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GHS-POPWARP User Guide

Volume preserving
Population Warp
User Guide
Version 1

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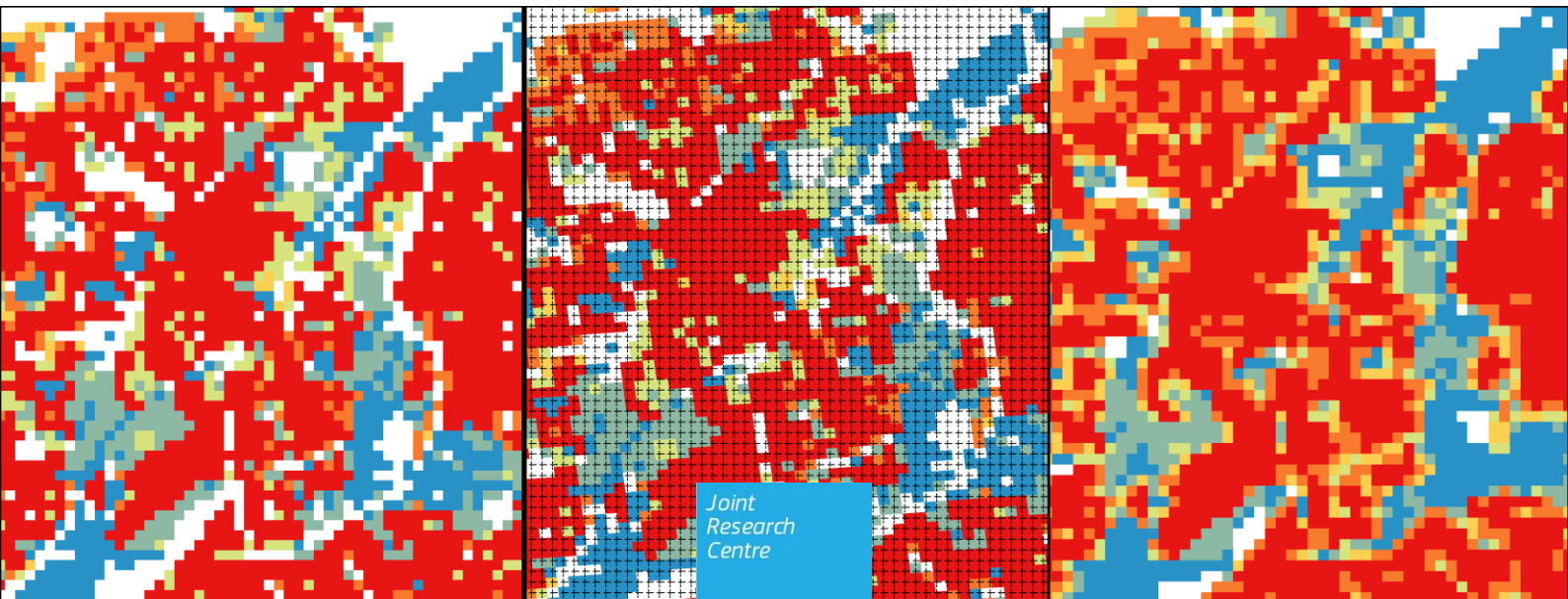

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Abstract

Changing the coordinate system of grids storing population counts is typically a challenging task, due to the need to keep the population totals unchanged (i.e. volume preservation).

The Population Warp tool (GHS-POPWARP) version 1, is an information system developed in the framework of the Global Human Settlement Layer (GHSL) project to convert geospatial raster grids of population counts between different map projections and/or spatial resolutions, while preserving population volumes.

The GHS-POPWARP v1 is a flexible tool to produce geospatial population counts grids in GeoTIFF format starting from another grid in a different coordinate system and/or resolution (i.e. cell size). The tool operationalises a stable and rigorous workflow long used in the Global Human Settlement Layer to handle gridded population data. The GHS-POPWARP v1 tool allows the creation of population counts grids via a sequence of oversampling, structure conversion and reprojection geospatial procedures. The principal purpose of the tool is to expand the interoperability of GHSL tools which require population grid data as input (e.g. GHS-DUG that strictly requires a kilometric population grid in equal area projection) or to simplify the warping of population grids for users less familiar with geospatial processing.

The tool is offered as a contribution to capacity enhancement in the framework of the multi-stakeholder effort for the uptake of the Degree of Urbanisation (DEGURBA) classification method. Degree of Urbanisation refers to the people-based harmonised definition of cities and settlements recommended by the 51st Session of the United Nations Statistical Commission as the methodology to delineate cities and rural areas for international statistical comparison. The GHS-POPWARP, as all GHSL tools, is issued with an end-user licence agreement, included in the download package.

1 Introduction

Population geospatial data are baseline information serving many applications across countless domains, including disaster risk management, transport planning, territorial management and others spanning sustainability and economics. In the last decade, spatial layers representing population distribution have been increasingly produced and adopted in research and policy support analyses. One particular typology of geospatial data representing population distribution is the population grid. A population grid is a net of equal size cells overlaying a territory, where each cell typically reports the population count (i.e. the number of people).

Population grids are at the basis of the Degree of Urbanisation method (see (Maffenini et al., 2020b)) that was adopted by the 51st United Nations Statistical Commission for the delineation of urban and rural areas for international statistical comparison. In addition, the Global Monitoring Framework of the 2030 Agenda for Sustainable Development includes several indicators that require disaggregation in urban and rural classes, and several others that are sensitive to how an urban area is delineated. Population grids are increasingly produced and used by researchers and statistical offices but their technical specifications vary.

To create a grid of settlement classes, needed to assess the Degree of Urbanisation, the GHS-DUG tool (Maffenini et al., 2020b) requires as input a population grid at 1 km resolution in an equal-area map projection[1]. While the population grid GHS-POP (Schiavina et al., 2019) is provided in World Mollweide equal area projection, other global population grids are provided in WGS84 coordinate system.

