



Drought Risk Assessment

-A Customized Toolbox

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Introduction

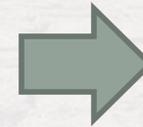
Differences with other extreme meteorological events:

1. Onset & end of a drought are difficult to determine (currently the least predictable)
2. No universal definitions: quantification of impact and provision for relief far more difficult
3. Greatest detrimental impact in the 20th century. Often on a large scale → 1st for number of people affected
4. Human activities can directly trigger a drought: overfarming, excessive irrigation, deforestation, over-exploitation of available water, erosion

Introduction (*cont.*)

NASA's Earth Observatory

- *Agricultural drought*: soil lacks moisture that a specific crop would need at a specific time
- *Meteorological drought*: negative deviations of long-term precipitation from the norm
- *Hydrological drought*: lack of sufficient surface and subsurface water supplies



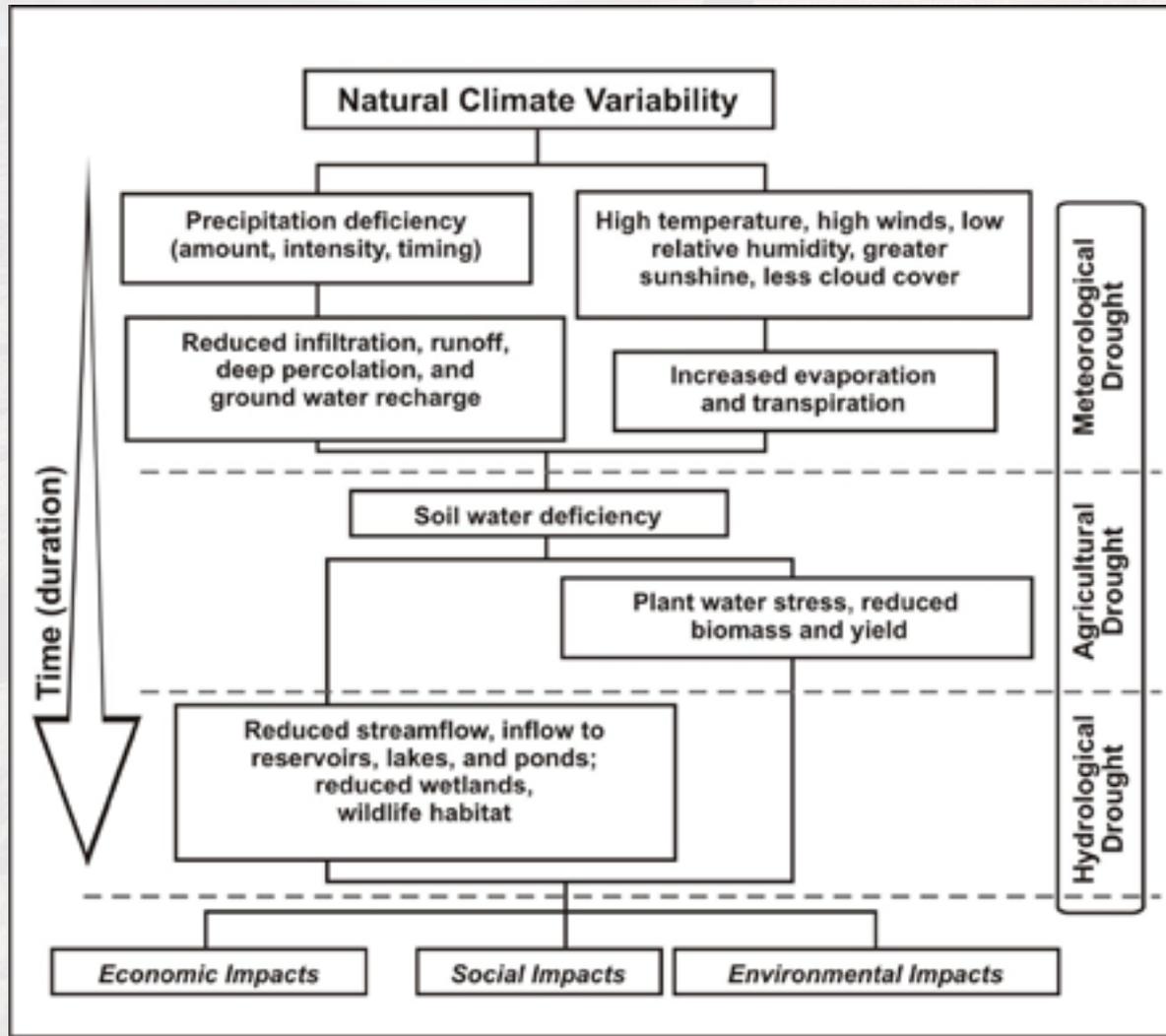
Introduction (*cont.*)

- *Socio-economic drought*: water scarcity starts affecting people's lives

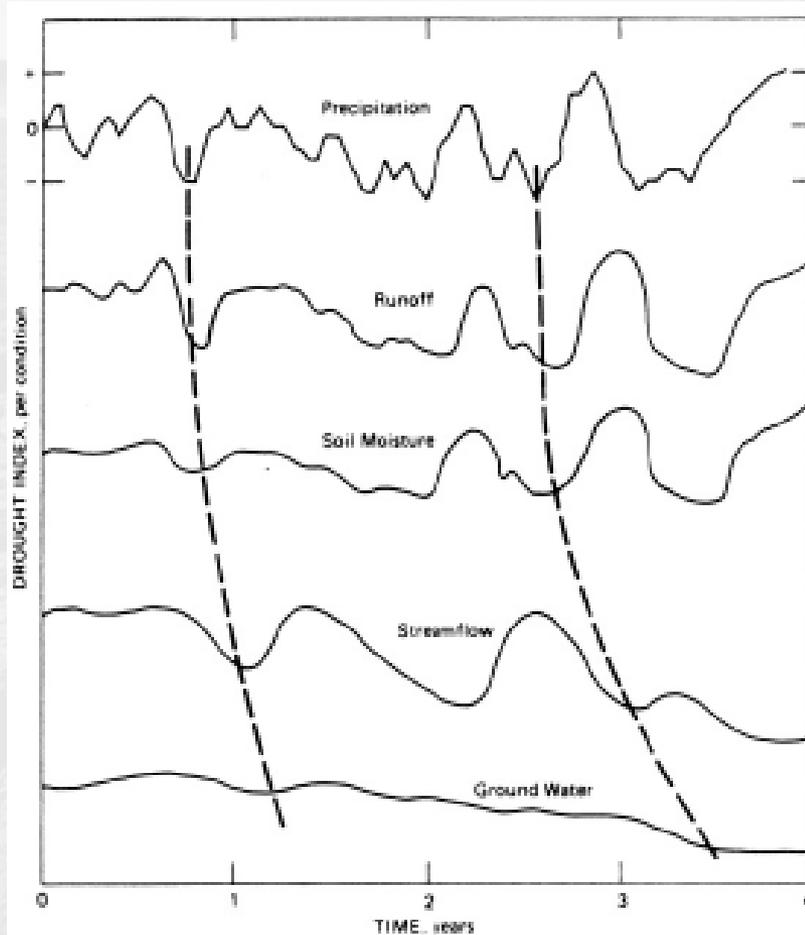


Introduction (*cont.*)

Source: National Drought Mitigation Center <http://www.drought.unl.edu/>



Introduction (*cont.*)



Proceeding of precipitation deficit throughout the hydrological cycle (Rasmusson, 1993)

Precipitation

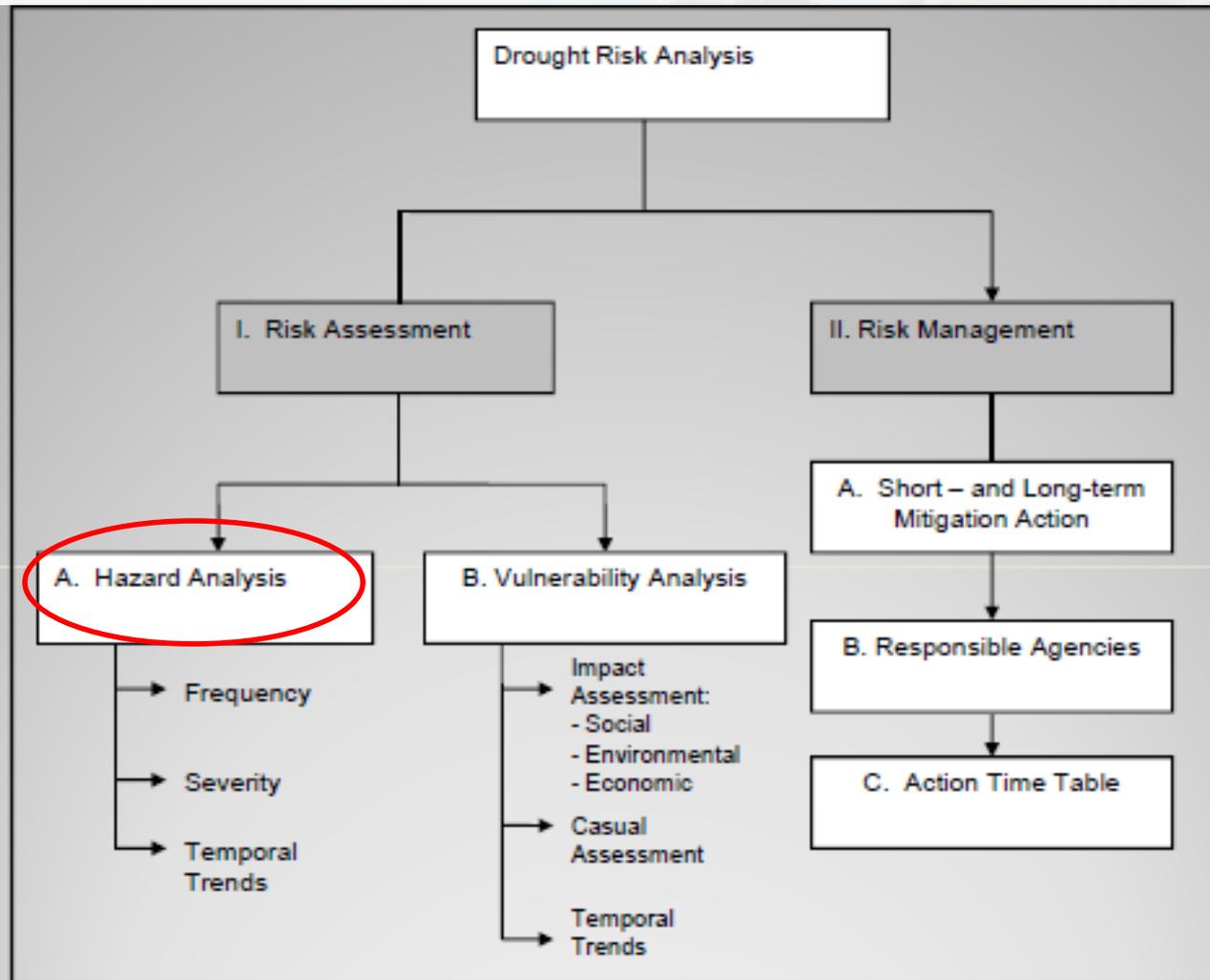
Runoff

Soil Moisture

Streamflow

Ground Water

Methods & Indicators



Drought Risk Analysis Framework. (After: Hayes *et al* 2004)

