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Application note

webXTREME: *R*-based web tool for calculating agroclimatic indices of extreme events

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ABSTRACT

We document the release of *webXTREME*, a new online tool for the evaluation of indices of climatic extremes (extreme temperatures and aridity) having impact on agricultural production. The tool is globally available and can be operated with either observed weather data or time series representing future climatic conditions. It is thus suitable for risk evaluation under climate change. *webXTREME* was implemented using *Shiny*, an open-source programming framework for creating web applications on the basis of the *R* Statistical Language.

1. Introduction

Extreme weather events such as frost, drought or excessive heat occurring during critical stages of plant development can cause extensive and sometimes irreversible damages to agricultural production. In Europe, for instance, several major droughts occurred in recent decades, including the catastrophic drought associated with the 2003 summer heat wave in the central parts of the continent and the drought that affected the Iberian Peninsula in 2004/2005, which caused a reduction in cereal production of more than 50% (García-Herrera et al., 2007).

Gauging the occurrence of extreme events and assessing their impact under climate change deliver the basis for risk management, decision-making, adaptation planning, and policy support (IPCC, 2012). The dissemination of agrometeorological information by National Meteorological and Hydrological Services (NMHSs), including various types of agrometeorological forecasts (Calanca, 2014), has been an important undertaking in this regard (Sivakumar, 2006). Support to the farming community is nowadays also provided via dedicated webpages, such as *agrometeo*.[1] A list of online weather and climate information for agrometeorologists and software components for use in agricultural meteorology has been compiled by the International Society for Agricultural Meteorology.[2]

The use of agroclimatic indices (Rivington et al., 2013) is a simple way to discriminate between favourable and adverse conditions taking into account specific plant requirements. Examples of their application to assess current and future conditions for agricultural production can be found in Bootsma et al. (2005) and Qian et al. (2010, 2012, 2013).

The potential of conceptually simple agroclimatic indices to address different types of agricultural systems should not downplay the necessity of dedicated software for their evaluation. Examples of software solutions released in recent years include the Microsoft .NET-based package *ClimIndices* (Confalonieri et al., 2010), *AgriCLIM* (Trnka et al., 2011) and its extension for Nordic countries, *N-AgriCLIM* (Rötter et al., 2013). Concerning drought, many tools exist, including for example various R-Packages for computing the Standardized Precipitation Index (SPI) and derivatives,[3] tools provided by the GreenLeaf Project,[4] or tools such as *DrinC*, the Drought Indices Calculator developed at the National Technical University of Athens (Tigkas et al., 2013). Other software components, such as *Vuln-Indices* (Lardy et al., 2015), target indices

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[1] http://www.agrometeo.ch/; accessed January 18, 2017.

[2] http://www.agrometeorology.org/topics/online-weather-and-climate-information-for-agrometeorologists/ and http://www.agrometeorology.org/topics/software-tools-useful-in-agrometeorology; accessed January 18, 2017.

[3] https://cran.r-project.org/web/packages/spi/index.html and https://cran.r-project.org/web/packages/SPEI/index.html; accessed January 18, 2017.

[4] http://greenleaf.unl.edu/; accessed January 18, 2017.

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needed for assessing the vulnerability of agricultural production systems to climate change.

Concerning extreme events, software for the evaluation of core indices as defined by the CCl/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices (Karl et al., 1999) can be obtained through the webpage of *ClimDex*.[5] However, the latter is oriented towards fulfilling climatological standards, and its application to agrometeorological decision problems requires modifications of the original code. Other tools with a similar background and scope are the *R*-Packages *SCI*[6] (which, along with *ClimDex*, has recently been incorporated into *ClimPact2*[7]), the Hydrologic and Climatic Analysis Toolkit (*HydroClimATe*),[8] or GIS applications such as *OpenClimateGIS*.[9]

To the best of the authors' knowledge, only few of the software components developed for the assessment of agrometeorological conditions are available as a web tool. This is the case with the *ClimateTranslator*[10] and *AgroClimate*.[11] The latter is a web-resource providing interactive tools and climate information for farmers in Southeast USA (Fraisse et al., 2006). Although the geographic focus of the platform is currently being enlarged, the main limitation comes from the fact that the software runs on preselected weather data. Consequently, *AgroClimate* cannot be employed for other regions of the world.