The GHS-POPWARP tool described here is developed to simplify the conversion of grids storing population counts to equal-area map projections required for the application of the Degree of Urbanisation (i.e. 1 km World Mollweide, EPSG:54009, and 1 km ETRS LAEA, EPSG:3035, as required by the GHS-DUG tool).

The benefits of the GHS-POPWARP tool go beyond the thematic application in the Degree of Urbanisation workflow. In fact, population warping is a sensitive and computationally intensive geospatial processing task that carries some risks to output a warped population grid with errors and/or distortions (errors in position and in terms of counts total volume). The GHS-POPWARP tool helps researchers and data users to warp population grids to fit their needs. Moreover, the tool has a much broader applicability to all processes of map-projection conversions applied to grids storing count values[2] from and to any GDAL-supported map projection (see Box 1, pp. 21).

The sub-section below explains the characteristics of population grids, and the ways in which such grids can be warped.

1.1 Population grids

A population grid is a powerful way to standardise reporting units. Information contained in population grids may be used to analyse issues that require a consistently high spatial resolution (i.e. small cell size), such as exposure to a certain hazard, demand for transport, but also to monitor changes of the population in the same area of interest across time. Census enumeration areas provide a high level of spatial resolution in urban areas, but usually a much coarser resolution in rural areas, which makes them less suitable for this type of analysis.

Several organisations, including the United Nations Global Geospatial Information Management (UN GGIM), the United Nations Population Fund (UNFPA) and the POPGRID Data Collaborative initiative, are promoting the production and use of population grids as they have a number of important advantages:

- grid cells all have the same size allowing for easy comparison;
- grids are stable over time;
- grids integrate easily with other data (for example, meteorological or air quality data);
- grid cells can be assembled to form areas reflecting a specific purpose and study area (mountain regions, water catchment areas, metropolitan areas)

There are several methods to produce population grids. One way is by disaggregation of population census based on a covariate (for example built-up areas, or a combination of several covariates); other methods

[1] Equal-area maps maintain true relative sizes of features, aiming for an accurate representation and measurement of areas on maps.

[2] The tool was developed to work with grids storing population counts but this does not prevent the use with grids storing count value of any nature.

NOTE: this tool is not designed for and will not work with grids representing density (e.g. persons/km^2); such grids should be transformed to counts before being used as input to this tool.

enabled by already geocoded population data can be implemented by aggregating household surveys (point locations) to a regular grid. Other methods can be implemented when demographic information (census) is unavailable or incomplete. In these cases it is possible to extrapolate by estimating population data from surveys, and modelling population distribution (see (Maffenini et al., 2020a) for details on population grids production).

Currently the number of population grid products with large territorial coverage is increasing, but each of the products has different assumptions, technical specifications (Leyk et al., 2019) and therefore different fitness for use. Population grids differ in population concepts, methods for production, spatial and temporal resolution, temporal coverage, distribution policy and also spatial reference (coordinate system).

1.1.1 Warping of population grids

One critical aspect of population grids is that they represent a given spatial distribution and volume of people (i.e. total number of persons) for the area being represented. This volume (e.g. the population of a country in a given year) should not suffer significant changes when converting such a grid from the coordinate system in which it is produced to another coordinate system. This process of fitting a geospatial layer to its correct positional location in a given coordinate system different from the original one is referred as warping and it is a commonly used procedure to convert the coordinate system of a raster layer (e.g. GDAL warp[3]). However, population warping (or in general warping of grids storing count values) is a particularly sensitive task that requires specific controls to preserve total population volume and preserve distortions. These requirements are addressed with the development of the GHS-POPWARP tool.

1.1.1.1 Operational population warping

The two key aspects of warping population grids are:

- Preserving total volume;
- Avoid distortions and population displacement.

These two aspects are addressed in the GHS-POPWARP tool via a sequence of geospatial procedures such as oversampling, structure conversion and reprojection (Figure 1), simply requiring the definition of the output grid characteristics (i.e. coordinate system and pixel resolution). The output characteristics can be manually defined or obtained from an existing reference grid. In the first case the output grid will be optimized to fit the input extent in the output coordinate system; in the second case the reference grid (provided by the user) is also used to align the output pixels to the reference (e.g. to produce grids aligned and easily comparable).