Methods & Indicators (*cont.*)

- Assessment of drought conditions is more accurate when the variable of interest is measured in situ
- Ideally, ground stations would be uniformly located and closely spaced in order to get the best information
- Costs associated with a dense spatial coverage are high (economic & human resources availability)
- Existing literature suggests several methods that have been developed to measure different types of drought
- Drought indicators can be divided into two main categories: ground-based or satellite-based, depending on their derivation

Methods & Indicators (*cont.*)

Ground-based Indicators

ü Meteorological drought: Palmer Drought Severity Index (PDSI), Standard Precipitation Index (SPI), Deciles

ü Agricultural drought : Crop Moisture Index (CMI)

ü Hydrological drought : Palmer Hydrological Drought Severity Index (PHDSI), Surface Water Supply Index (SWSI)

Methods & Indicators (*cont.*)

Satellite-based Indicators:

Rainfall Estimate (RFE), Water Requirement Satisfaction Index (WRSI)

Persendt (2009) divides satellite-based drought indicators into three groups:

(i) State of the vegetation, extrapolated using the reflective channels:

Normalized Difference Vegetation Index (**NDVI**), Vegetation Condition Index (**VCI**)

(ii) Surface brightness temperature, extrapolated from the thermal channels:

Temperature Condition Index (**TCI**)

(iii) Combination of (i) and (ii):

Ratio between Land Surface Temperature (**LST**) and NDVI, Vegetation Health Index (**VHI**)

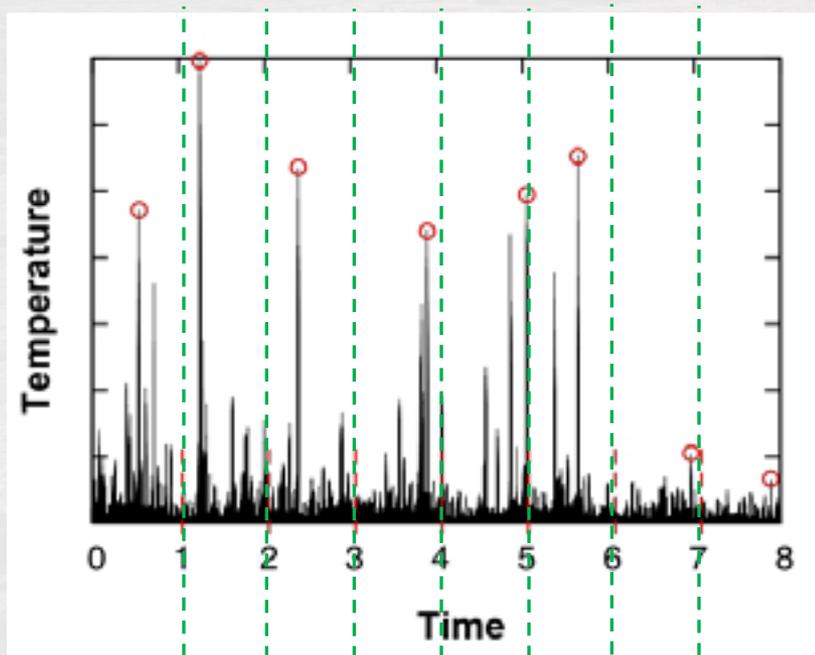
Extreme Value Analysis

The extreme value theory deals with the modeling of extreme observations

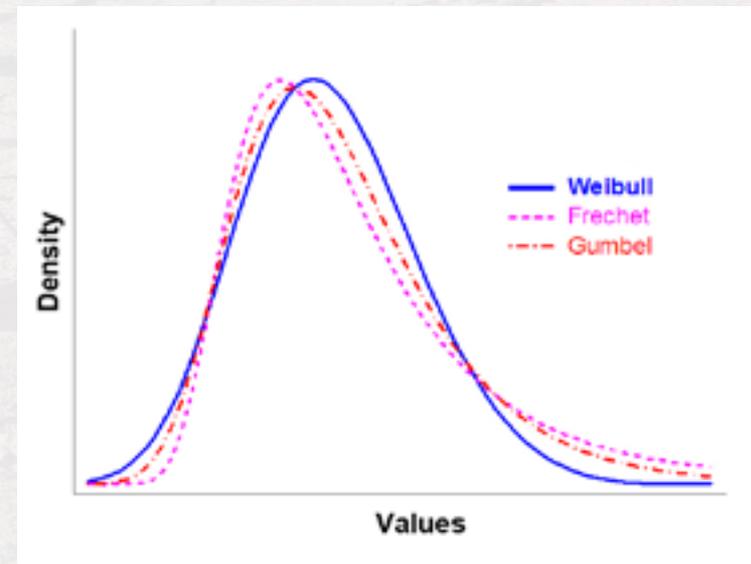
1. Block Maxima: Generalized Extreme Value (GEV) distribution to model values found in the tails of the distribution of observed values
2. Peak-over-threshold (POT): Generalized Pareto Distribution (GPD) to model all observations exceeding a certain threshold

Extreme Value Analysis (*cont.*)

Block Maxima/Minima: maxima/minima over a pre-defined time frame (e.g. weeks, months, years, etc.)



GEV distribution



Pros:

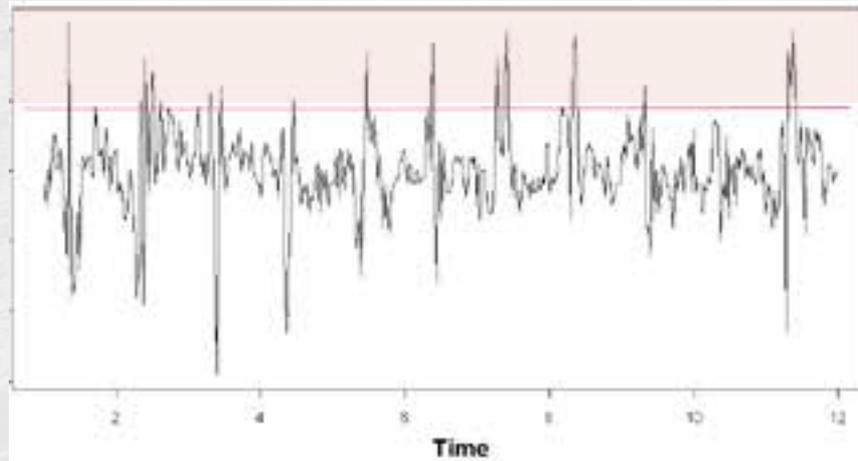
- It does not require threshold calibration
- Less autocorrelation (compared to POT)

Cons:

- Some data is not used

Extreme Value Analysis (*cont.*)

Peak-over-threshold (POT): values exceeding a pre-defined threshold

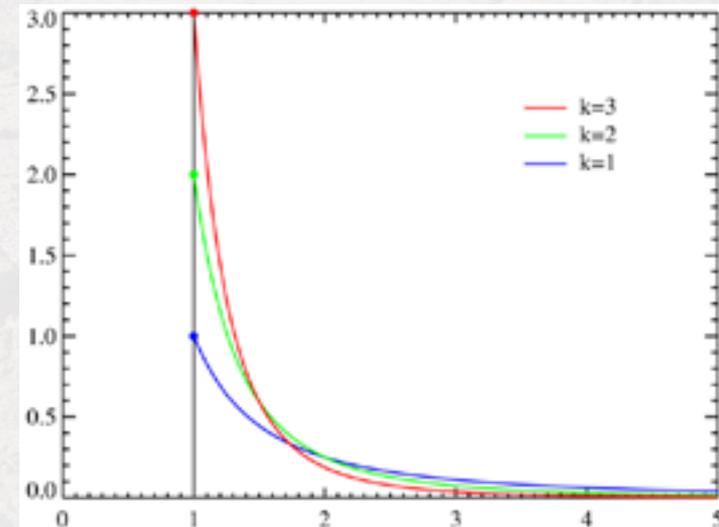


Pros:

- All data is used
- It allows user to choose a threshold



Pareto distribution



Cons:

- Sensitive choice of threshold

Extreme Value Analysis (*cont.*)

- From fitted distribution we can estimate how often the extreme quantiles occur with a certain return level
- Return Levels: defined as values that are expected to be equaled or exceeded on average once every interval of time (T) (with a probability of $1/T$)

Example:

Block maxima approach → Time series made of yearly maxima

Time (return period): 10 years

Return Levels:

10-year return levels are values expected to be equaled or exceeded on average once every 10 years ($1/10 = 10\%$ probability)

Custom Toolbox

The R software for Statistical Computing



PROS:

- Free and open source
- Native cross-platform and 64-bit support
- Huge community, brilliant developers (1500+ projects on R-Forge, 4500+ available packages on CRAN)
- Lots of packages to handle geospatial data: **rgdal**, **maptools**, **raster**, **RgoogleMaps**, **plotKML**, **OpenStreetMap**, **RPyGeo**, **sp**, **splancs**, **spatstat**, and many more!

