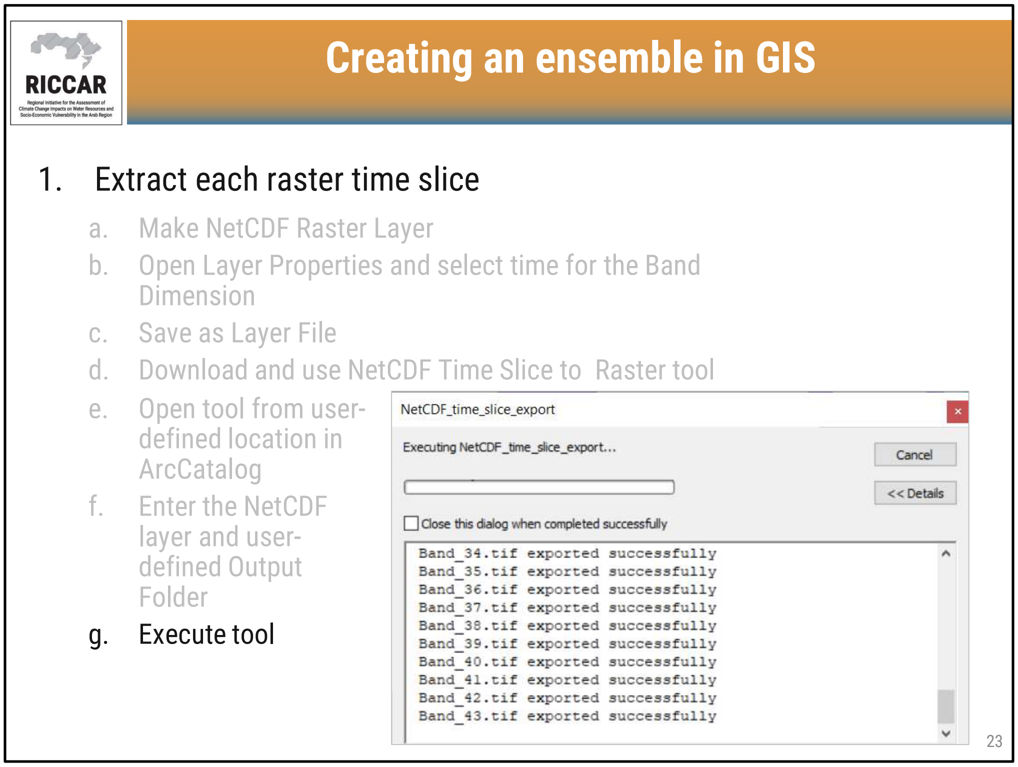
- NetCDF Time Slice to Raster tool may be located in a subdirectory under the user-defined location (NetCDF_time_slice_export.gdb > NetCDF_Time_Slice_Export > NetCDF_time_slice_export



- Select the Input NetCDF layer as saved during step 1.c.
- Once completed, select OK.

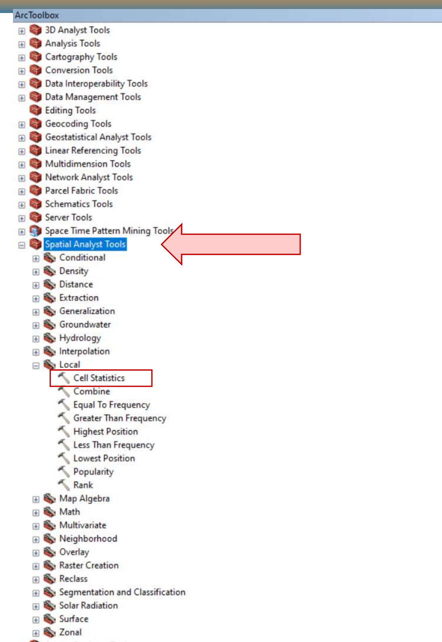


- When executing NetCDF Time Slice to Raster tool, the .tif files will automatically named Band_(number). The numbers will be in chronological order from 1 to n, where n is the number of time slices. For daily precipitation and temperature, each RICCAR NetCDF will have 365 time slices (or 366 during leap years), representing each day of the year. For the extreme climate indices, there are 150 time slices, one for each year (1951-2100).
- Common error: If the NetCDF Time Slice to Raster output is only one file (Band_1.tif), it means that the user did not select time as the Band Dimension (step 1.b) before saving as layer file (Step 1.c).
- Note that tool execution may take several minutes depending on computer speed.

RICCAR

Creating an ensemble in GIS

1. Extract each raster time slice
2. Calculate annual (or seasonal) projections
   a. 1 NetCDF file (one model, one RCP scenario)



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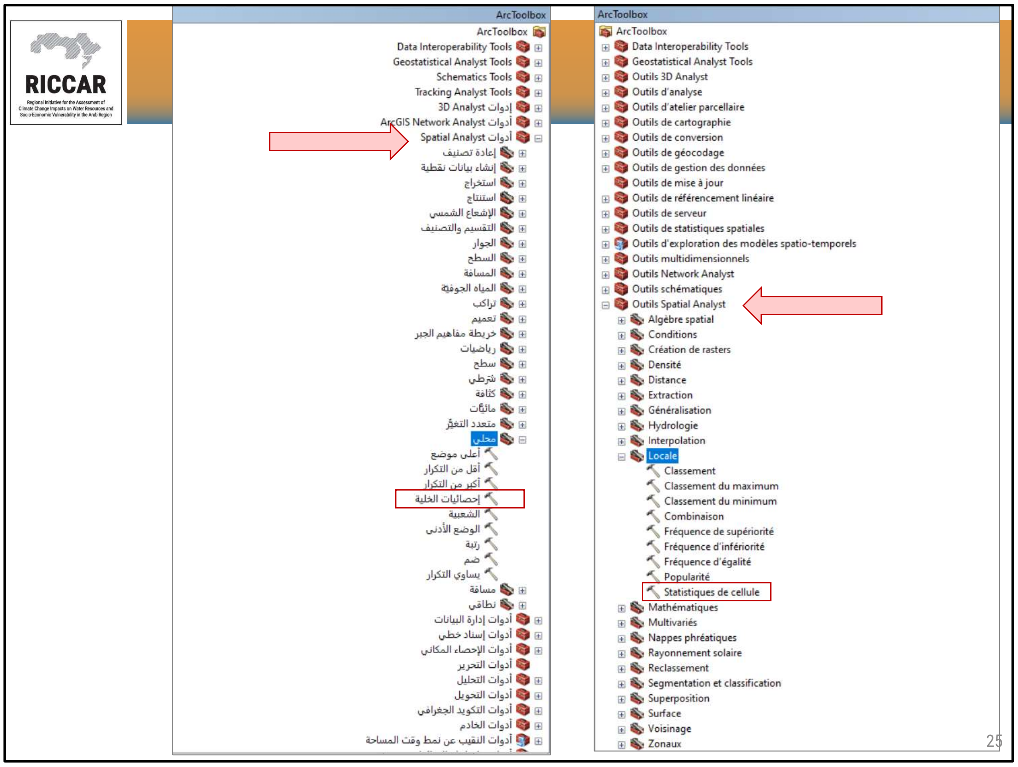
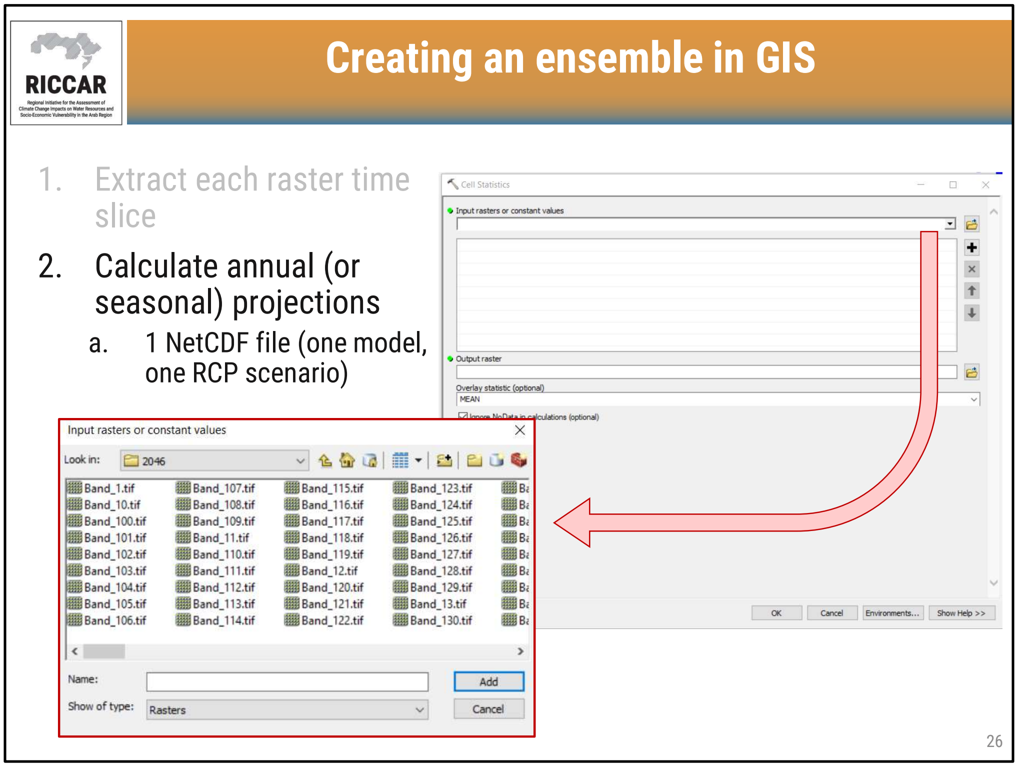
- Cell Statistics tool is located under Spatial Analyst Tools > Local
- Tool requires activation of the Spatial Analyst extension, available in ArcMap under Customize > Extensions