This note documents the release of *webXTREME*,[12] a web-based tool for quick assessment of the occurrence of extreme events with impact on agriculture. The tool aims at global access (i.e. access from any device that has an internet connection) and global availability of extensions and updates (no installation required). Weather data are supplied by the user. While this can appear at first sight less practical than a direct link to existing regional or national databases, as is the case with *AgroClimate*, this choice has the advantage of being more flexible. For instance, the tool can be operated with daily weather series obtained from downscaling global or regional climate scenarios and thus used for assessing the likelihood of critical conditions in agricultural production under a range of future climates.

2. Implementation and deployment

webXTREME was implemented using *Shiny*[13] (Beeley, 2013; Chang et al., 2016), an open-source web application framework developed by the *RStudio* Team to create interactive web applications based on the *R* Statistical Language (R Core Team, 2016). *Shiny* is designed to enable a quick and easy deployment of interactive *R*-based applications. It uses a 'reactive programming' approach in which output objects are automatically rendered whenever an input value is modified, without the need to reload the browser.

The bidirectional communication between the web browser and the *R* environment relies on the *R* package 'httpuv' (RStudio and Inc., 2015), which provides socket and protocol support for handling HTTP and WebSocket requests within *R*. Basic *Shiny* functionalities can be enhanced by integrating advanced features from other packages. This is the case with 'htmlwidgets,' a framework for embedding JavaScript visualizations into *R*. Code written in HTML, CSS or JavaScript can also be linked to the *Shiny* app.

Typically, a *Shiny* app is made of two distinct components,[14] (1) a user-interface (UI) script ('ui.R') that specifies the layout and appearance of the web app, and (2) a server script ('server.R') that defines how to combine inputs into outputs along with all the operations to be performed. In *webXTREME*, these operations are (i) data loading and parsing, (ii) computation of indices, and (iii) drawing of plots and preparation of downloadable output files. For convenience, a third file, 'global.R', can be added in case variables need to be shared across 'ui.R' and 'server.R'. The directory 'www' contains external files that are required by the web application such as a logo. If needed, other files to be sourced must be placed in the directory 'attachments'.

In practice, *webXTREME* comes with an intuitive layout that lets scientists and practitioners configure the solving algorithms (specification of plant specific thresholds and critical time windows) for targeting specific problems. Three agroclimatic indices for cold and heat shocks as well as extreme aridity are implemented in the current release. They are:

- cold shocks: number of days in [DOY_{start}, DOY_{end}] with daily minimum temperature (AIRTMIN) falling short of a user-defined threshold ($AIRTMIN_{crit}$)
- heat shocks: number of days in [DOY_{start}, DOY_{end}] with daily maximum temperature (AIRTMAX) exceeding a user-defined threshold
- extreme aridity: number of days in [DOY_{start}, DOY_{end}] with $ARID > ARID_{crit}$, where ARID denotes the aridity index proposed by Woli et al. (2012).

Here, [DOY_{start}, DOY_{end}] is used to specify the time of the year (start and end in day-of-the-year or DOY) over which the indices are evaluated.

3. Source code

In *webXTREME*, the two basic components of the *Shiny* app are joined into a single *R*-code (Fig. 1). On top (lines 1–5) are the library imports necessary to extend the functionality of *Shiny* (e.g. handling of interactive helpers, JavaScript based tables/plots) or to change the default theme. This is followed (lines 9–11) by the external functions needed for the evaluation of ARID (Woli et al., 2012).

The server instructions ('server.R') are covered by lines 15–44. Two types of operations are shown in Fig. 1. First, 'reactive' expressions that are triggered when at least one input has changed or when an action button is pressed ('eventReactive'). For instance, ' computeIndicators' (line 24) is triggered when pressing 'button.in dicator' on the interface; it has 4 inputs (input$UNDERLYING, input$THRESHOLD, input$DATE_START, input$DATE_END) and one call to a reactive expression ('computeSM'). Second, rendering operations ('renderUI', 'renderDataTable', and 'renderDygraph') produce and assign outputs (denoted 'output$' in the code, e.g. line 29).

In *webXTREME*, three types of outputs are produced: (1) UI outputs (lines 28–34) that modify the UI depending on inputs (e.g., the suggested critical values depend on the selected underlying input), (2) tabular outputs (lines 36–39), and (3) graphical outputs (lines 41–42).