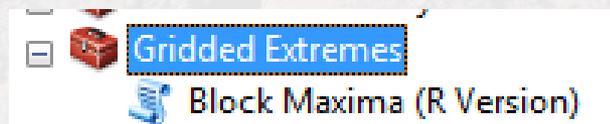
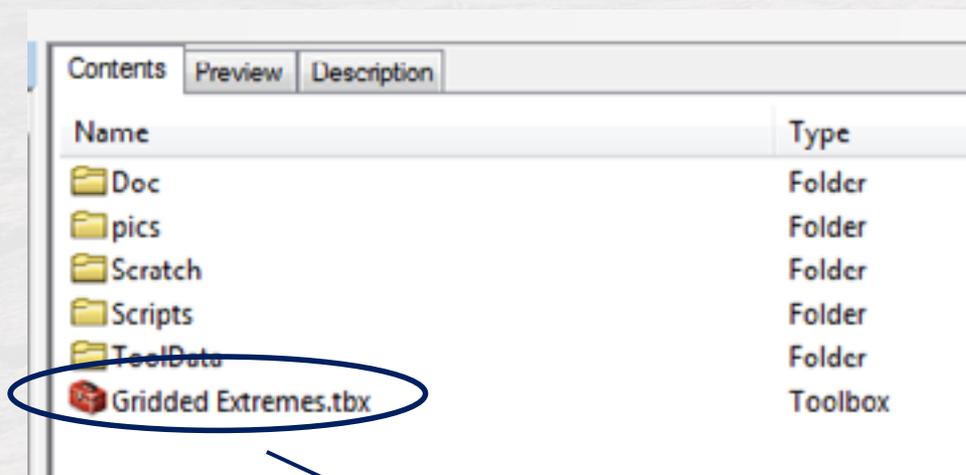
CONS:

- Not as efficient and fast compared to lower-level languages (or even Python)
- Memory performance and big data handling (**Revolution R** improves this)

Custom Toolbox



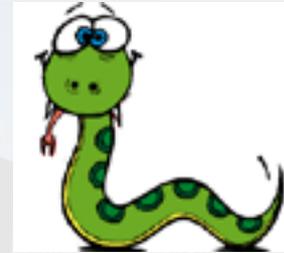
Credits: resources.arcgis.com



← Custom .py script

Custom Toolbox

Sneak Peek



```
def BlockMaxima():
    """ Get User Provided Inputs """
    inputWorkSpace = ARCPY.GetParameterAsText(0)
    outputWorkSpace = ARCPY.GetParameterAsText(1)
    rperiods = ARCPY.GetParameterAsText(2)
    rperiods = [str(i) for i in rperiods.split(";")]
    rperiods = ":".join(rperiods)
    useMinima = ARCPY.GetParameterAsText(3)
    useConfInt = ARCPY.GetParameterAsText(4)
    useCoeff = ARCPY.GetParameterAsText(5)
```

Read arguments from script tool

Set arguments and execute R command



```
""" Create R Command """
pyScript = SYS.argv[0]
toolDir = OS.path.dirname(pyScript)
rScript = OS.path.join(toolDir, "BlockMaxima.r")
ARCPY.SetProgressor("default", "Executing R Script...")

args = ["R", "--slave", "--vanilla", "--args", rScript, inputWorkSpace,
        outputWorkSpace, rperiods, useMinima, useConfInt, useCoeff]

""" Uncomment Next Two Lines to Print/Create Command Line Args """
#cmd = RARC.createRCommand(args, rScript)
#ARCPY.AddWarning(cmd)

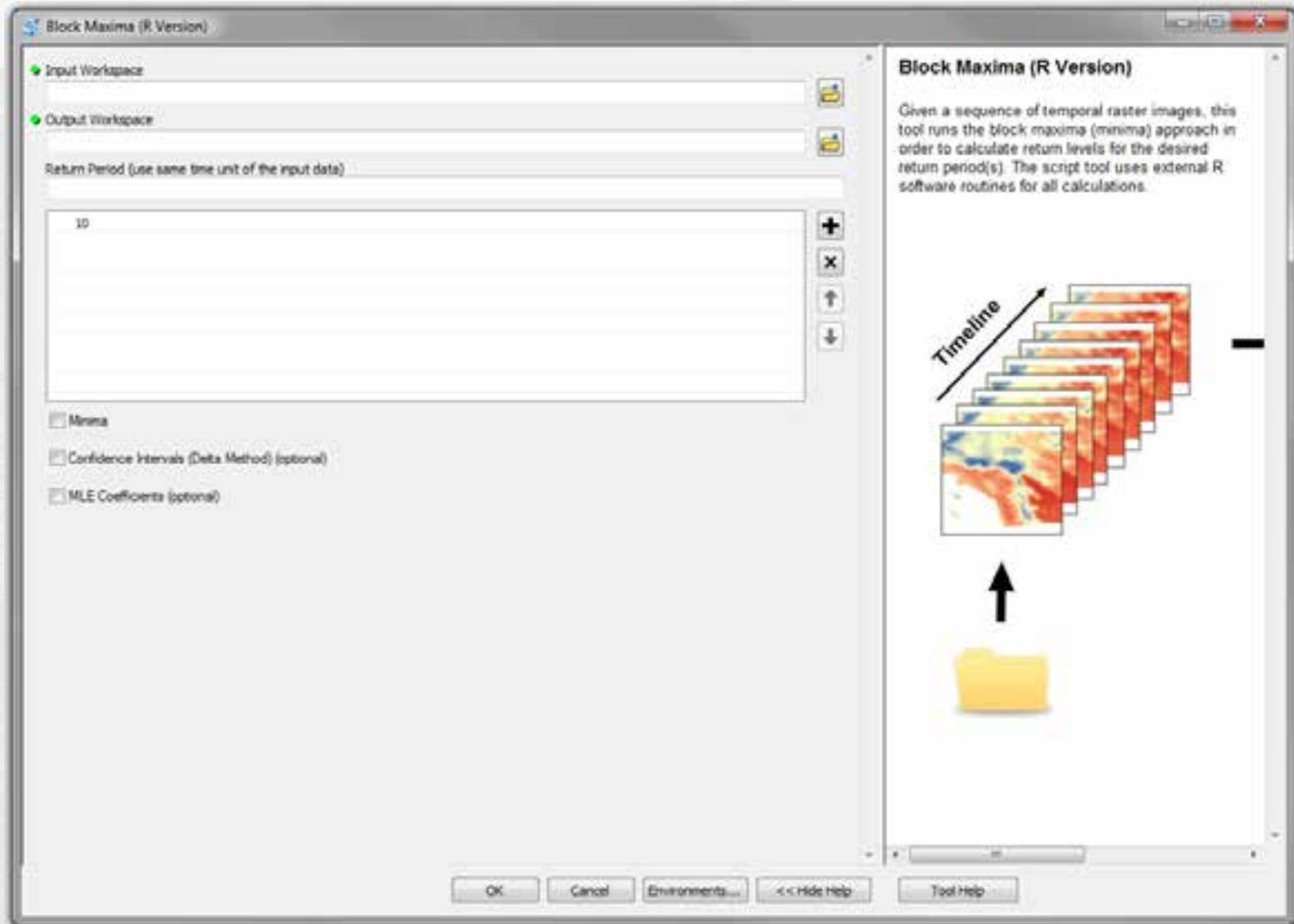
""" Execute Command """
scriptSource = open(rScript, 'rb')
rCommand = SUB.Popen(args,
                    stdin = scriptSource,
                    stdout = SUB.PIPE,
                    stderr = SUB.PIPE,
                    shell=True)
```



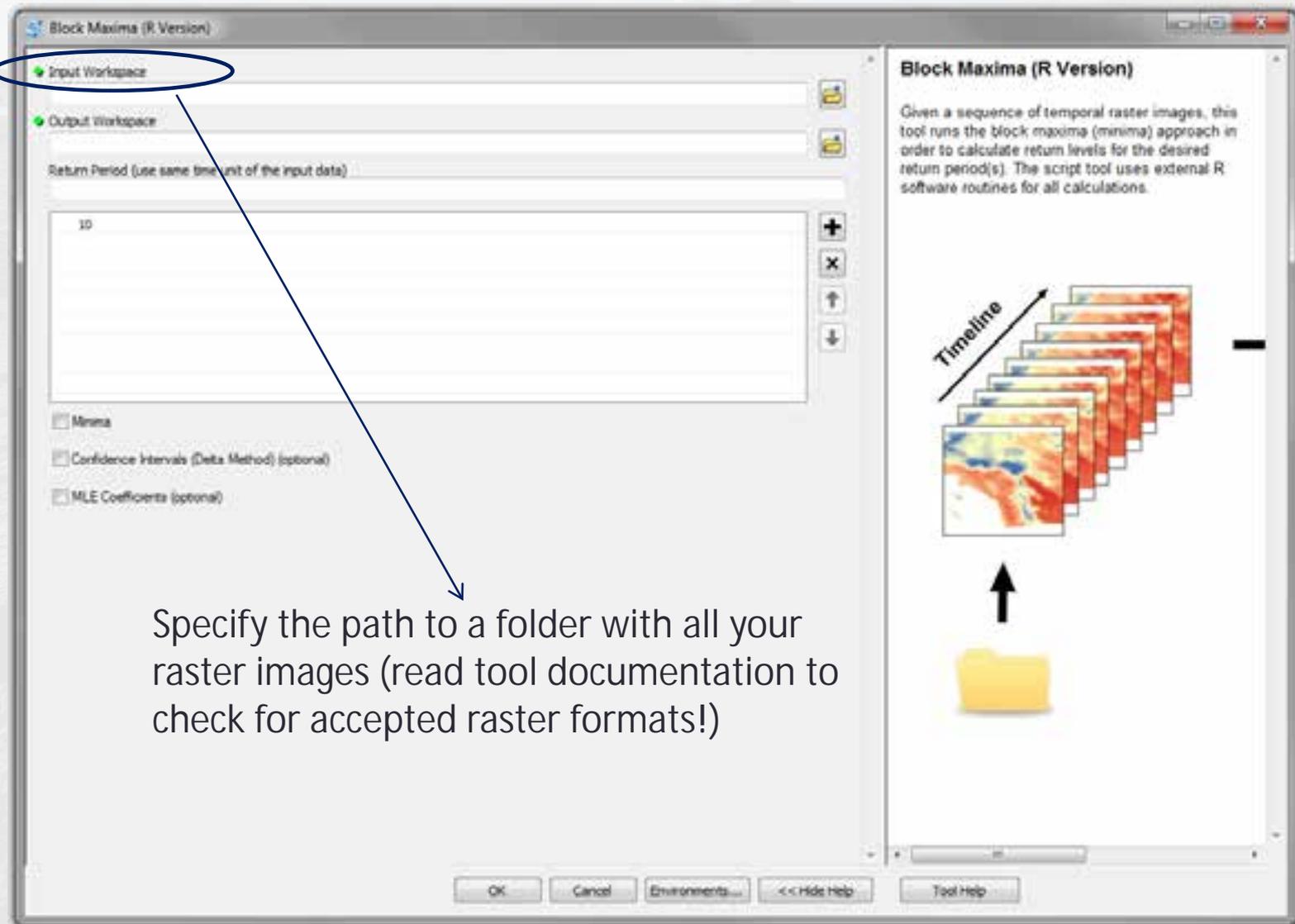
Read args from console

```
""" Get Arguments """
Args <- commandArgs()
RSource <- Args[5]
inputWorkSpace <- Args[6]
outputWorkSpace <- Args[7]
rperiods <- Args[8]
useMinima <- as.integer(Args[9])
useConfInt <- as.integer(Args[10])
useCoeff <- as.integer(Args[11])
```