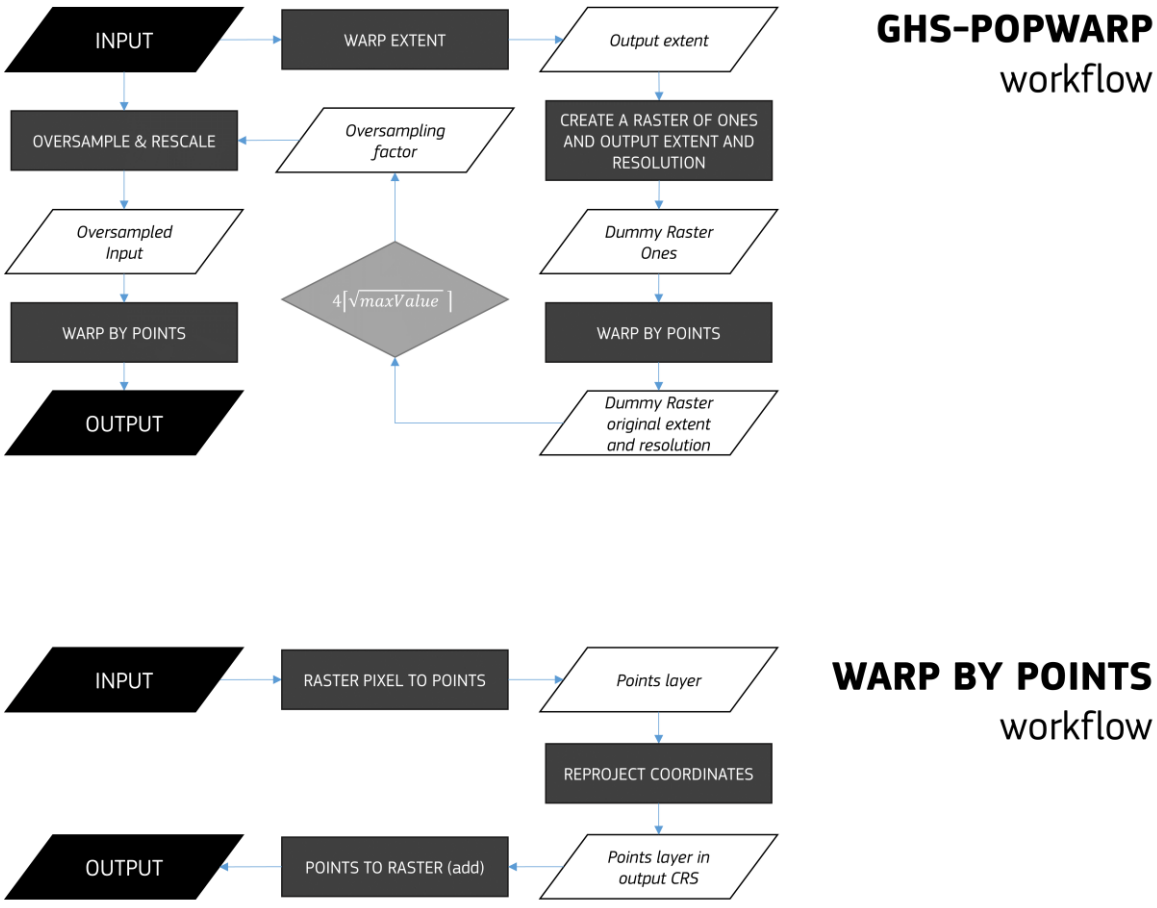
The preserving-total-volume procedure implemented in GHS-POPWARP exploits a data conversion technique to ensure that all counts are transferred from the original grid to the final one. This procedure is defined "Warp by Points" and consists in a first conversion from raster (e.g. the input population grid) to points (i.e. one point for each raster pixel) storing the grid values as attribute field, followed by a vector reprojection of points locations to the final coordinate system and a final conversion (features rasterization) from points to raster using an additive procedure (i.e. each final cell sums the values of all points within its boundaries).

This technique alone will preserve the total volume but could introduce distortions (e.g. discontinuous population distribution in a fully populated original area, in those areas where output granularity is much finer than the original). Therefore, the GHS-POPWARP solves the distortion and displacement issue by performing an oversampling procedure to the original input grid. However, such solution is highly computational intensive as it requires to increase the raster dimension by several times according to the typology of spatial conversion requested. The tool automatically calibrates the optimal oversampling factor in order to keep a minimum of 16 points of the "Warp by Points" procedure for each final grid cell, and integrates an automated tiling approach to avoid memory overflows. This procedure is implemented by creating a dummy raster grid with the desired output characteristics (i.e. coordinate system and pixel resolution, and, in case of a target reference grid, the cell alignment) and the extent required to cover the whole input grid extent, filled with ones (i.e. all pixel values have value equal to 1), and apply the "Warp by Points" procedure toward the original grid (coordinate system, pixel resolution and alignment). The maximum raster value represents the number of output pixel (i.e. pixels of the warped population grid) that falls within an original pixel (i.e. pixels of the input grid). As the algorithm uses linear oversampling factors (i.e. n oversampling both on x and y axes, therefore n^2 within a pixel), a square root is applied and the upper rounded integer (i.e. ceiling) is taken and multiplied by 4 (i.e. for a minimum of 16 points for each output pixel) to obtain the calibrated oversampling factor n. The input grid is then oversampled

[3] https://gdal.org/programs/gdalwarp.html

using this factor n and rescaled by n^2 (i.e. each pixel is regularly subdivided into n^2 pixels with the same value and divided by n^2) to finally apply the "Warp by Points" procedure and obtain the warped grid. The minimum of 16 points for each output pixel is empirically estimated as the trade-off value to reduce distortions without an unsustainable increase of computational time.

Figure 1 GHS-POPWARP workflow



2 Standalone tool

The standalone version of the tool allows the user to perform the classification using a simple graphical user interface.

2.1 Installation

2.1.1 System requirements

The Global Human Settlement "*Population Warp*" (GHS-POPWARP) is graphical tool developed in MATLAB and created for Windows. The main algorithm runs through a MATLAB compiled code, therefore the MATLAB Runtime is required. Its system requirements are listed below (Table 1)

Table 1 System requirements

Requirements	**Operating system**	**Processor**	**RAM**	**Disk space**
Minimum	Windows 7	Any Intel or AMD x86-64 processor	6 GB	150 Mb (+ 700 Mb for Matlab Runtime)
Recommended	Windows 10	Any Intel or AMD x86-64 processor	16 GB	150 Mb (+ 700 Mb for Matlab Runtime)

GHS-POPWARP operates on raster grids: the larger the grid, the higher will be the required memory. However, the tool implements an adaptive algorithm to accommodate the process into the available RAM memory at the beginning of the computation.

2.1.2 Installation procedure

2.1.2.1 Install MATLAB Runtime

GHS-POPWARP is developed in MATLAB and the MATLAB Runtime is required to run the tool.

The specific version to be installed is **R2020b (9.9)**, Windows 64-bit version.