The definition of the UI is covered by lines 48–79. The interface contains one side bar with major inputs ('fileInput', 'numericInput', 'selectInput'), buttons ('actionButton'), along with dynamic input elements ('uiOutput'), and a main panel with three tabs for different outputs ('dataTableOutput', 'dygraphOutput').

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[5] http://etccdi.pacificclimate.org/software.shtml; accessed January 18, 2017.

[6] http://europeandroughtcentre.com/software/standardized-climate-indices-sci/; accessed January 18, 2017.

[7] https://github.com/ARCCSS-extremes/climpact2; accessed January 18, 2017.

[8] https://water.usgs.gov/ogw/hydroclimate/; accessed January 18, 2017.

[9] https://earthsystemcog.org/projects/openclimategis/; accessed January 18, 2017.

[10] https://www.earthsystemcog.org/projects/downscaling-2013/climatetranslator; accessed January 18, 2017.

[11] http://www.agroclimate.org/; accessed January 18, 2017.

[12] http://www.modextreme.org/webxtreme; accessed January 18, 2017.

[13] Shiny is available either through the RStudio webpage (http://shiny.rstudio.com/; accessed January 18, 2017) or the R-CRAN packages repository (https://cran.r-project.org/web/packages/shiny/index.html; accessed January 18, 2017).

[14] See http://shiny.rstudio.com/articles/basics.html (accessed January 18, 2017).

```
### Load packages to extend basic shiny functionality
library(shinyBS)      # add helpers
library(DT)           # Java-Script based interactive tables
library(dygraphs)     # Java-Script based interactive plots
library(shinythemes)  # modify default theme

[...]

# Source external modules for index computation
source("./attachments/ET0.R")  # functions to compute ET0
source("./attachments/SM.R")   # functions to compute soil moisture

[...]

shinyServer(function(input, output, session) {

   ### Reactive operations
   getData <- reactive({input$DATAFILE})
      # import and parse weather from a CSV-file
   getSoilParams <- reactive({input$TEXTURE_CLASS, input$EXTRACTION_DEPTH})
      # load soil parameters
   computeSM <- eventReactive(input$button.sm, {input$LATITUDE, getSoilParams()})
      # compute soil moisture
   computeIndicators <- eventReactive(input$button.indicator, {computeSM(), input$UNDERLYING,
                                      input$THRESHOLD, input$DATE_START, input$DATE_END})
      # calculate indicator values

   ### UI outputs
   output$ui.underlying <- renderUI({})
      # get available underlyings based on uploaded CSV-file
   output$ui.threshold <- renderUI({input$UNDERLYING})
      # adapt range, default and critical values based on selected underlying
   output$ui.end.date <- renderUI({input$DATE_START})
      # UI element containing possible end dates for risk period

   ### Tabular outputs
   output$TableData <- renderDataTable({getData()})               # display loaded weather data
   output$TableSM <- renderDataTable({computeSM()})               # add and display computed soil moisture
   output$TableIndices <- renderDataTable({computeIndicators()})  # calculate and display indicator values

   ### Graphical outputs
   output$plot <- renderDygraph({computeIndicators()})  # interactive plot with indicator values

})

[...]

shinyUI(fluidPage(

   sidebarLayout(sidebarPanel(  # SIDE BAR
      ### Input parameters
      fileInput("DATAFILE"),
      numericInput("LATITUDE"),
      numericInput("EXTRACTION_DEPTH"),
      selectInput("TEXTURE_CLASS"),
      selectInput("DATE_START"),

      ### Buttons for eventReactive based actions
      actionButton("button.sm"),  # trigger soil moisture calculation (computeSM)
      actionButton("button.indicator"),  # trigger indicator calculation (computeIndicators)

      ### Display UI outputs
      uiOutput("ui.end.date"),
      uiOutput("ui.underlying"),
      uiOutput("ui.threshold")
   )),

   mainPanel(tabsetPanel(  # MAIN PANEL WITH TABS

      ### Display tabular and graphical outputs
      tabPanel(title = "Data Upload",
      dataTableOutput("TableData")),
      tabPanel(title = "Soil Moisture Budget Computation",
      dataTableOutput("TableSM")),
      tabPanel(title = "Occurrence of Extreme Conditions",
      dygraphOutput("plot"))
   ))

))
```

Fig. 1. Excerpts from the source code (most relevant subsets) with inputs/outputs for core (reactive) expressions.