RICCAR
ArcToolbox
Data Interoperability Tools
Geostatistical Analyst Tools
Schematics Tools
Tracking Analyst Tools
3D Analyst أدوات
ArcGIS Network Analyst أدوات
Spatial Analyst أدوات
ArcToolbox
Data Interoperability Tools
Geostatistical Analyst Tools
Outils 3D Analyst
Outils d'analyse
Outils d'atelier parcellaire
Outils de cartographie
Outils de conversion
Outils de géocodage
Outils de gestion des données
Outils de mise à jour
Outils de référencement linéaire
Outils de serveur
Outils de statistiques spatiales
Outils d'exploration des modèles spatio-temporels
Outils multidimensionnels
Outils Network Analyst
Outils schématiques
Outils Spatial Analyst
Algèbre spatial
Conditions
Création de rasters
Densité
Distance
Extraction
Généralisation
Hydrologie
Interpolation
Locale
Classement
Classement du maximum
Classement du minimum
Combinaison
Fréquence de supériorité
Fréquence d'infériorité
Fréquence d'égalité
Popularité
Statistiques de cellule
Mathématiques
Multivariés
Nappes phréatiques
Rayonnement solaire
Reclassement
Segmentation et classification
Superposition
Surface
Voisinage
Zonaux
25



- Select raster files

Calendar days and Corresponding Output Raster Band

Days	Output Raster (.tif)
1 Jan – 31 Jan	Band_1 to Band_31
1 Feb – 28 Feb	Band_32 to Band_59
1 Mar – 31 Mar	Band_60 to Band_90
1 Apr – 30 Apr	Band_91 to Band_120
1 May – 31 May	Band_121 to Band_151
1 Jun – 30 Jun	Band_152 to Band_181
1 Jul – 31 Jul	Band_182 to Band_212
1 Aug – 31 Aug	Band_213 to Band_243
1 Sep – 30 Sep	Band_244 to Band_273
1 Oct – 31 Oct	Band_274 to Band_304
1 Nov – 30 Nov	Band_305 to Band_334
1 Dec – 31 Dec	Band_335 to Band_365

Days	Output Raster (.tif)
1 Jan – 31 Jan	Band_1 to Band_31
1 Feb – 29 Feb	Band_32 to Band_60
1 Mar – 31 Mar	Band_61 to Band_91
1 Apr – 30 Apr	Band_92 to Band_121
1 May – 31 May	Band_122 to Band_152
1 Jun – 30 Jun	Band_153 to Band_182
1 Jul – 31 Jul	Band_183 to Band_213
1 Aug – 31 Aug	Band_214 to Band_244
1 Sep – 30 Sep	Band_245 to Band_274
1 Oct – 31 Oct	Band_275 to Band_305
1 Nov – 30 Nov	Band_306 to Band_335
1 Dec – 31 Dec	Band_336 to Band_366