Check for the official MATLAB website to download and install:

https://it.mathworks.com/products/compiler/matlab-runtime.html

2.1.2.2 Install GHS-POPWARP

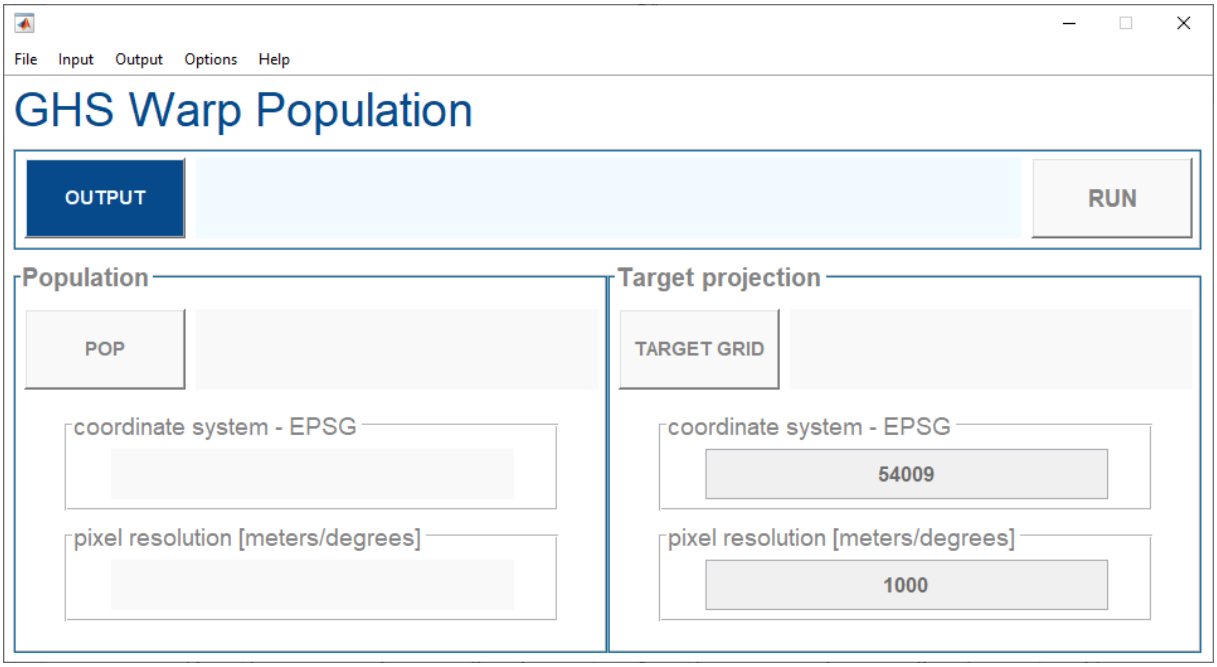
Once the MATLAB Runtime is installed, if you have not done so already, download the GHS-POPWARP tool from the GHSL website (Tools section):

https://ghsl.jrc.ec.europa.eu/tools.php

Unzip the GHS-POPWARP zip file and run the executable directly by double clicking the *exe* file.

The first time GHS-POPWARP is launched on a new computer it performs several checks and initialization steps, therefore it can take up to 2 minutes to start.

Figure 2 GHS-POPWARP first startup GUI



2.1.2.3 Remove GHS-POPWARP

To uninstall GHS-POPWARP simply delete the entire folder containing the.*exe* file.

MATLAB Runtime can also be removed if not necessary for other applications.

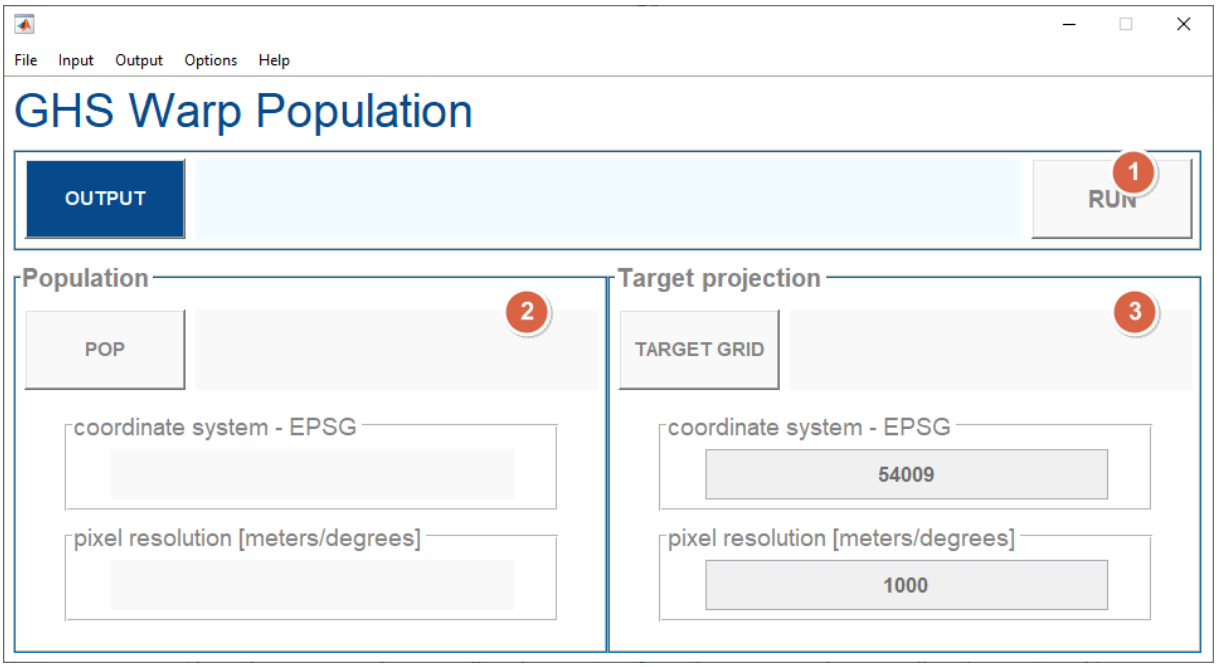
2.2 The graphical user interface

The GHS-POPWARP graphical user interface is created in MATLAB and distributed as a standalone application.