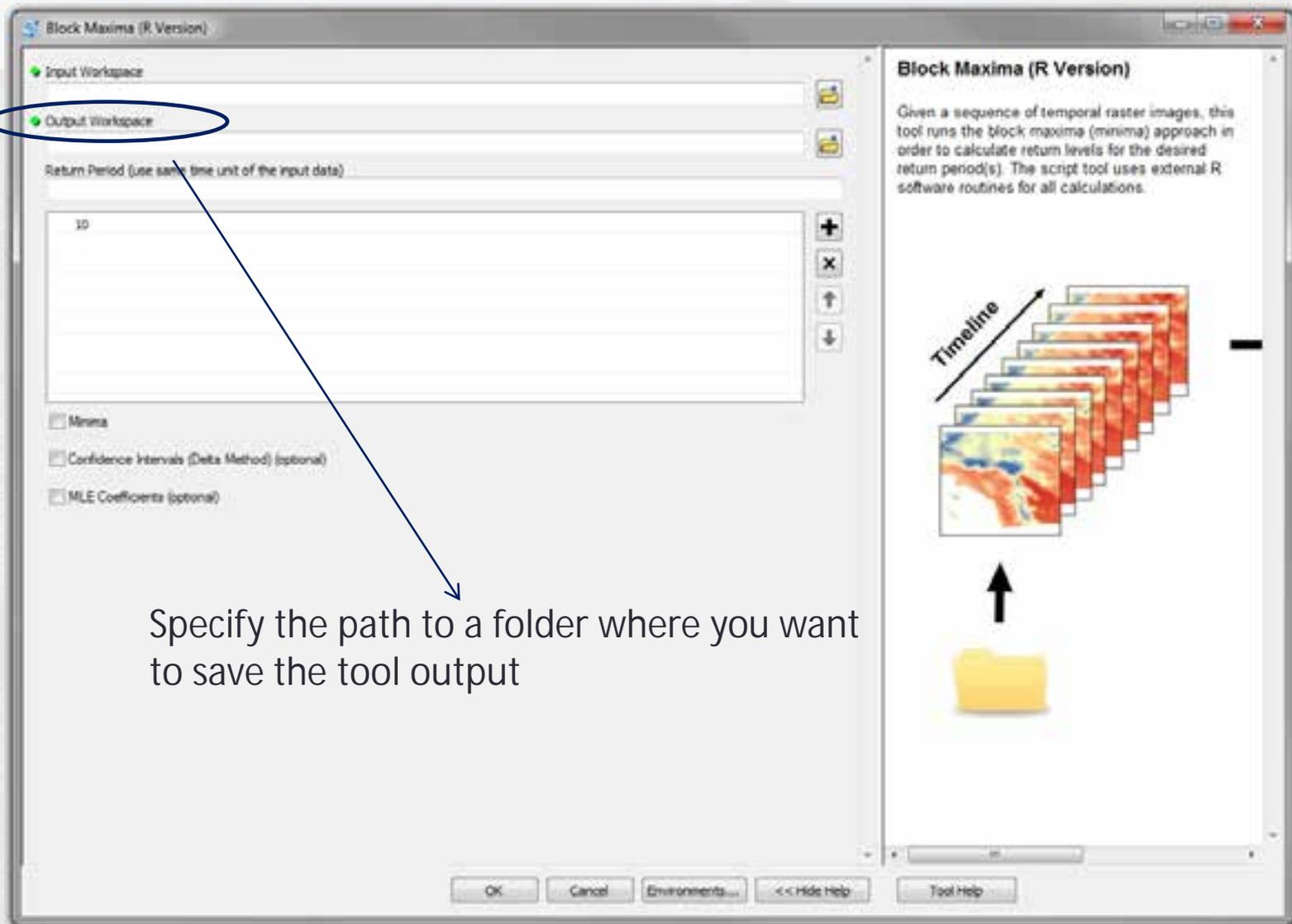
Custom Toolbox (*cont.*)



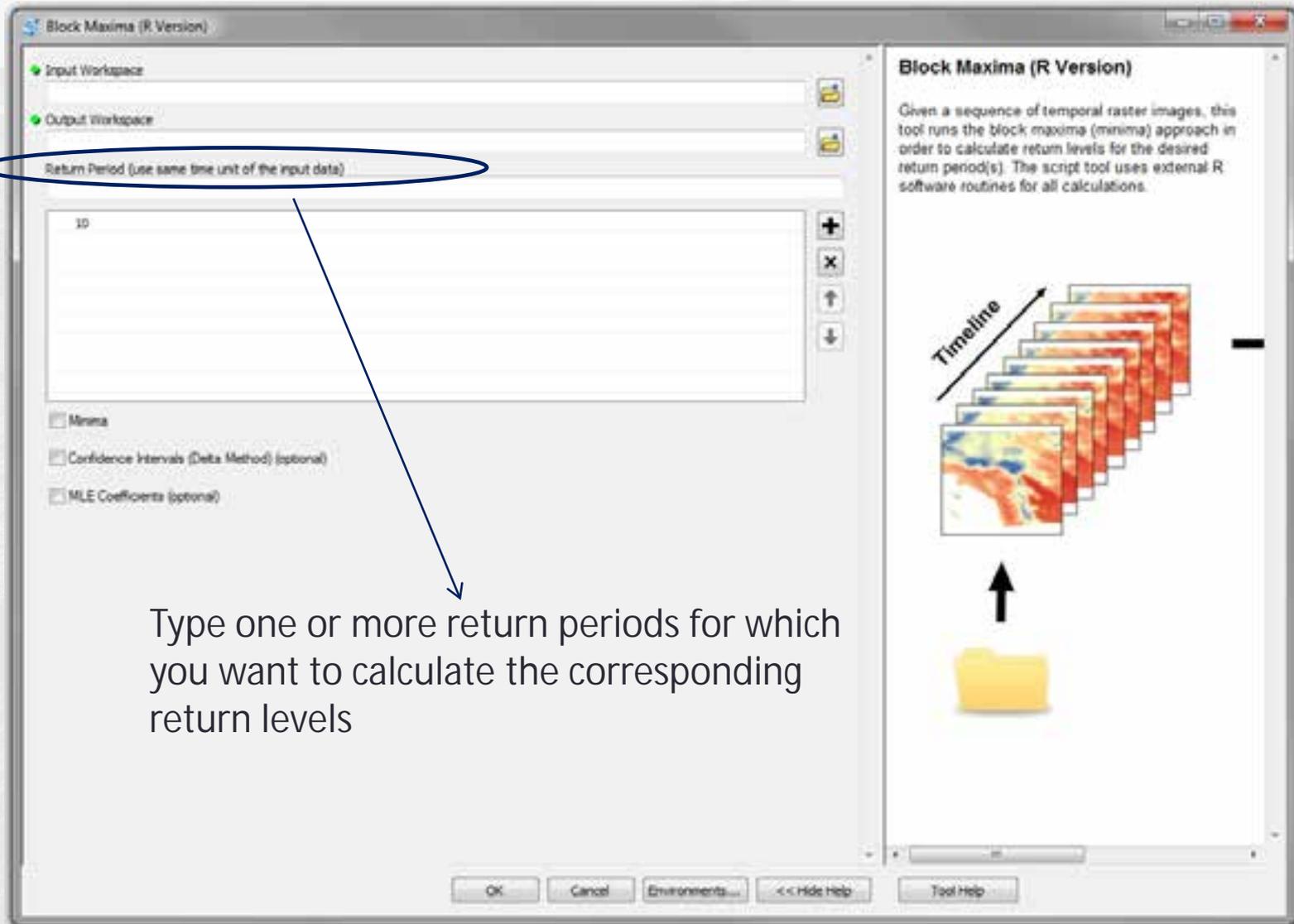
Custom Toolbox (*cont.*)



Custom Toolbox (*cont.*)

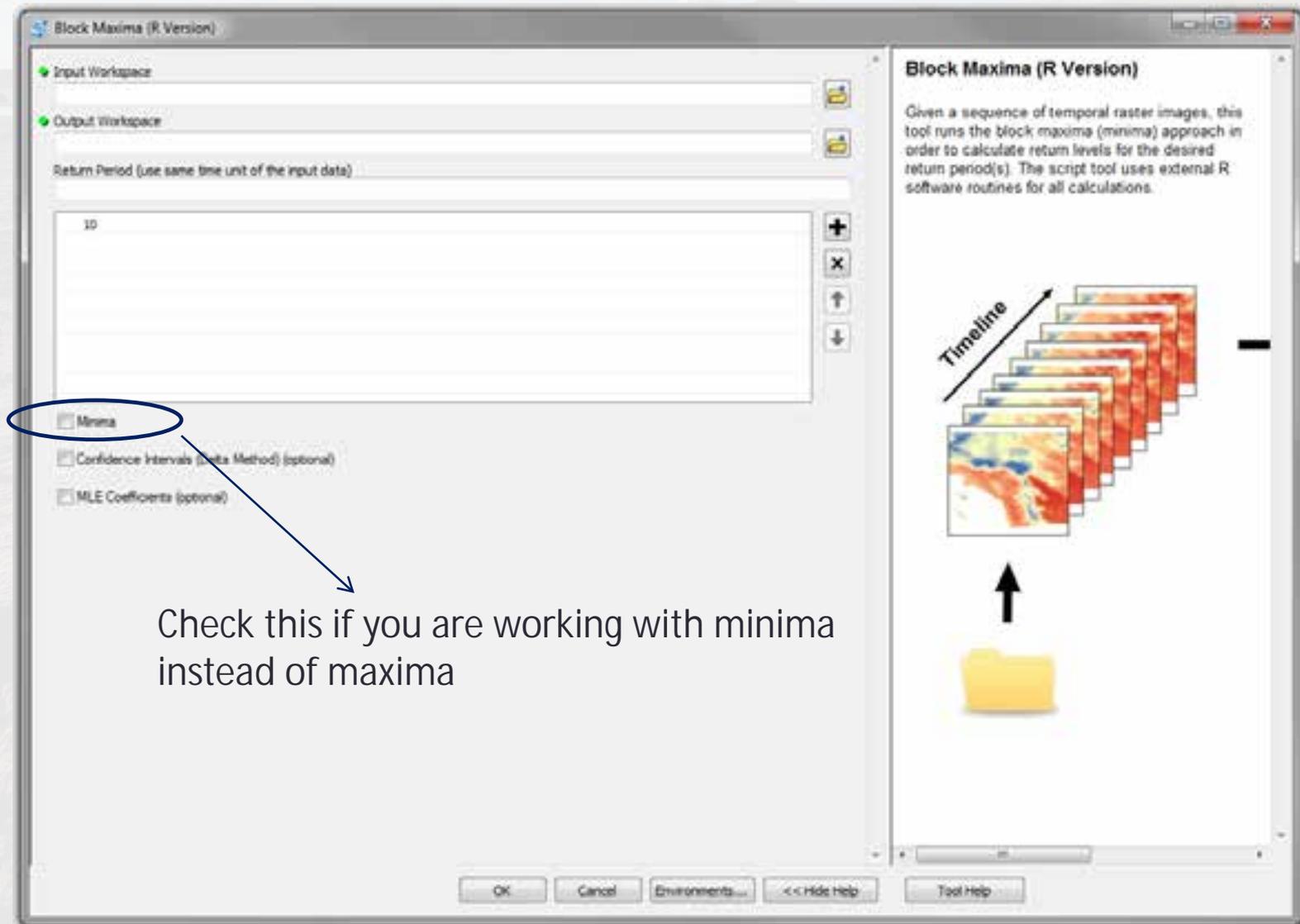


Custom Toolbox (*cont.*)