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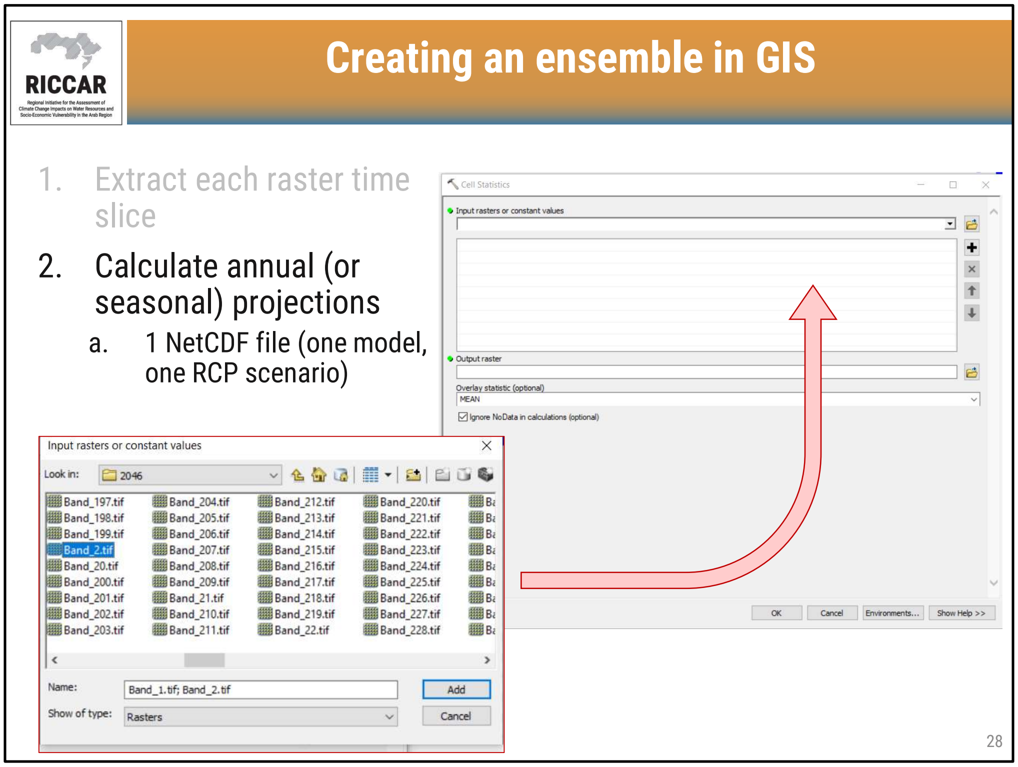
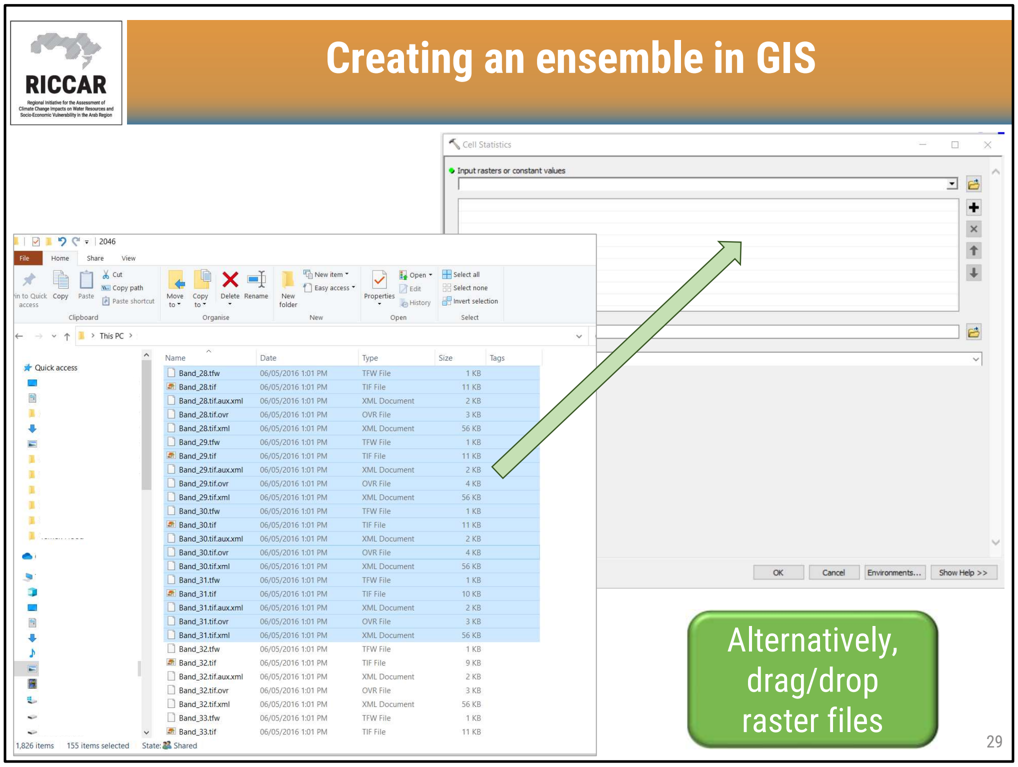
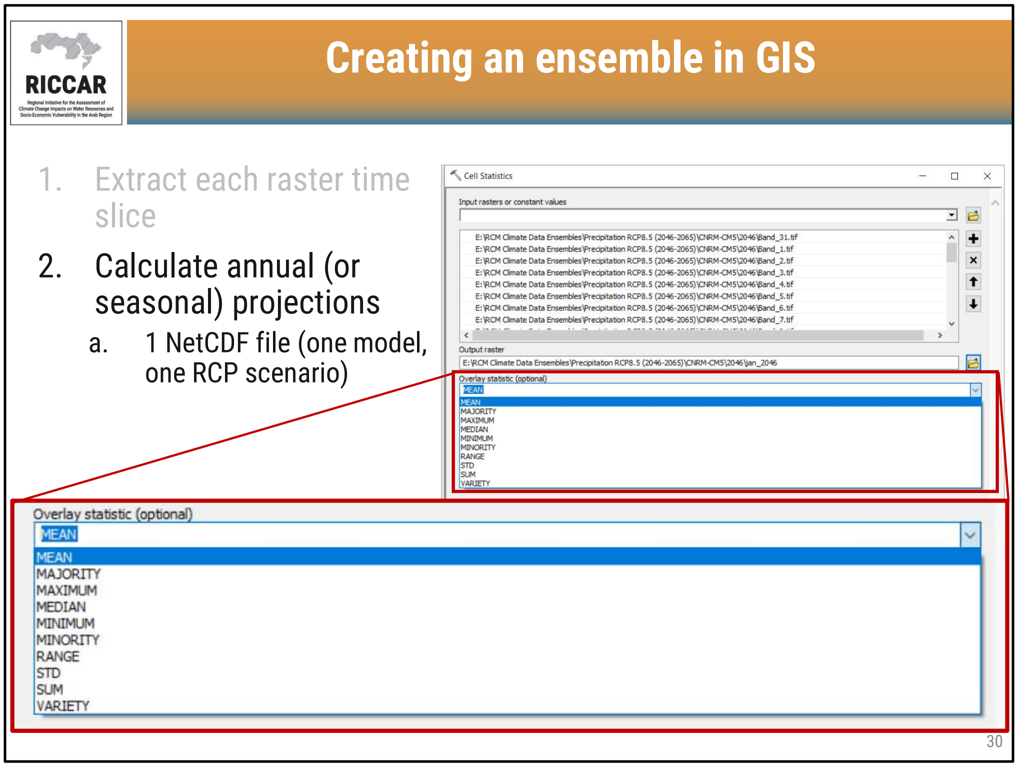
- The table on the left is for normal calendar years and the table on the right is for leap years (with 29 February, i.e. 2020, 2024, 2028)



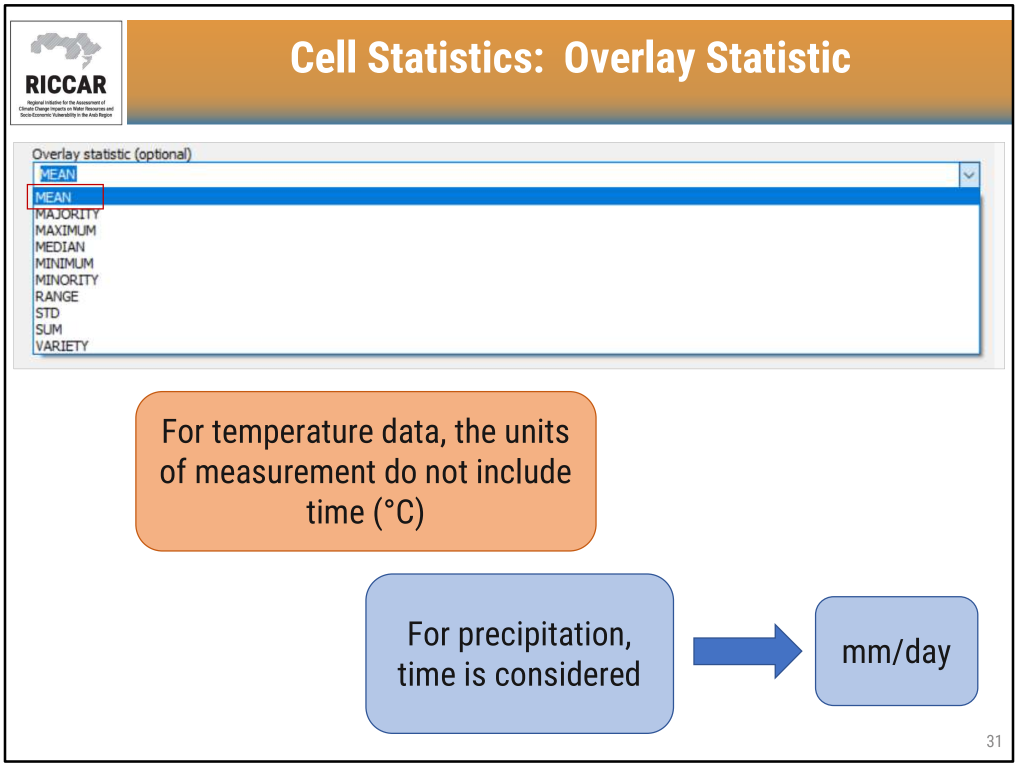
- The raster files not listed in chronological order
- Because of this, it can be tedious to select appropriate raster bands (i.e. for January)



- Be sure to select complete raster file. There will be 5 files for each raster (.tif, .tif.aux.xml, .tif.ovr, .tif.xml, and .tfw).
- After this is completed, may get warning message indicating “Invalid drop item/One or more dropped items were invalid and will not be added to the control”. Disregard this message. It is because all 5 files per raster were selected, but all are not necessary to execute the tool.