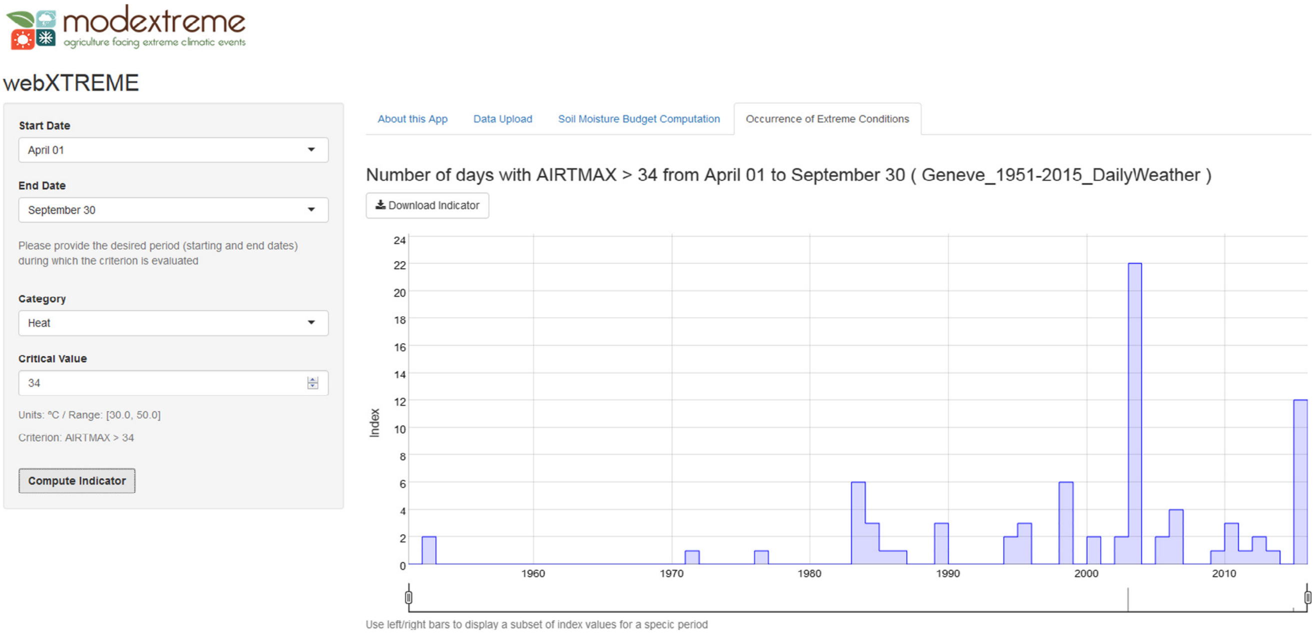
4. Data, parameters and formats

webXTREME comes with minimal data requirements. Users need to provide time series of daily minimum (AIRTMIN) and maximum (AIRTMAX) air temperature and precipitation amounts (RAIN). If available, estimates of the reference evapotranspiration (ET_0) can also be added. Otherwise, ET_0 is calculated internally following Hargreaves and Samani (1985) (as documented in Allen et al., 1998). In this case, the latitude of the location must be specified along with the inputs required for the evaluation of the soil moisture budget (as part of the computation of ARID), namely extraction depth and one of four soil texture classes (silty clay, silty loam, sandy loam and sand).

Weather data need to be formatted as a CSV file (plain ASCII, comma separated), with date specified as YYYY-MM-DD, DD/MM/YYYY or MM/DD/YYYY and column names 'DATE', 'RAIN', 'AIRTMAX', 'AIRTMIN' and 'ET0' (this latter being optional). The same format has been adopted for the tabular outputs.