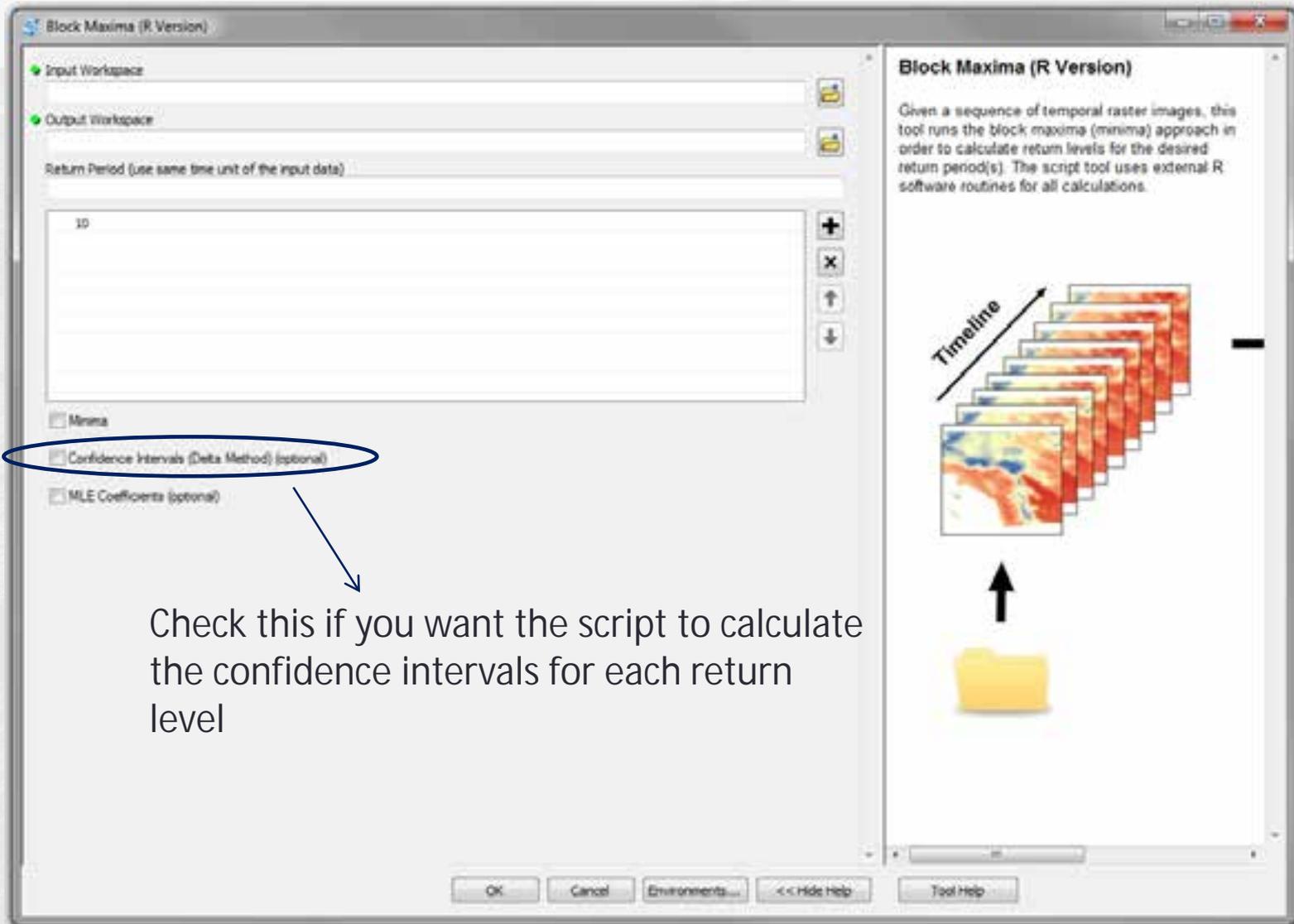


Type one or more return periods for which you want to calculate the corresponding return levels

Custom Toolbox (*cont.*)

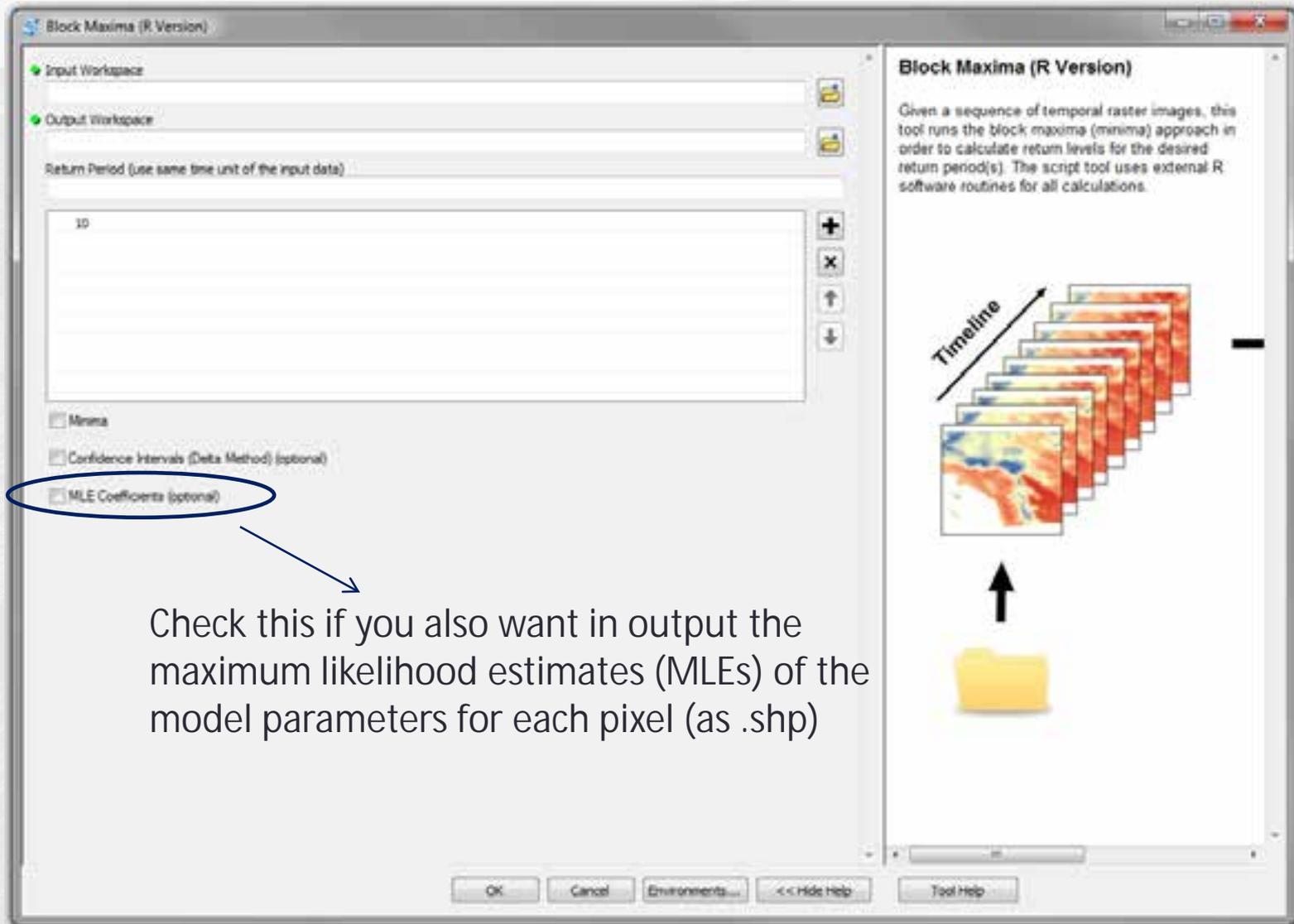


Custom Toolbox (*cont.*)