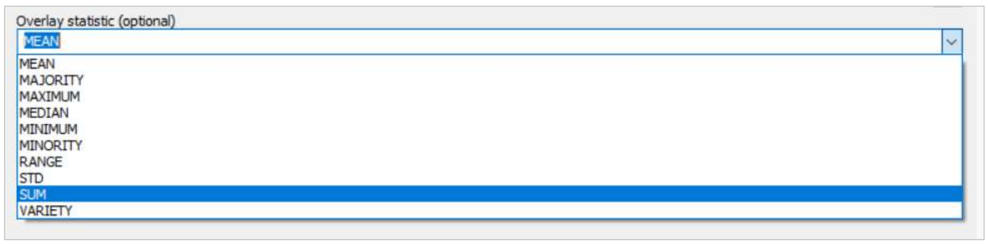
- Output raster file name is user-defined



- Mean is the default overlay statistic
- Selecting mean as the overlay statistic for temperature will calculate the average temperature of all the raster selected.
- If mean is selected as the overlay statistic for precipitation, the result will report the average precipitation in mm/day (because the NetCDF file and rasters are daily data)

Cell Statistics: Overlay Statistic

For precipitation, more common to report units in mm/month or mm/year



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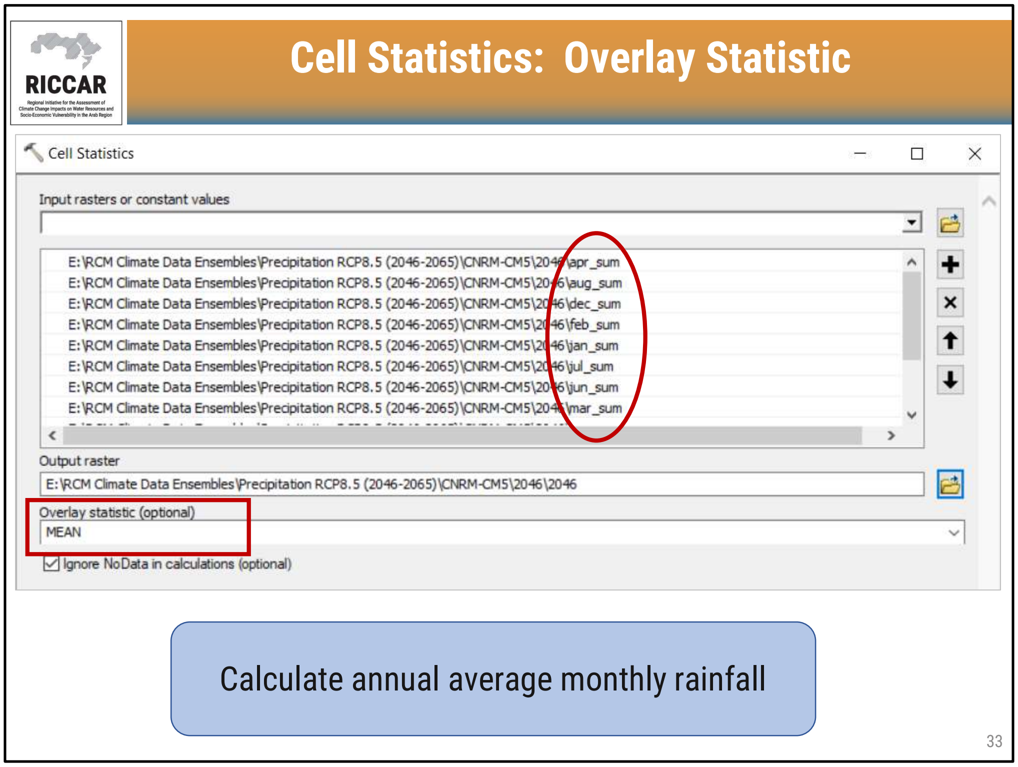
- Select sum as the overlay statistic to sum monthly data or yearly data



- To find the annual (or seasonal) average of monthly rainfall, select the monthly values as the input rasters and mean as the overlay statistic
- If reporting total yearly rainfall, this was completed in previous step, using the sum as the overlay statistic, selecting all 365 (or 366) raster files.

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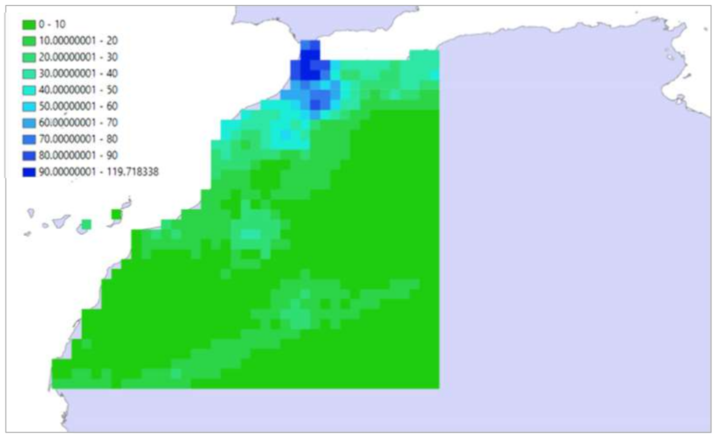
Exercise: Calculate seasonal precipitation (October-March)

1. Data: EC-EARTH, RCP8.5, year 2030 (extracted dataset)
2. Extract NetCDF to raster using tool
3. Sum monthly precipitation
4. Calculate mean monthly precipitation



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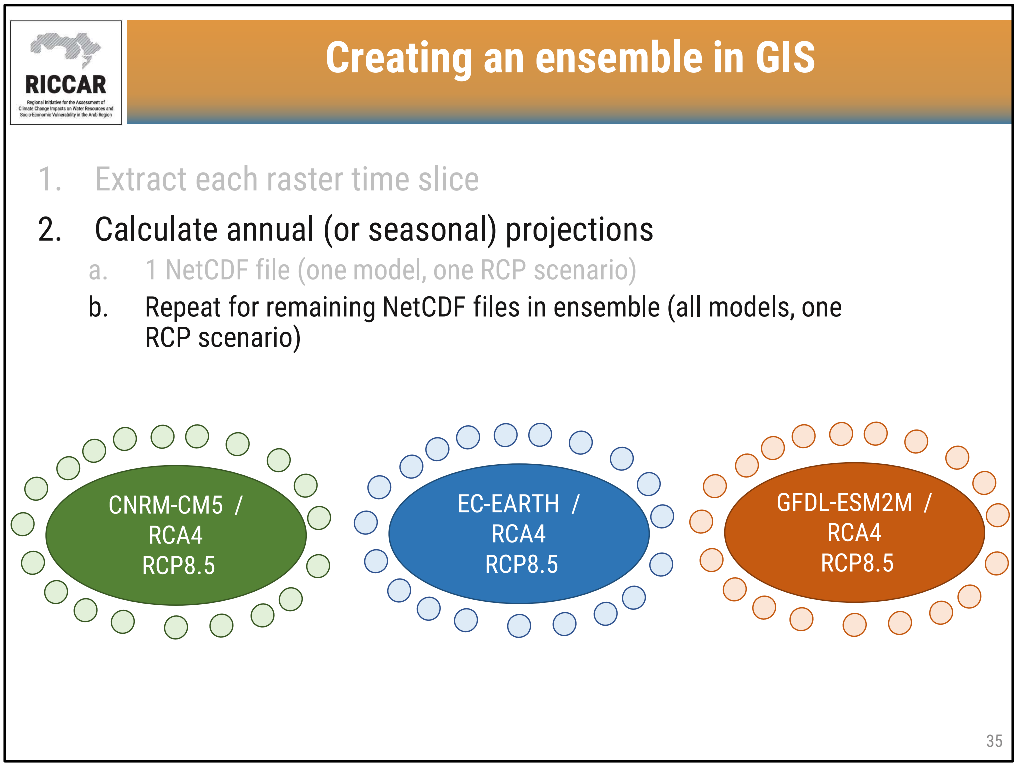
- Note that October-March is calculated as January-March 2030 and October-December 2030.
- Result will be as shown when completed. (Adding color scheme and the background map is optional.) Results should range from 0 to 119.72 mm/month.
- Results for each month: Oct: 0 – 197.8; Nov: 0 – 135.28; Dec: 0 – 354.92; Jan: 0 – 47.01; Feb: 0 – 167.81; Mar: 128.43 mm/month