5. Example application

To illustrate the use of *webXTREME*, results of an analysis of extreme conditions in winter wheat (*Triticum aestivum* L.) cultivation (number of days with AIRTMAX ≥ 34 °C and the number of days with ARID ≥ 0.85) for Western Switzerland are shown in Figs. 2 and 3. Daily weather data for Genève Observatoire



Start Date: April 01

End Date: September 30

Please provide the desired period (starting and end dates) during which the criterion is evaluated

Category: Heat

Critical Value: 34

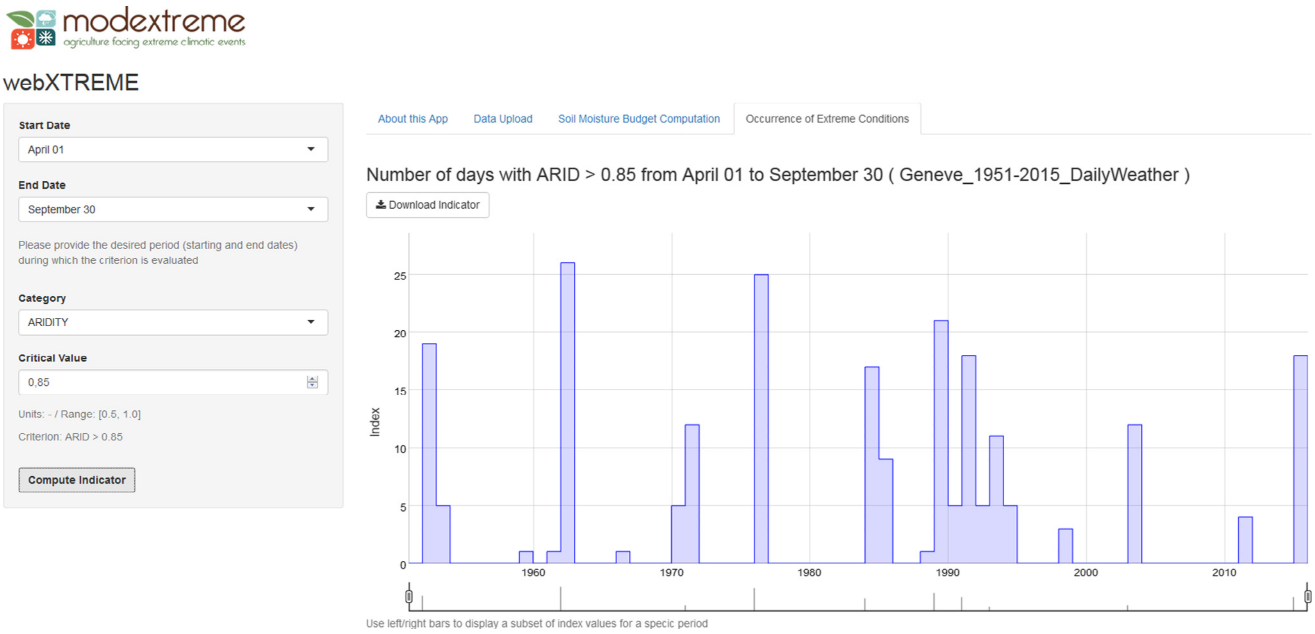
Units: °C / Range: [30.0, 50.0]

Criterion: AIRTMAX > 34

Number of days with AIRTMAX > 34 from April 01 to September 30 (Geneve_1951-2015_DailyWeather)

Use left/right bars to display a subset of index values for a specic period

Fig. 2. Analysis of the occurrence of extreme heat (number of days with AIRTMAX > 34 °C during April-July) at Genève Observatoire (6°09′E, 46°12′N, 405 m a.s.l.), 1951–2015.



Start Date: April 01

End Date: September 30

Please provide the desired period (starting and end dates) during which the criterion is evaluated

Category: ARIDITY

Critical Value: 0,85

Units: - / Range: [0.5, 1.0]

Criterion: ARID > 0.85

Number of days with ARID > 0.85 from April 01 to September 30 (Geneve_1951-2015_DailyWeather)

Use left/right bars to display a subset of index values for a specic period

Fig. 3. Analysis of the occurrence of extreme aridity (number of days with ARID ≥ 0.85 during April-July) at Genève Observatoire (6°09′E, 46°12′N, 405 m a.s.l.), 1951–2015.