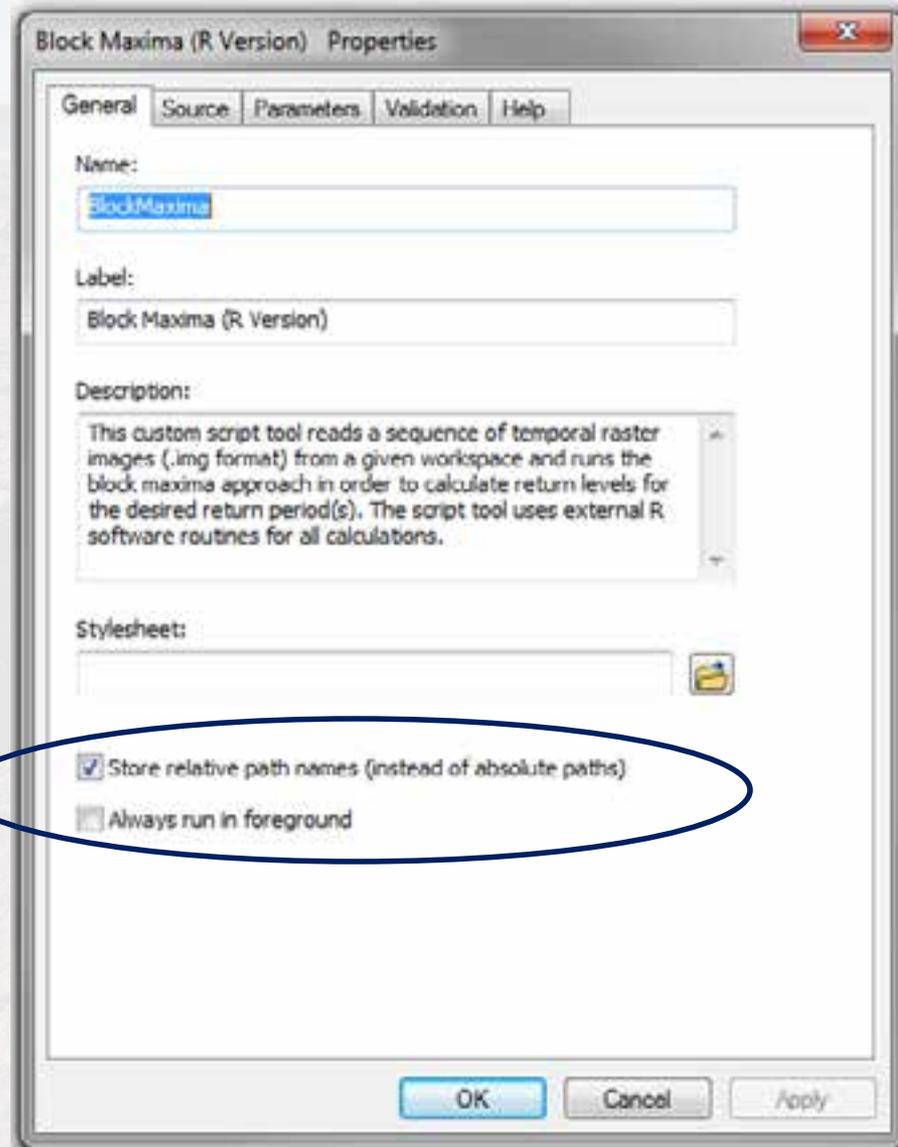
Check this if you want the script to calculate the confidence intervals for each return level

Custom Toolbox (*cont.*)



Check this if you also want in output the maximum likelihood estimates (MLEs) of the model parameters for each pixel (as .shp)

Custom Toolbox (*cont.*)

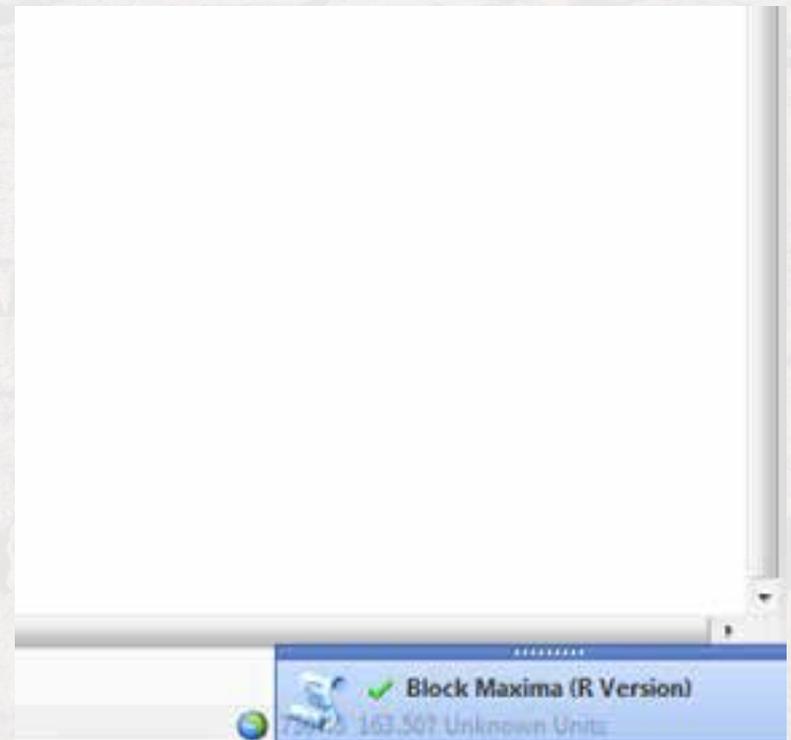


Custom Toolbox (*cont.*)

Run as a geoprocessing task in the background. Preferred if you need to keep working in ArcGIS while running the tool



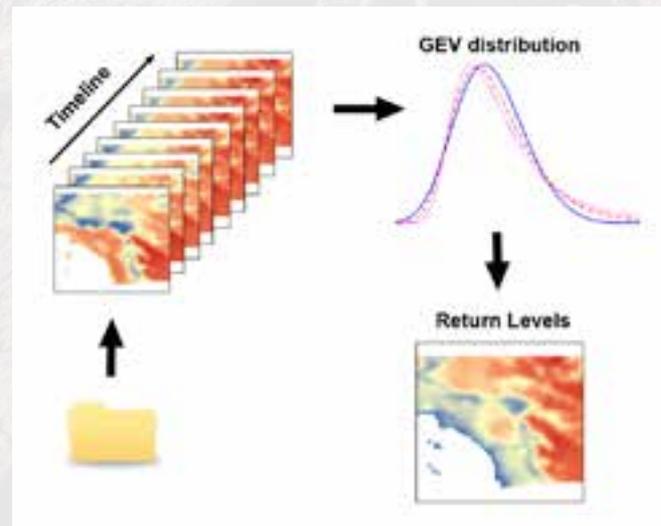
...after completion



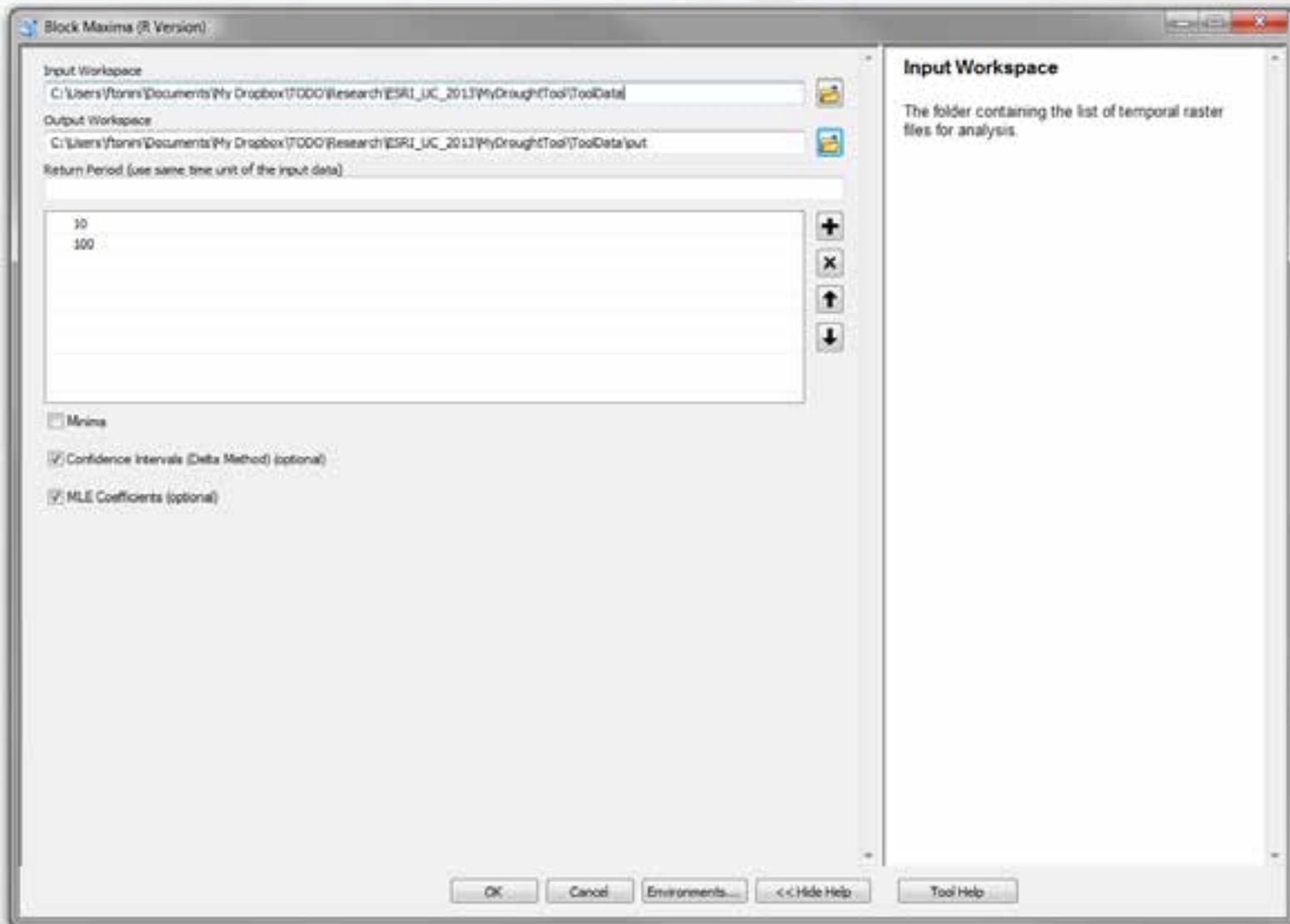
Custom Toolbox (*cont.*)

Example: maximum monthly temperature from 2000 to 2002, LA-San Diego area.
2.5 arcmin (~ 4 km)

- Source: © 2011, PRISM Climate Group “PRISM Climate Group, Oregon State University, <http://prism.oregonstate.edu>”. Not for commercial purposes!
- Test data comes with the toolbox (folder “ToolData”)
- Total of 36 images (36 months). **NOTE:** Quite small for asymptotic models; use longer time series to avoid unreliable/unstable estimates



Custom Toolbox (*cont.*)