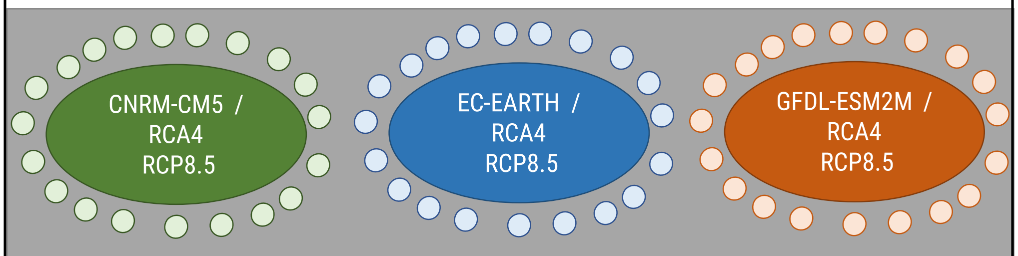


- Models shown are the RICCAR GCMs/RCM. Note that ensembles can be composed of any GCM/RCM combination as long as the domain, spatial resolution, RCP scenario, and bias-corrected (or not bias-corrected) are the same.
- Smaller circles represent the mean precipitation (or temperature) for one year per GCM/RCM.

RICCAR

Creating an ensemble in GIS

1. Extract each raster time slice
2. Calculate annual (or seasonal) projections
   a. 1 NetCDF file (one model, one RCP scenario)
   b. Repeat for remaining NetCDF files in ensemble (all models, one RCP scenario)
   c. Calculate mean for all models in ensemble



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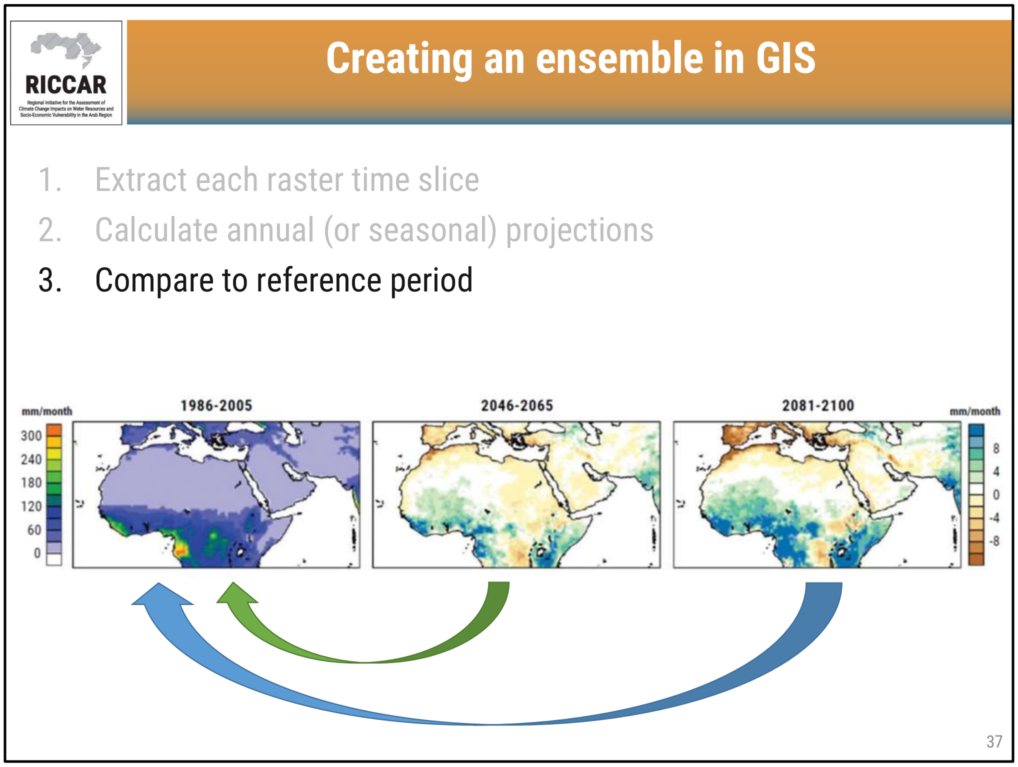
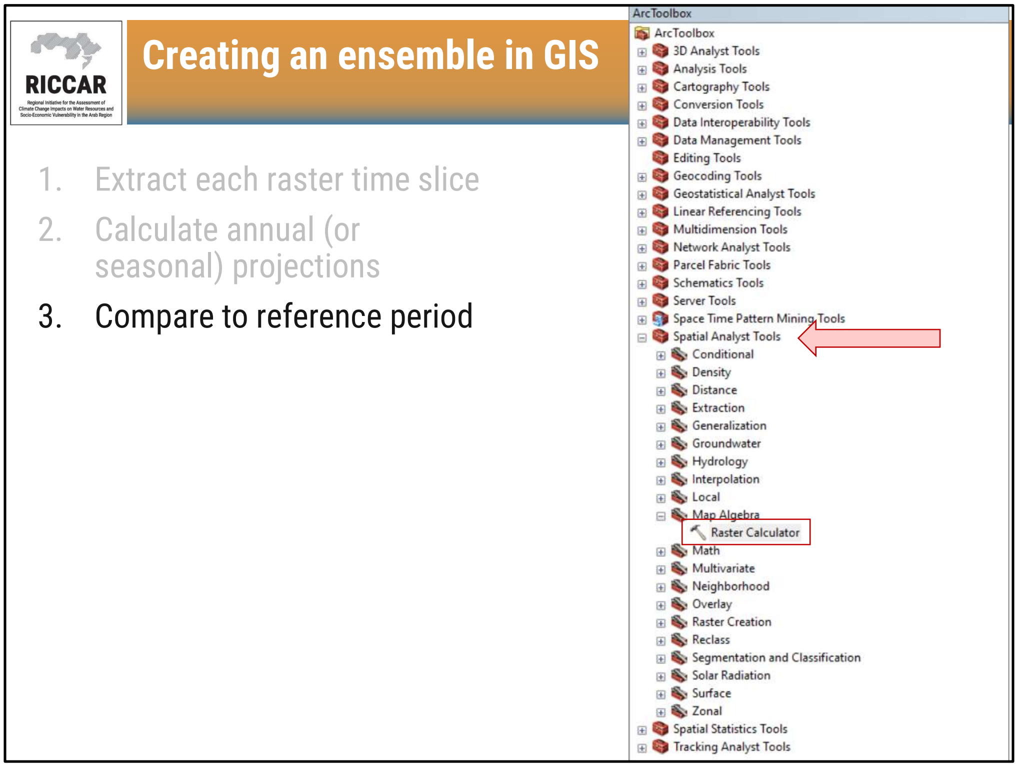
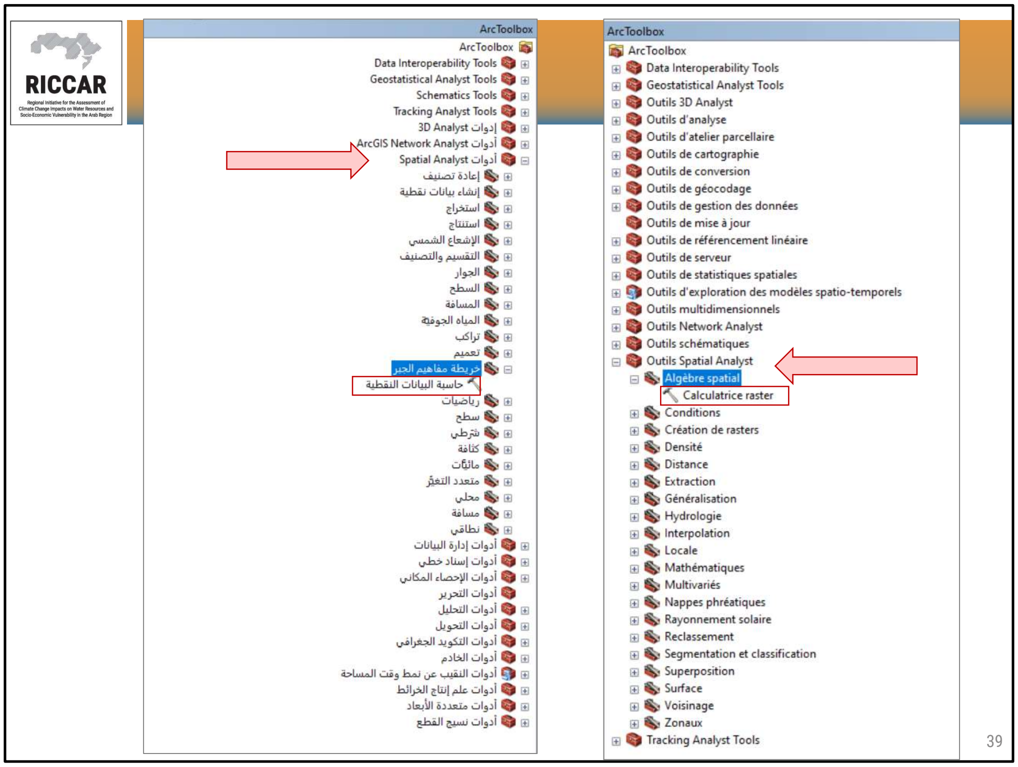