The main window is divided in three areas:

1. Top panel, which contains the buttons to select the output folder and to start the process;
2. Left panel, which allows to select the input population raster grid to be warped;
3. Right panel, where the new coordinate system and pixel resolution are chosen

Figure 3 GHS-POPWARP main windows and areas



After the start, the user has to first choose the output folder, as it is used to store both results and temporary files l. Then all other inputs are activated and can be selected.

2.2.1 Menu bar

The menu bar is organized in five sections:

1. File
2. Input
3. Output
4. Options
5. Help

2.2.1.1 File menu

Table 2 File menu bar

Item	Action	Shortcut
Run	Starts the population warping process	CTRL + R
Clear all	Clear all inputs	
Quit	Exit GHS-POPWARP and close the main window	CTRL + Q

2.2.1.2 Input

Table 3 Input menu bar

Item	Action	Shortcut
Population Grid	Select and load the input population raster	CTRL + P
Target Reference Grid	Select and load a target reference grid to warp to	CTRL + T

2.2.1.3 Output

Table 4 Output menu bar

Item	Action	Shortcut
Output	Set the output folder	CTRL + O

2.2.1.4 Options

Table 5 Options menu bar

Item	Action	Shortcut
Warp and snap to target grid	Use a target reference grid to derive coordinate system and pixel resolution. The warped input will also be aligned to this grid. (default: deactivated)	
Open output folder when process completes	The output folders is automatically opened in windows explorer when the process is completed (default: activated)	
Multicore	Use all available machine cores (default: single core)	

2.2.1.5 Help

Table 6 Help menu bar

Item	Action	Shortcut
Online help	Open a web page to the POPWARP documentation website using the default browser	CTRL + H
About GHS-POPWARP	Open a new window containing GHS-POPWARP version number, release date and contact information	

2.2.2 Buttons

All panels contain buttons; some of them provide the same functionality as the single menu entries and are an alternative way to set input data and start the warping process.

Table 7 Buttons

Item	Action	Shortcut
OUTPUT	Set the output folder	CTRL + O
RUN	Starts the GHS-POPWARP computation	CTRL + R
POP	Select and load the Population raster to warp	CTRL + P
TARGET GRID	Select and load a target grid to derive target coordinate system and pixel resolution. The warped result will also be aligned to this grid.	CTRL + T

2.2.3 Editable text fields

The Target projection panel contains two editable text fields that show the EPSG code of the projection to warp to and the desired new pixel resolution. If the target grid option is activated those text fields are read directly from the target raster and cannot be manually modified.

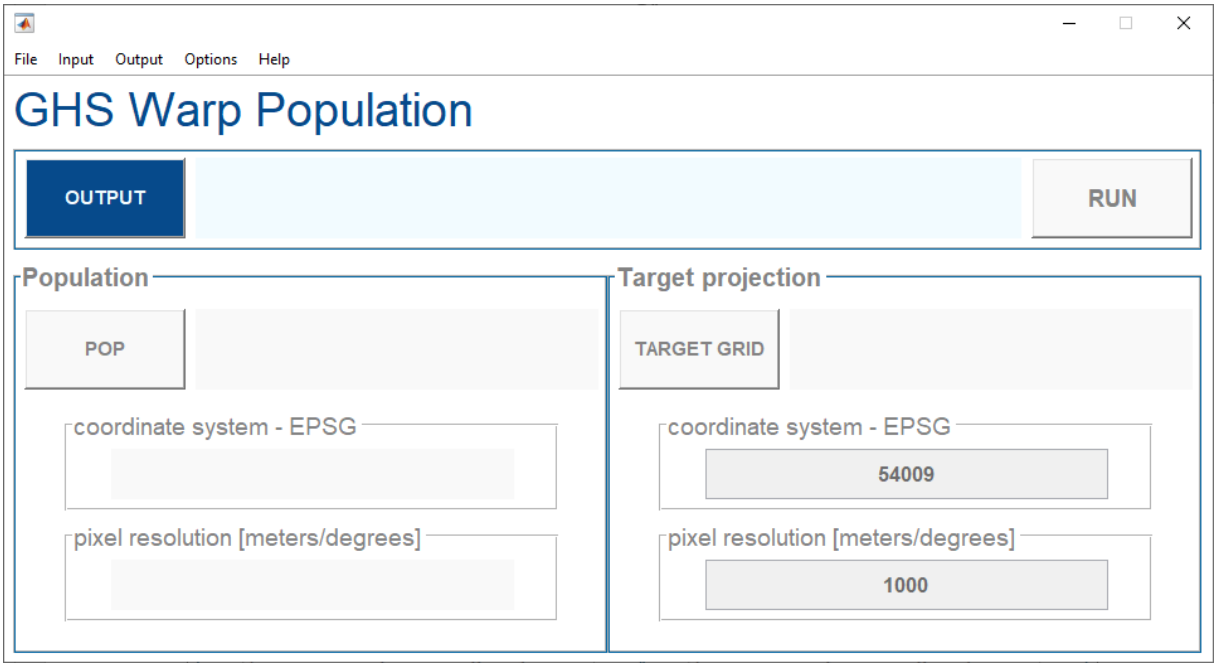
Table 8 Editable text fields

Item	Action
coordinate system - EPSG	Display and modify the target coordinate system: the user can set the new coordinate system using EPSG code number (read only with target grid option activated) See www.epsg.io for EPSG codes definitions
pixel resolution [meters/degrees]	Display and modify the target pixel resolution (cell size): the user can set the new pixel resolution, which will be taken as meters or decimal degrees according to the coordinate system selected above (read only with target grid option activated)