Custom Toolbox (*cont.*)

```
Messages
Executing: BlockMaxima "C:\Users\ftonini\Documents\My Dropbox\TODO\Research\ESRI_UC_2013\MyDroughtTool
\ToolData" "C:\Users\ftonini\Documents\My Dropbox\TODO\Research\ESRI_UC_2013\MyDroughtTool\ToolData\out"
10;100 NO MINIMA USE INTERVALS MLE TABLE
Start Time: Thu Jun 20 11:35:35 2013
Running script BlockMaxima...
Loading Libraries....
C:\PROGRAM-1\R\R-215-1.0\bin\x64\Rterm.exe --slave --vanilla --args C:\Users\ftonini\Documents\My
Dropbox\TODO\Research\ESRI_UC_2013\MyDroughtTool\Scripts\BlockMaxima.r C:\Users\ftonini\Documents
\My Dropbox\TODO\Research\ESRI_UC_2013\MyDroughtTool\ToolData C:\Users\ftonini\Documents\My
Dropbox\TODO\Research\ESRI_UC_2013\MyDroughtTool\ToolData\out 10;100 0 1 1
Reading and stacking rasters from input folder...
Calculation of return levels begins...
MLE did not converge in one or more cells: those values are being interpolated..."
Calculations Complete..."

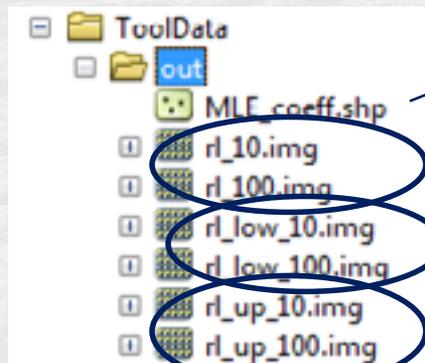
Completed script BlockMaxima...
Succeeded at Thu Jun 20 11:37:58 2013 (Elapsed Time: 2 minutes 23 seconds)
```

Time may vary depending on your processor specs and length of time series

When the MLE estimation algorithm does not converge for a pixel, its value is interpolated for the 8 near. Neighbors. It typically happens when time series is not long enough or is almost constant

Custom Toolbox (*cont.*)

Results:



.shp with all MLE coefficients for each pixel

Return Levels

rl_XX

Lower confidence intervals

rl_low_XX

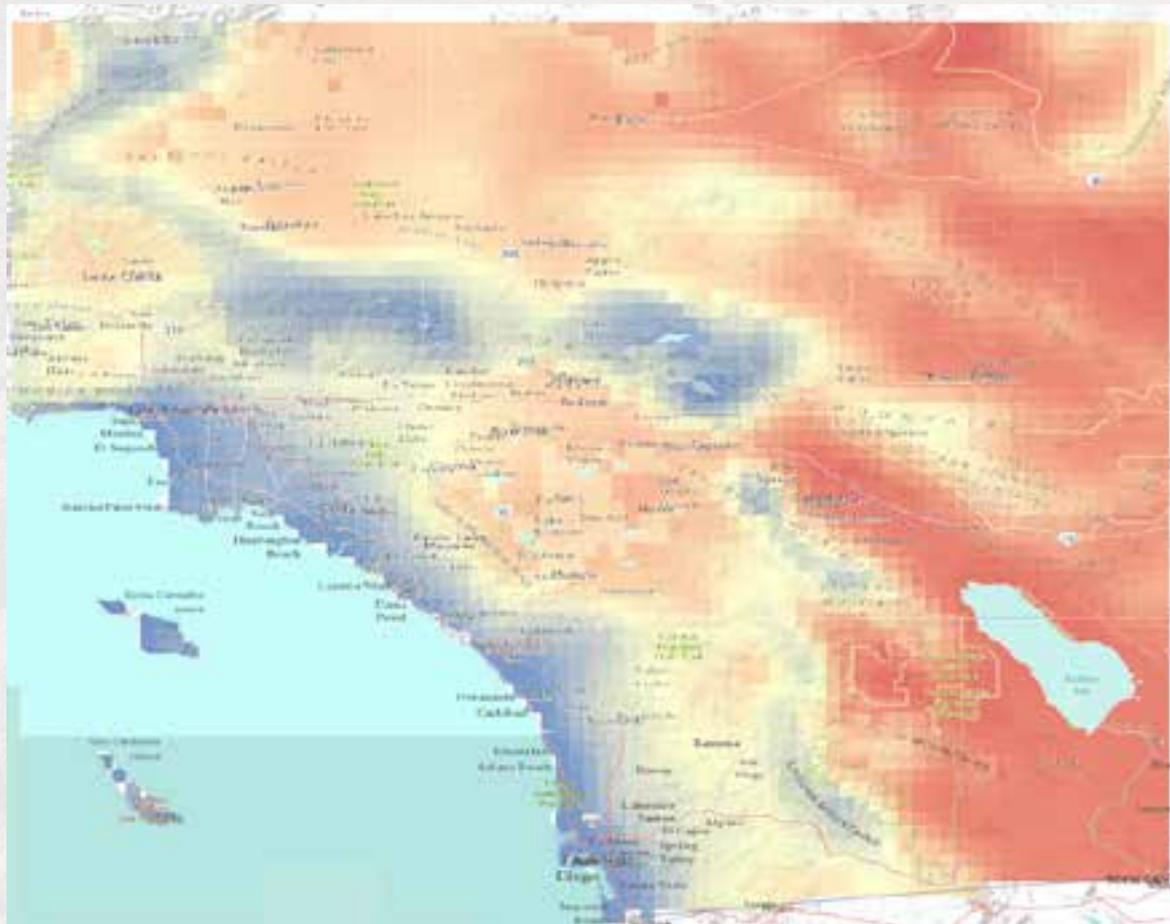
Upper confidence intervals

rl_up_XX

Custom Toolbox (*cont.*)

Results:

10-month return levels (= average 10% probability of being equaled or exceeded)



Custom Toolbox (*cont.*)

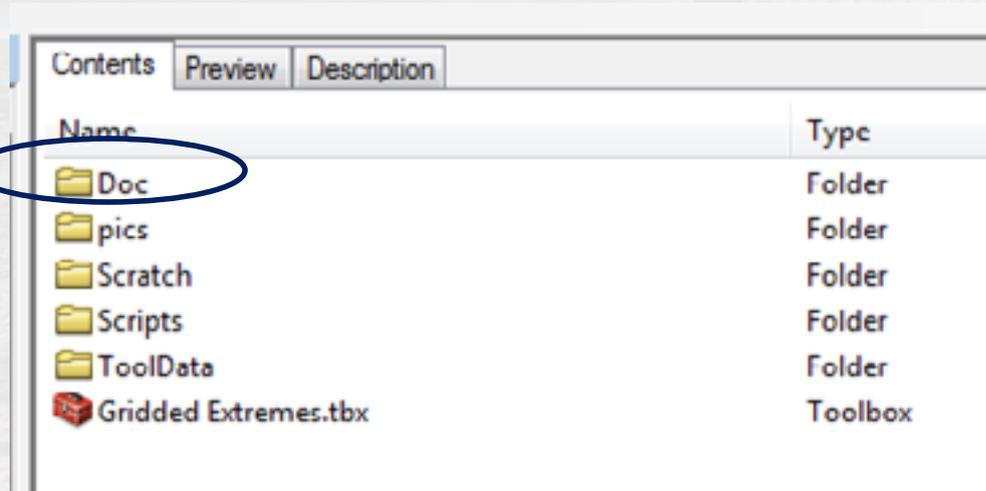
Results:

MLE coefficients .shp table

fid	Shape	gum_flag	mu	sig	shp	mu_inf	mu_sup	sig_inf	sig_sup	shp_inf	shp_sup
0	Point	0	24.7	9.89	-0.66	21.2	28.21	6.45	12.94	-0.98	-0.34
1	Point	0	24.3	9.56	-0.65	20.83	27.83	6.3	12.82	-0.99	-0.31
2	Point	1	21.0	6.91	0	18.69	23.46	5.11	8.71	0	0
3	Point	1	19.3	6.55	0	17.04	21.56	4.83	8.26	0	0
4	Point	1	17.7	6.18	0	15.57	19.83	4.55	7.8	0	0
5	Point	1	16.9	6.11	0	14.8	19.02	4.5	7.72	0	0
6	Point	1	17.2	6.21	0	15.1	19.36	4.56	7.85	0	0
7	Point	1	17.6	6.35	0	15.41	19.79	4.65	8.02	0	0
8	Point	1	17.4	6.37	0	15.26	19.66	4.69	8.04	0	0
9	Point	1	18.9	6.39	0	14.79	18.19	4.71	8.06	0	0
10	Point	1	18.6	6.39	0	14.46	18.87	4.71	8.07	0	0
11	Point	1	16.6	6.56	0	14.4	18.95	4.86	8.31	0	0
12	Point	0	19.5	9.71	-0.76	15.79	23.25	5.89	13.73	-1.23	-0.28
13	Point	1	16.3	7.61	0	13.96	18.81	5.19	8.83	0	0
14	Point	0	18.8	9.33	-0.62	15.19	22.58	5.7	12.96	-1.1	-0.15
15	Point	1	17.0	7.06	0	14.63	19.5	5.23	8.99	0	0
16	Point	1	18.1	7.04	0	15.69	20.56	5.22	8.86	0	0
17	Point	1	19.6	7.05	0	17.17	22.05	5.23	8.88	0	0
18	Point	1	20.7	7.24	0	18.26	23.26	5.36	9.11	0	0
19	Point	0	24.3	9.66	-0.62	20.53	28.12	5.97	13.35	-1.08	-0.16
20	Point	0	24.8	9.86	-0.63	21	28.62	6.21	13.54	-1.06	-0.2
21	Point	0	24.9	9.93	-0.62	21.1	28.73	6.28	13.58	-1.05	-0.2
22	Point	0	24.8	10.0	-0.63	21.01	28.61	6.39	13.62	-1.03	-0.23
23	Point	0	24.5	10.1	-0.64	20.8	28.37	6.53	13.69	-1.02	-0.27
24	Point	0	24.3	10.1	-0.65	20.54	28.14	6.56	13.78	-1.03	-0.27
25	Point	0	24.0	10.1	-0.64	20.28	27.89	6.82	13.72	-1.03	-0.25
26	Point	0	23.9	10.0	-0.64	20.17	27.77	6.46	13.67	-1.03	-0.24
27	Point	0	23.9	10.0	-0.64	20.15	27.76	6.44	13.66	-1.04	-0.24
28	Point	0	23.9	10.0	-0.64	20.18	27.77	6.45	13.67	-1.04	-0.25
29	Point	0	23.9	10.1	-0.65	20.17	27.79	6.48	13.75	-1.04	-0.25

Custom Toolbox (*cont.*)