- Ensemble projections are frequently reported as a change in value to quantify climate change, compared to a reference period.
- Reference period used for RICCAR is 1986-2005, defined by IPCC AR5.
- Figure shown is from the RICCAR Arab Climate Change Assessment Report - Main Report, Figure 21, RCP8.5 showing mean change in annual precipitation



- To compare projected values to the reference period, use the Raster Calculator, found under Spatial Analyst > Map Algebra.
- Note that the Spatial Analyst extension must be active.


RICCAR
ArcToolbox
ArcToolbox
Data Interoperability Tools
Geostatistical Analyst Tools
Schematics Tools
Tracking Analyst Tools
إدوات 3D Analyst
أدوات ArcGIS Network Analyst
أدوات Spatial Analyst
إعادة تصنيف
إنشاء بيانات نقطية
استخراج
استنتاج
الإشعاع الشمسي
التقسيم والتصنيف
الجوار
السطح
المسافة
المياه الجوفية
تراكب
تعميم
خريطة مفاهيم الجبر
حاسبة البيانات النقطية
رياضيات
سطح
شرطي
كثافة
مائيّات
متعدد التغيّر
محلي
مسافة
نطاقي
أدوات إدارة البيانات
أدوات إسناد خطي
أدوات الإحصاء المكاني
أدوات التحرير
أدوات التحليل
أدوات التحويل
أدوات التكويد الجغرافي
أدوات الخادم
أدوات التنقيب عن نمط وقت المساحة
أدوات علم إنتاج الخرائط
أدوات متعددة الأبعاد
أدوات نسيج القطع
ArcToolbox
ArcToolbox
Data Interoperability Tools
Geostatistical Analyst Tools
Outils 3D Analyst
Outils d'analyse
Outils d'atelier parcellaire
Outils de cartographie
Outils de conversion
Outils de géocodage
Outils de gestion des données
Outils de mise à jour
Outils de référencement linéaire
Outils de serveur
Outils de statistiques spatiales
Outils d'exploration des modèles spatio-temporels
Outils multidimensionnels
Outils Network Analyst
Outils schématiques
Outils Spatial Analyst
Algèbre spatial
Calculatrice raster
Conditions
Création de rasters
Densité
Distance
Extraction
Généralisation
Hydrologie
Interpolation
Locale
Mathématiques
Multivariés
Nappes phréatiques
Rayonnement solaire
Reclassement
Segmentation et classification
Superposition
Surface
Voisinage
Zonaux
Tracking Analyst Tools
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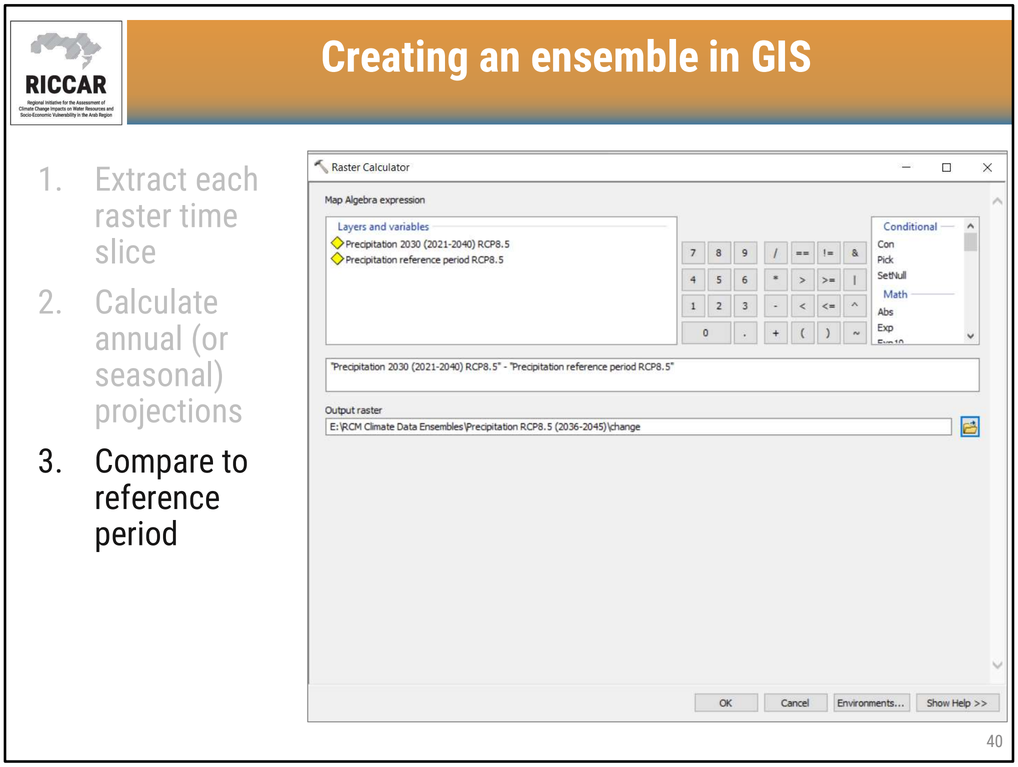

- Note that raster files must be added to ArcMap project to use in the Raster Calculator (shown in Layers and variables).
- Subtract the reference period value from the projected value to calculate the change.
- Recommended to provided a user-defined Output Raster rather than leave the default name to help facilitate future access of the raster file. Note that ArcMap often limits the number of characters in the file name (shown as “change” in the example).