2.2.4 Guided run

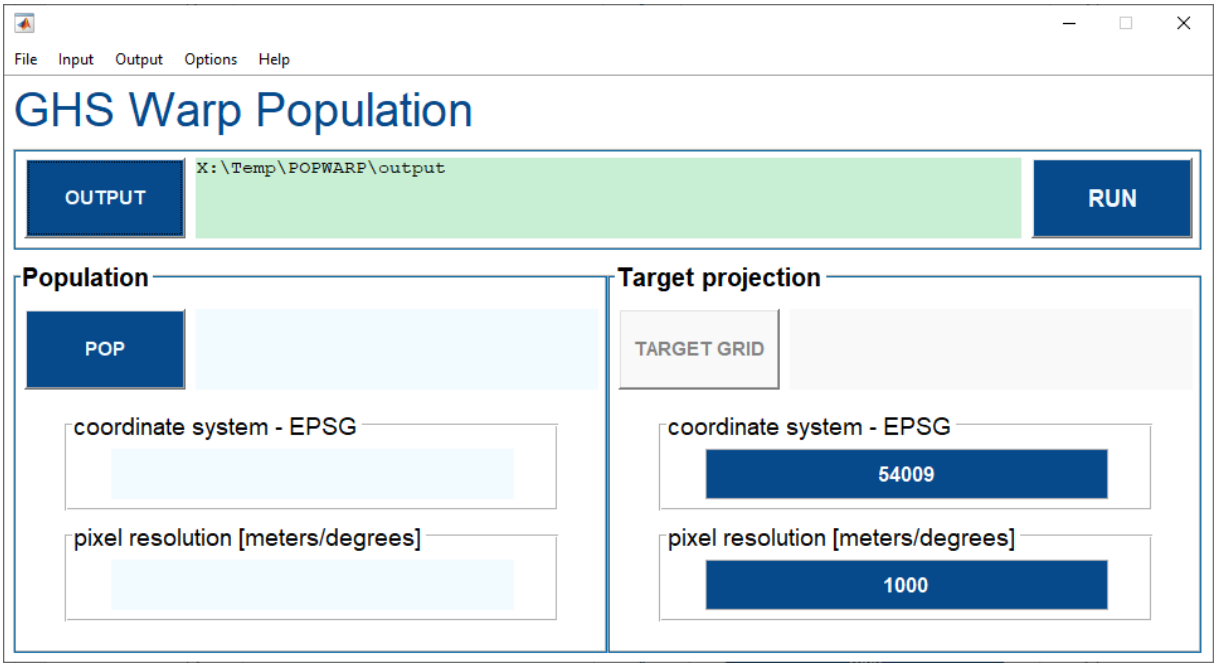
After starting GHS-POPWARP, the only active command is the output button (Figure 4): this is to set the output folder (path) first in order to create the log file and check disk write permission for results. Below in the shaded italic text lines the actions and commands the user should prompt to run the GHS-POPWARP Tool.

Figure 4 GHS-POPWARP startup



The user clicks on OUTPUT and selects the output folder. (Figure 5)

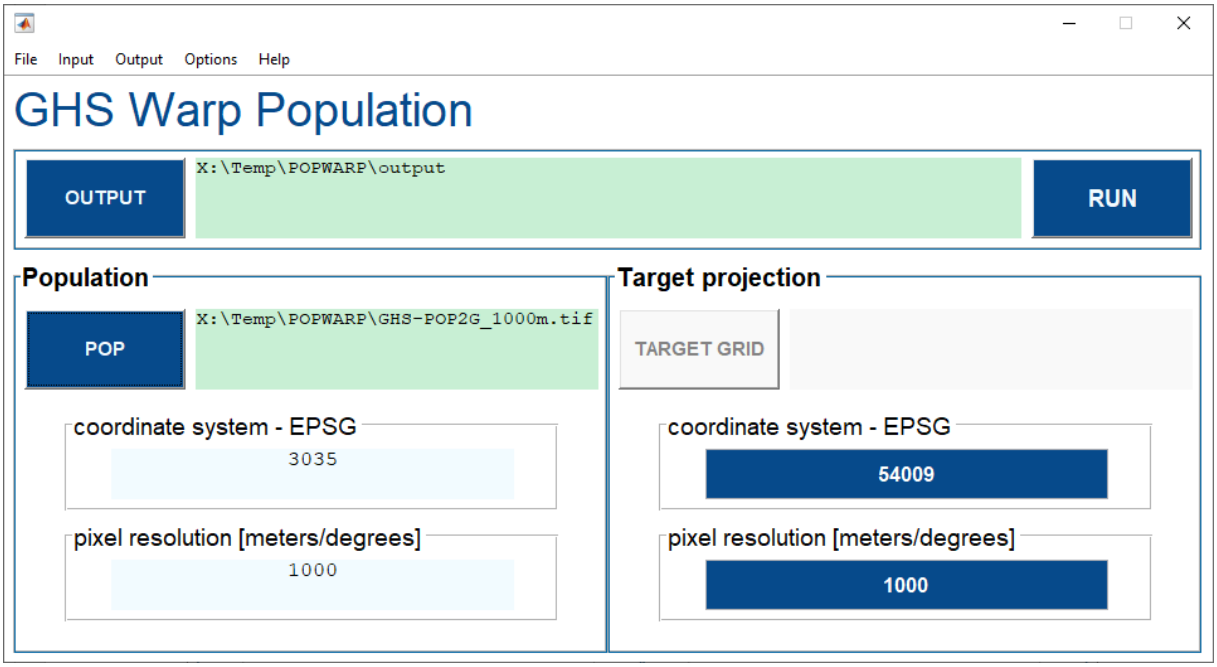
Figure 5 Output folder selected



Once output is set, all other input panels become active.