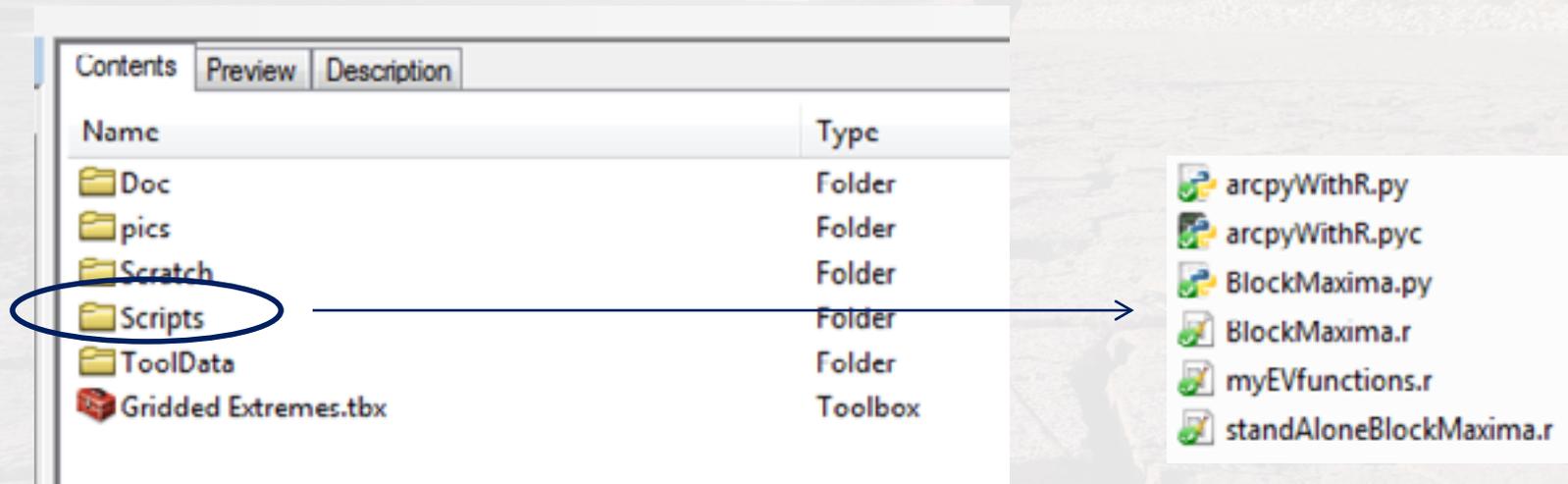
Doc folder:



VERY IMPORTANT: .doc file containing all necessary instructions to set everything up before running the tool (e.g. R installation, PATH variables, etc.)

Custom Toolbox (*cont.*)

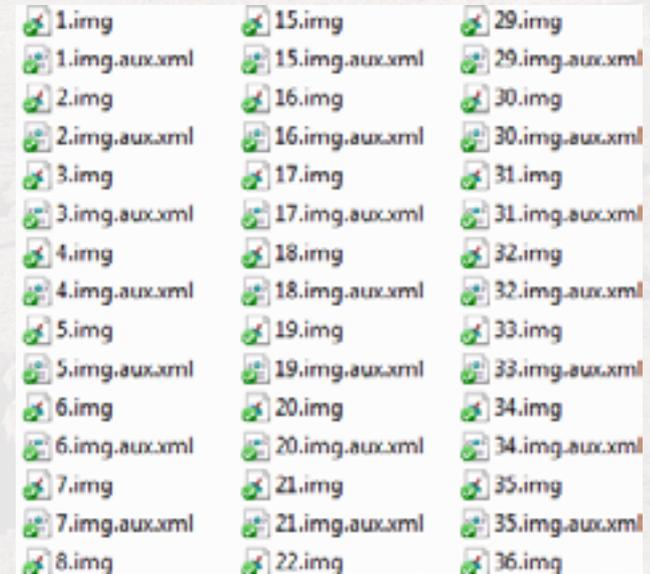
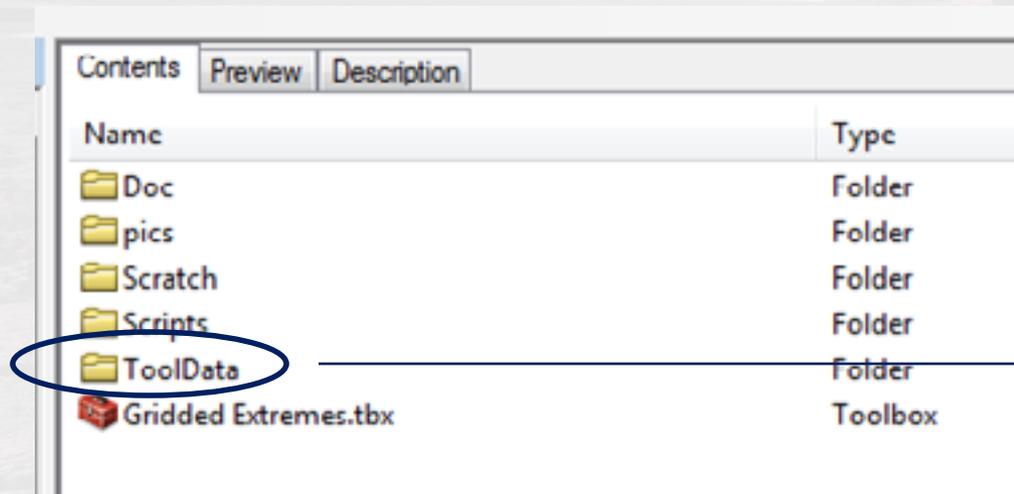
Scripts folder:



All required scripts (standalone R script, Python script tool, R script called from .py main script and some external modules)

Custom Toolbox (*cont.*)

ToolData folder:



Test data: monthly maximum temperatures from PRISM climate group, extracted for 3 consecutive years

References

Gridded Extremes Applications:

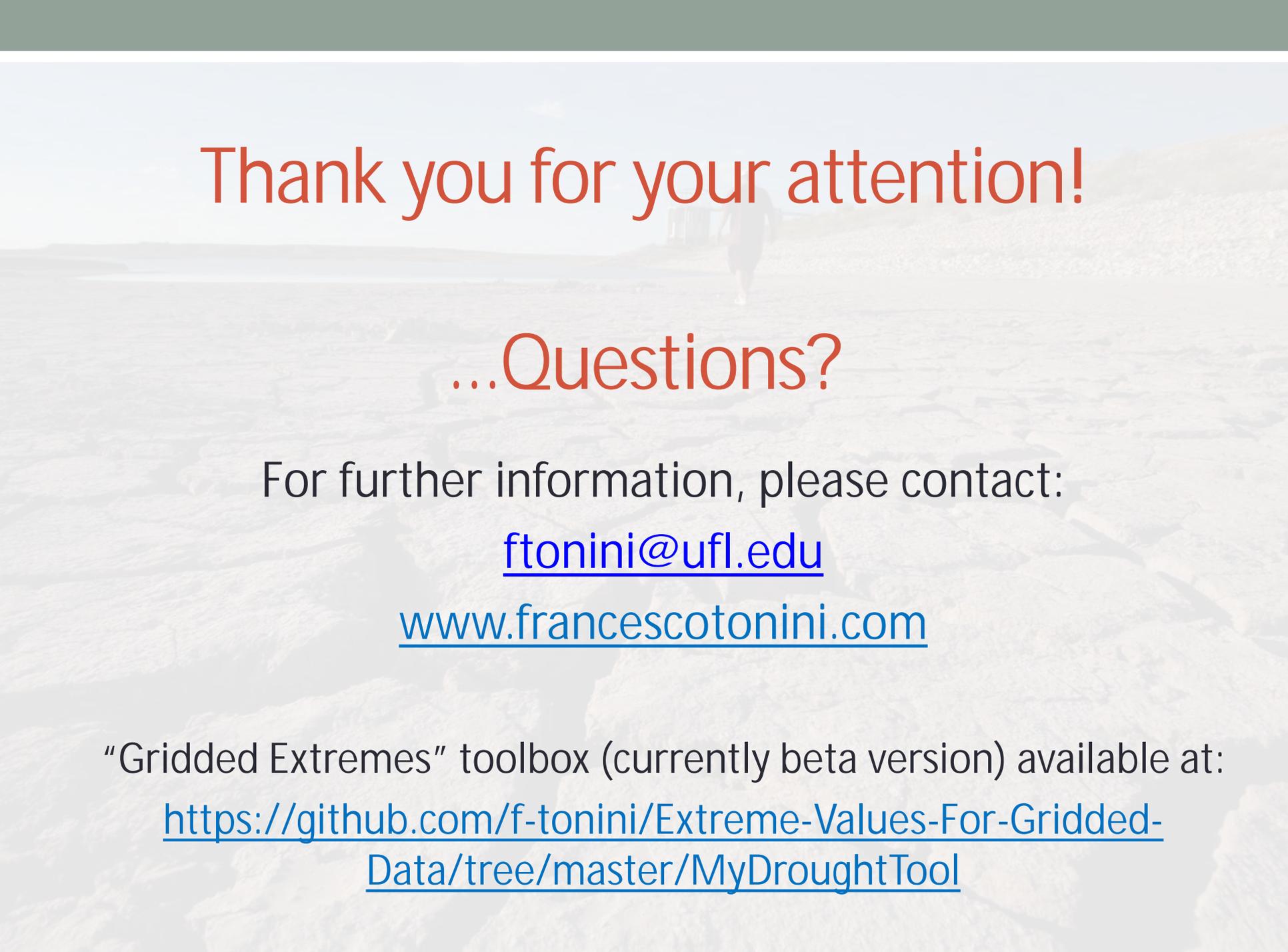
- Tonini F., Jona Lasinio G., Hochmair H.H. (2012). Mapping Return Levels of Absolute NDVI Variations for the Assessment of Drought Risk in Ethiopia. *Int J App Earth Obs Geoinf*, 18, pp 564-572. DOI: <http://dx.doi.org/10.1016/j.jag.2012.03.018>.
- Sanabria, L.A., Cechet, R.P., 2010. Extreme value analysis for gridded data. In: International Congress on Environmental Modelling and Software Modelling for Environment's Sake, Fifth Biennial Meeting, Ottawa, Canada.

Extreme Value Theory:

- Coles, S. 2001. An Introduction to Statistical Modeling of Extreme Values. Springer-Verlag.
- Beirlant, J., Goegebeur, Y., Segers, J., Teugels, J. Statistics of Extremes: Theory and Applications. Wiley Series in Prob. & Statistics.

Web:

- Persendt, F. 2009. <http://www.applied-geoinformatics.org/index.php/agse/conference2009/paper/viewFile/34/28>

A person is walking away from the camera on a rocky beach. In the background, there is a building and a body of water under a clear sky.

Thank you for your attention!

...Questions?

For further information, please contact:

ftonini@ufl.edu

www.francescotonini.com

“Gridded Extremes” toolbox (currently beta version) available at:

<https://github.com/f-tonini/Extreme-Values-For-Gridded-Data/tree/master/MyDroughtTool>