Extreme climate indices

ID	Indicator Name
FD0	Frost days
SU25	Summer days
ID0	Ice days
TR20	Tropical nights
GSL	Growing season length
TXx	Max Tmax
TNx	Max Tmin
TXn	Min Tmax
TNn	Min Tmin
TN10p	Cool nights
TX10p	Cool days
TN90p	Warm nights
TX90p	Warm days

ID	Indicator Name
WSDI	Warm spell duration indicator
CSDI	Cold spell duration indicator
DTR	Diurnal temperature range
RX1day	Max 1-day precipitation amount
Rx5day	Max 5-day precipitation amount
SDII	Simple daily intensity index
R10	Number of heavy precipitation days
R20	Number of very heavy precipitation days
Rnn	Number of days about nn mm
CDD	Consecutive dry days
CWD	Consecutive wet days
R95p	Very wet days
R99p	Extremely wet days
PRCPTOT	Annual total wet-day precipitation

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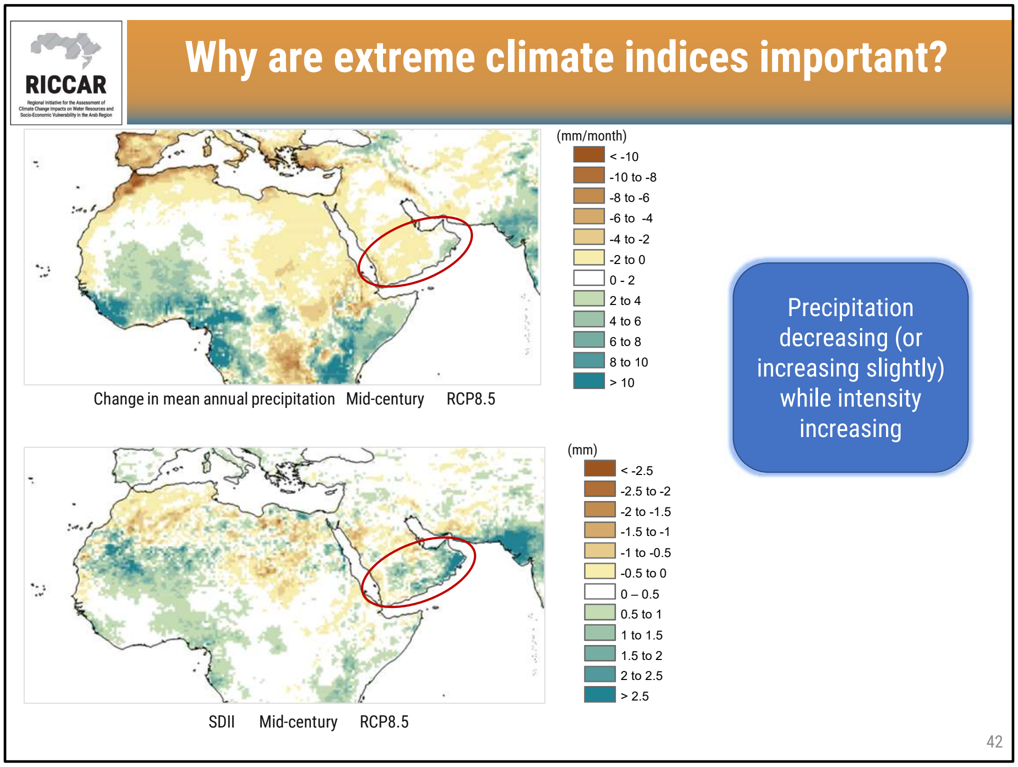
- 27 Core Indices defined by ETCCDI (Expert Team on Climate Change Detection and Indices)
- The 7 indices highlighted were used for RICCAR, plus SU35 and SU40. Note that the indicator name may differ slightly.
- Definitions and units of measurement:
  - FD0 – Annual count when TN (daily minimum) < 0 °C (days)
  - SU25 – Annual count when TX (daily maximum) > 25 °C (days)
  - ID0 - Annual count when TX (daily maximum) < 0 °C (days)
  - TR20 – Annual count when TN (daily minimum) > 20 °C (days)
  - GSL – Annual count (1 Jan to 31 Dec in northern hemisphere, 1 Jul to 30 Jun in southern hemisphere) between first span of at least 6 days with daily mean temperature > 5 °C and first span after 1 Jul (1 Jan in southern hemisphere) of 6 days with daily mean temperature < 5 °C (days)
  - TXx – Monthly maximum value of daily maximum temperature (°C)
  - TNx – Monthly maximum value of daily minimum temperature (°C)
  - TXn – Monthly minimum value of daily maximum temperature (°C)
  - TNn – Monthly minimum value of daily minimum temperature (°C)
  - TN10p – Percentage of days when minimum temperature < 10th percentile (days)

  - TX10p – Percentage of days when maximum temperature < 10^{th} percentile (days)
  - TN90p – Percentage of days when minimum temperature > 90^{th} percentile (days)
  - TX90p – Percentage of days when maximum temperature > 90^{th} percentile (days)
  - WDSI – Annual count of days with at least 6 consecutive days when maximum temperature > 90^{th} percentile (days)
  - CSDI – Annual count of days with at least 6 consecutive days when minimum temperature > 10^{th} percentile (days0
  - DTR – Monthly mean difference between daily maximum and daily minimum temperature (°C)
  - RX1day – Monthly maximum 1-day precipitation (mm)
  - RX5day – Monthly maximum consecutive 5-day precipitation (mm)
  - SDII – Annual total precipitation divided by the number of wet days (precipitation ≥ 1.0 mm) (mm/days)
  - R10 – Annual count when precipitation ≥ 10 mm (days)
  - R20 – Annual count when precipitation ≥ 20 mm (days)
  - Rnn – Annual count when precipitation ≥ nn mm (nn is user-defined threshold) (days)
  - CDD – Maximum number of consecutive days with precipitation < 1 mm (days)
  - CWD – Maximum number of consecutivey days with precipitation ≥ 1 mm (days)
  - R95p – Annual total precipitation when daily precipitation > 95^{th} percentile (mm)
  - R99p – Annual total precipitation when daily precipitation > 99^{th} percentile (mm)
  - PRCPTOT – Annual total precipitation in wet days (precipitation ≥ 1 mm) (mm)
- Can calculate indices from NetCDF files using CDO or from time series data (.txt) for single point location using RClimDex (http://etccdi.pacificclimate.org/software.shtml)


Why are extreme climate indices important?
RICCAR
(mm/month)
< -10
-10 to -8
-8 to -6
-6 to -4
-4 to -2
-2 to 0
0 - 2
2 to 4
4 to 6
6 to 8
8 to 10
> 10
Change in mean annual precipitation Mid-century RCP8.5
Precipitation decreasing (or increasing slightly) while intensity increasing
(mm)
< -2.5
-2.5 to -2
-2 to -1.5
-1.5 to -1
-1 to -0.5
-0.5 to 0
0 – 0.5
0.5 to 1
1 to 1.5
1.5 to 2
2 to 2.5
> 2.5
SDII Mid-century RCP8.5
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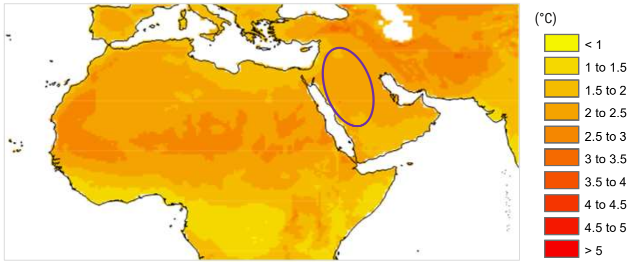
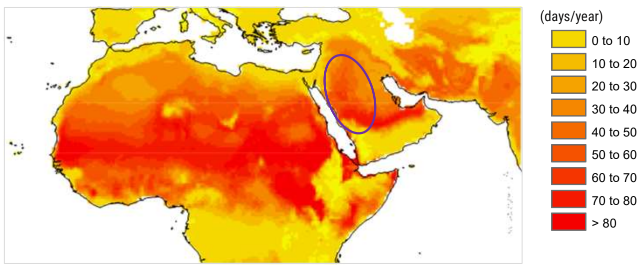
Why are extreme climate indices important?