The user chooses the input population grid. (Figure 6)

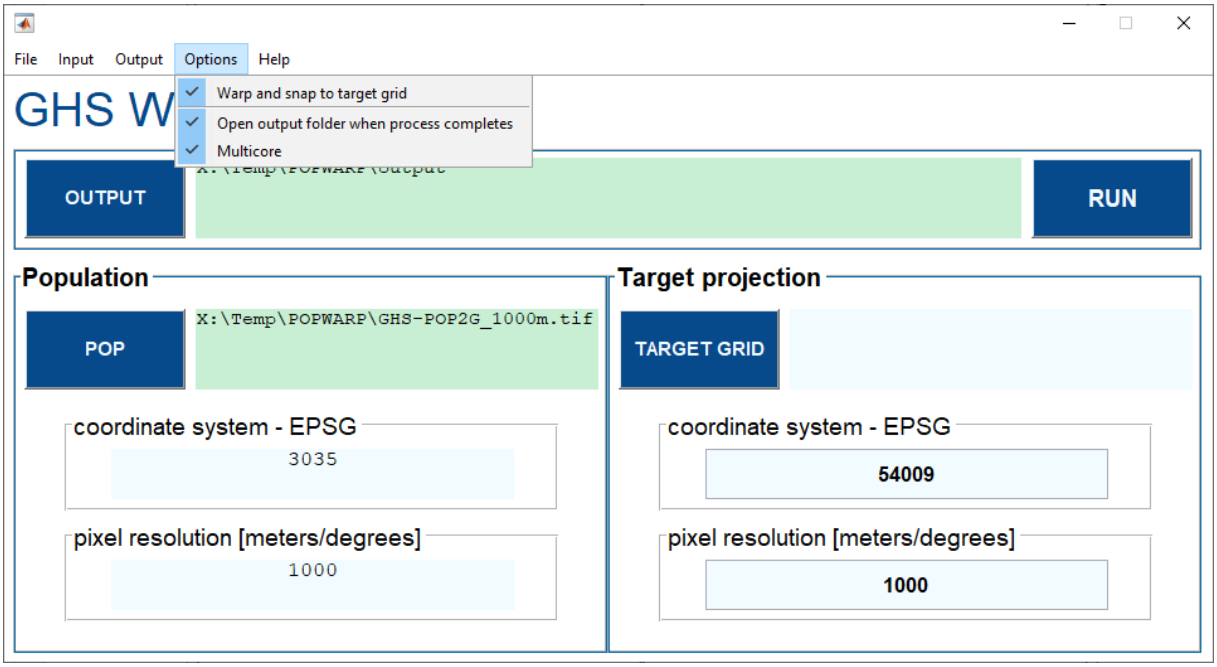
Figure 6 Input population grid selected



The coordinate system and pixel resolutions boxes are filled with the value read from the input population raster. The user can now write the new coordinate system and pixel resolutions values in the Target projection panel or activate the target grid option to read those parameters from another raster.

The user chooses the "Warp and snap to target grid" option (Figure 7)

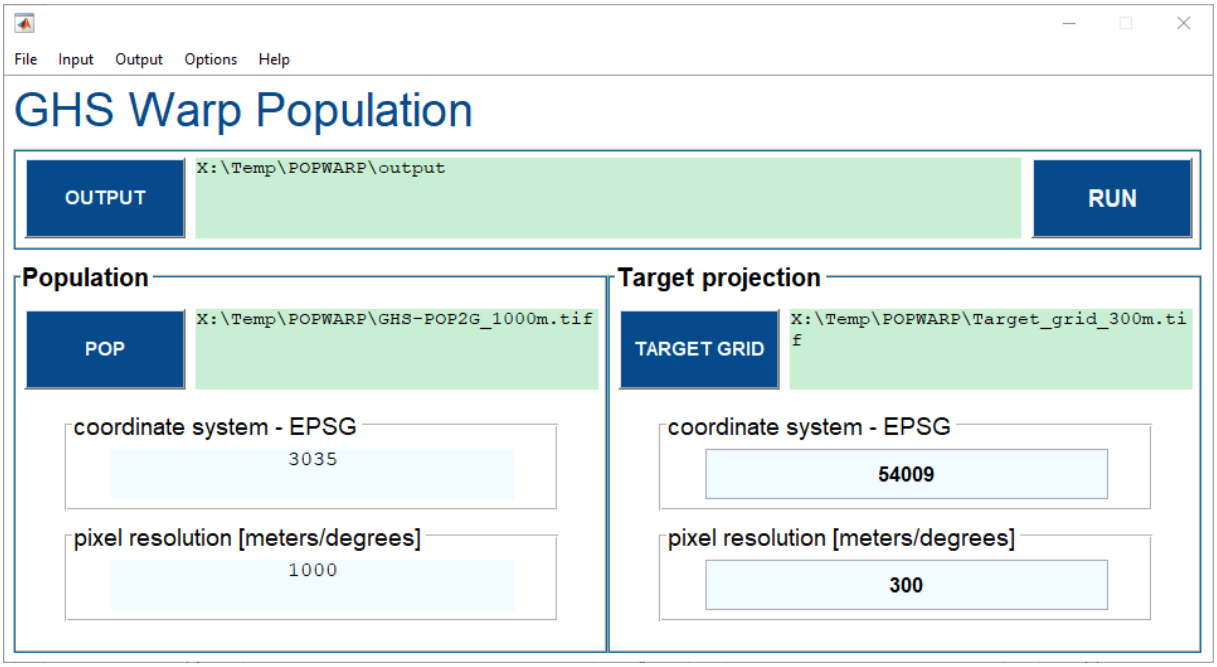
Figure 7 "Warp and snap to target grid" option selected



The user can then select the target grid.