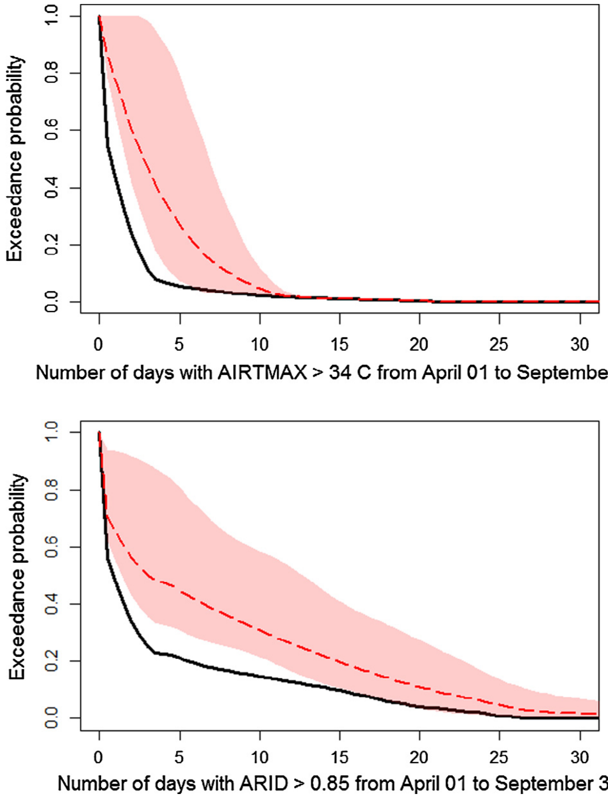


Fig. 4. Exceedance probability of critical conditions (top: extreme heat; bottom: extreme aridity) at Genève Observatoire (6°09′E, 46°12′N, 405 m a.s.l.) under present-day (black line) and a range of future climatic conditions representative for mid 21st century (reddish area) and their mean (red dashed line). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

(6°09″E, 46°12″N, 405 m a.s.l.) were obtained from the ECA&D database[15] (Klein Tank et al., 2002) for the period 1951–2015. In line with other studies (Donat and Alexander, 2012), the results of the analysis performed with *webXTREME* indicate increasing incidence of extreme high temperatures, with exceptional conditions occurring in 2003 and again in 2015 (Fig. 2). Concerning extreme aridity, no clear tendency appears in the output (Fig. 3). The results nevertheless suggest a risk of facing an exceptionally dry season (more than 10 days with ARID > 0.85) in one out of five years.

For the same site, possible changes in the occurrence of critical conditions under future climates are illustrated in Fig. 4. To prepare the figure, *webXTREME* was fed with synthetic time series representing a selection of ENSEMBLES-RT2B scenarios valid for the 2050s (van der Linden and Mitchell, 2009) and available from ENSEMBLES-ELPIS database (Calanca and Semenov, 2013). Given the scenarios, daily data was created with the LARS-WG weather generator (Semenov and Barrow, 1997). Results such as those shown in Fig. 4 could be taken as a starting point for a more detailed assessment of climate change impacts.

6. Discussion and conclusions

This application note describes the release of *webXTREME*, a new online tool for calculating indices of agroclimatic extremes. *webXTREME* was developed for quick assessments of agroclimatic risks associated with extreme temperatures and aridity. It is intended neither as a replacement for existing, more comprehensive software solutions, nor as a competitor against operational decision support systems such as *AgroClimate*. To the best of our knowledge, the tool covers a specific niche in that it is completely web based, thus providing access to the evaluation routines also in situations where computer infrastructure is limited, while being open for user-supplied data and climate change scenarios. It can hence be applied to any location in the world for diagnostic studies, risk evaluation, and assessments of climate change impacts.

The choice of *R* as a background programming language was motivated by its increasing popularity for statistical data analysis and the growing availability of packages that could potentially be integrated into the tool. This same line of thoughts led to the adoption of *Shiny* for developing the web application. We believe that a programming environment that facilitates the deployment of web applications for data analysis is important to promote collaboration within the scientific community and between scientists and stakeholders.

Software availability

Name of Software: *webXTREME.*

Developer: Tommy Klein.

Contact Address: Agroscope, Reckenholzstrasse 191, 8046 Zurich, Switzerland.

E-mail: tommy.klein@alumni.ulg.ac.be.

Availability: http://modextreme.org/webxtreme.

Deployment: https://github.com/tommy-klein/webXTREME/tree/master/main.

Costs: free for non-profit use.

Programming languages: *R*, *Shiny*.

License: *webXTREME* is released under the terms of the GNU Public License (http://www.gnu.org/licenses/, accessed January 18, 2017).

Acknowledgements

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[15] http://eca.knmi.nl/dailydata/; accessed January 18, 2017.

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