Change in mean annual temperature Mid-century RCP8.5



SU40 Mid-century RCP8.5

Temperature increasing such that intense heat waves (> 40 °C) more likely

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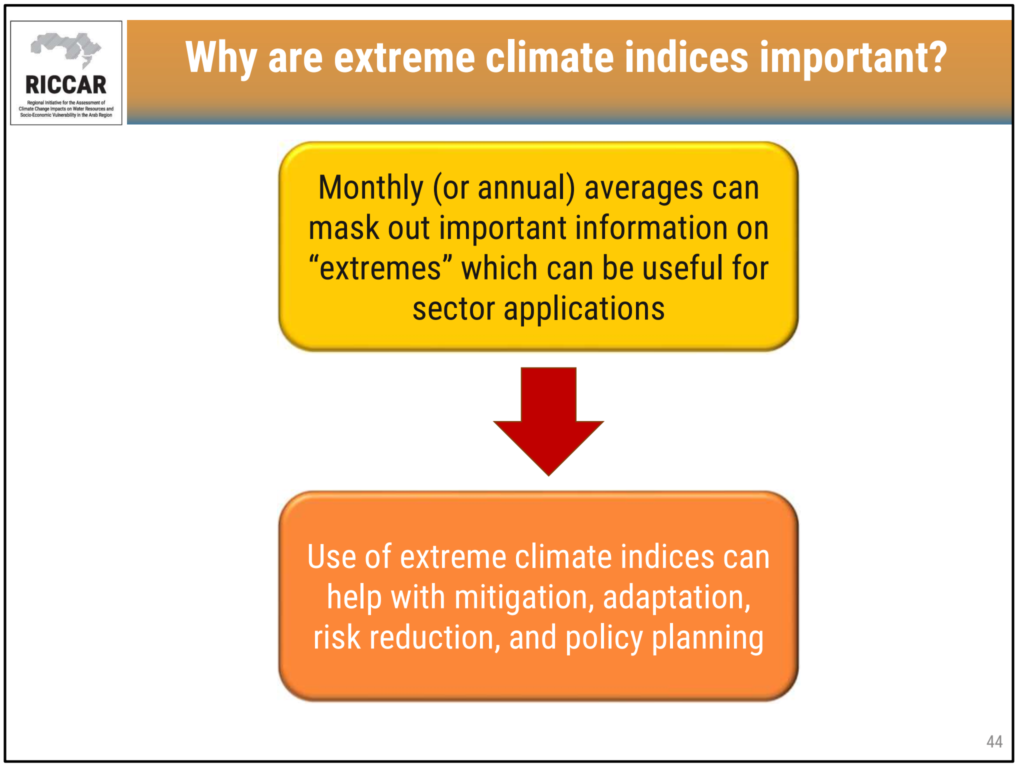
RICCAR
Why are extreme climate indices important?
Monthly (or annual) averages can mask out important information on "extremes" which can be useful for sector applications
Use of extreme climate indices can help with mitigation, adaptation, risk reduction, and policy planning
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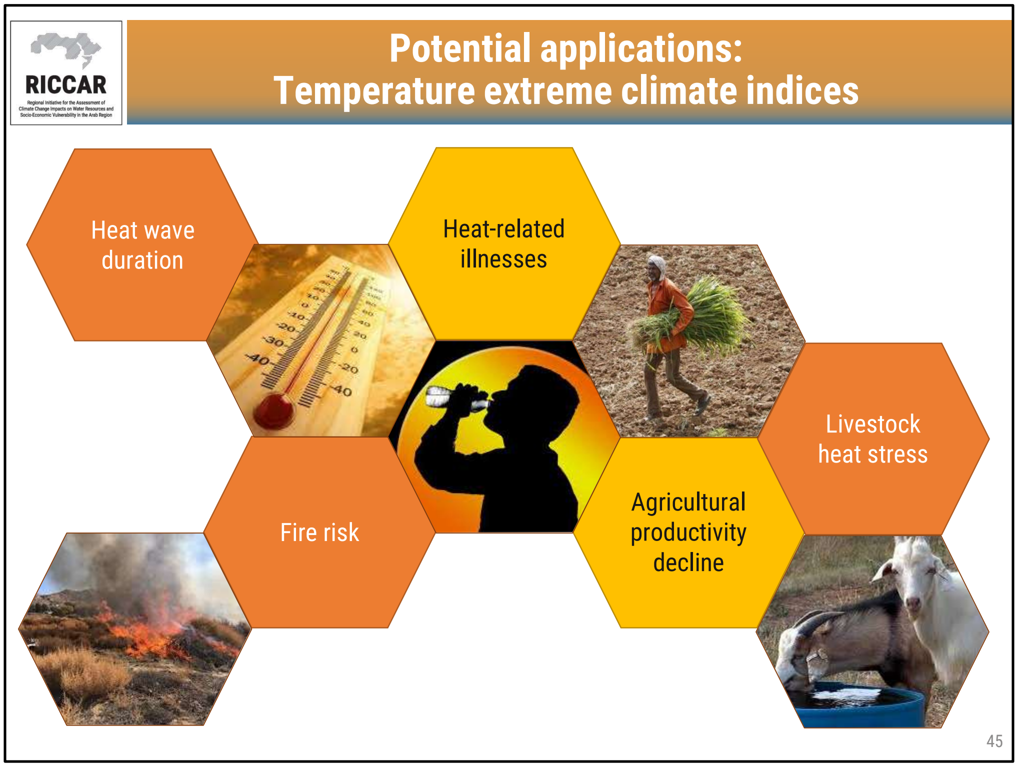
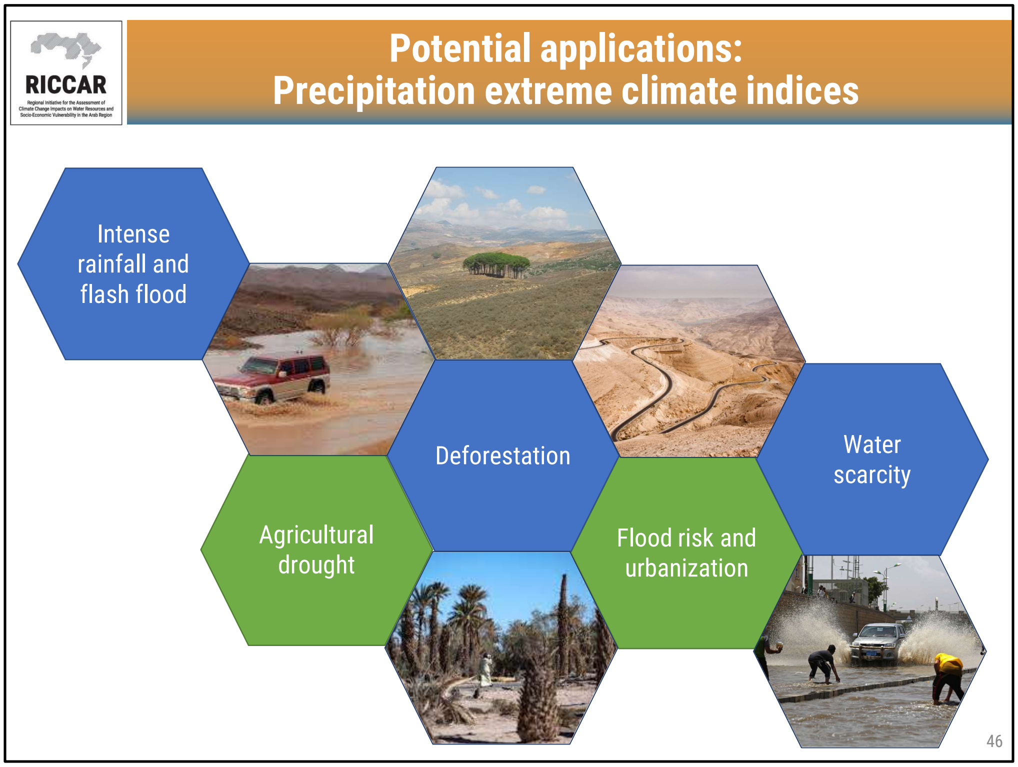

RICCAR
Potential applications:
Temperature extreme climate indices
Heat wave duration
Heat-related illnesses
Livestock heat stress
Fire risk
Agricultural productivity decline
45


RICCAR
Potential applications:
Precipitation extreme climate indices
Intense rainfall and flash flood
Deforestation
Water scarcity
Agricultural drought
Flood risk and urbanization
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RICCAR
Thank You
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