The user chooses the target grid (Figure 8)

Figure 8 Target grid selected

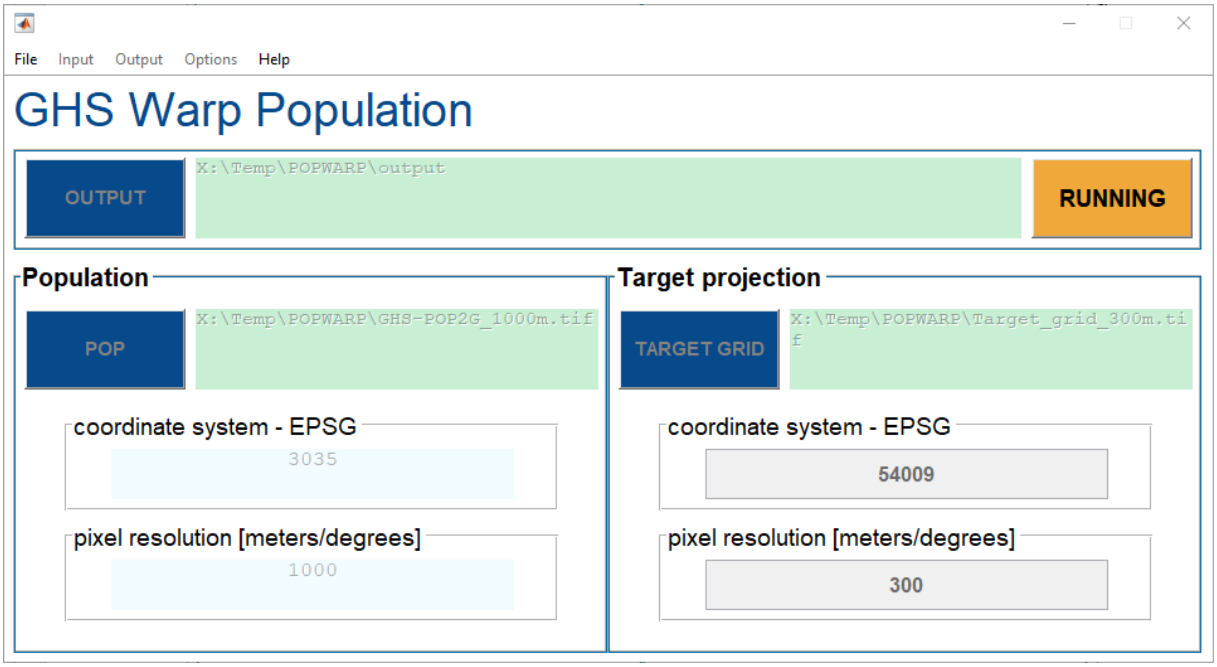


When the target grid is selected the target coordinate system and pixel resolution values become read only.

The user hits run (Figure 9)

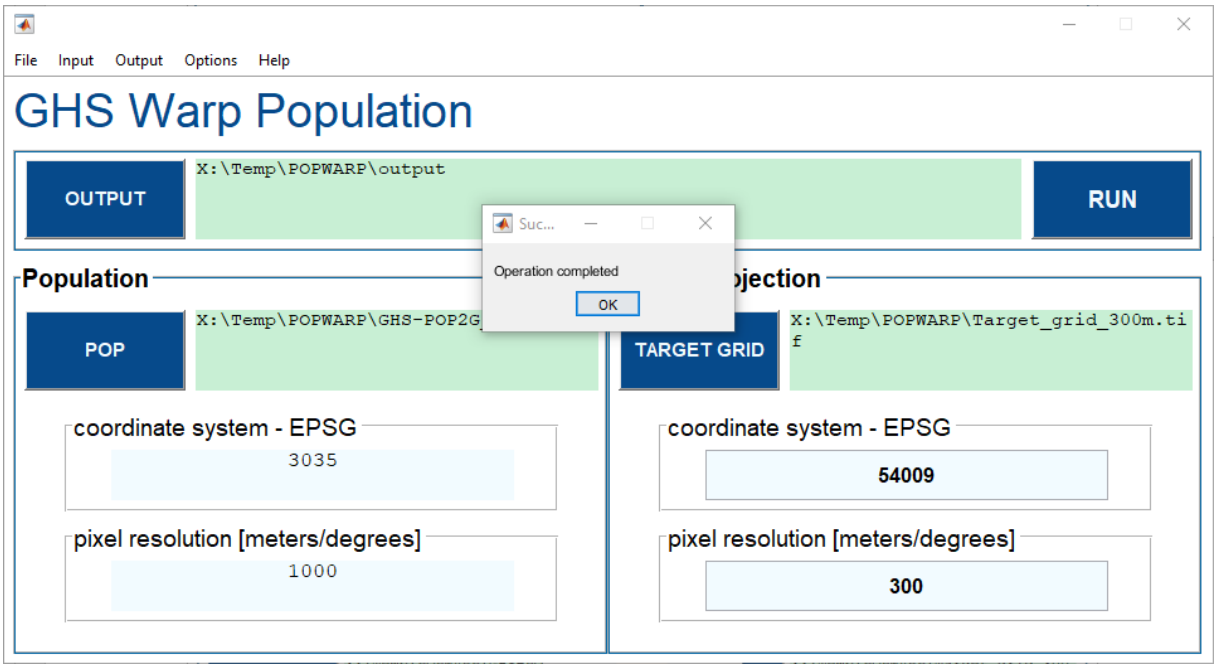
All commands are disabled when running, the RUN button becomes orange with label RUNNING and the mouse pointer transform into wheel (Figure 9).

Figure 9 GHS-POPWARP running



Once the run is completed everything is reactivated again.

Figure 10 Run successful



3 ArcGIS toolbox

The ArcGIS toolbox version of the tool allows the user to perform the grid warping directly from ArcGIS. The main algorithm is still run through the same MATLAB code used for the standalone version to ensure equivalent results from both tools, therefore the MATLAB Runtime is required.

3.1 Installation

3.1.1 System requirements

The requirements are the same as listed in 2.1.1.

3.1.2 Installation procedure

3.1.2.1 Install MATLAB Runtime

GHS-POPWARP is developed in MATLAB and the MATLAB Runtime is required to run the tool.

The specific version to be installed is **R2020b (9.9)**, Windows 64-bit version.

Check for the official MATLAB website to download and install:

https://it.mathworks.com/products/compiler/matlab-runtime.html

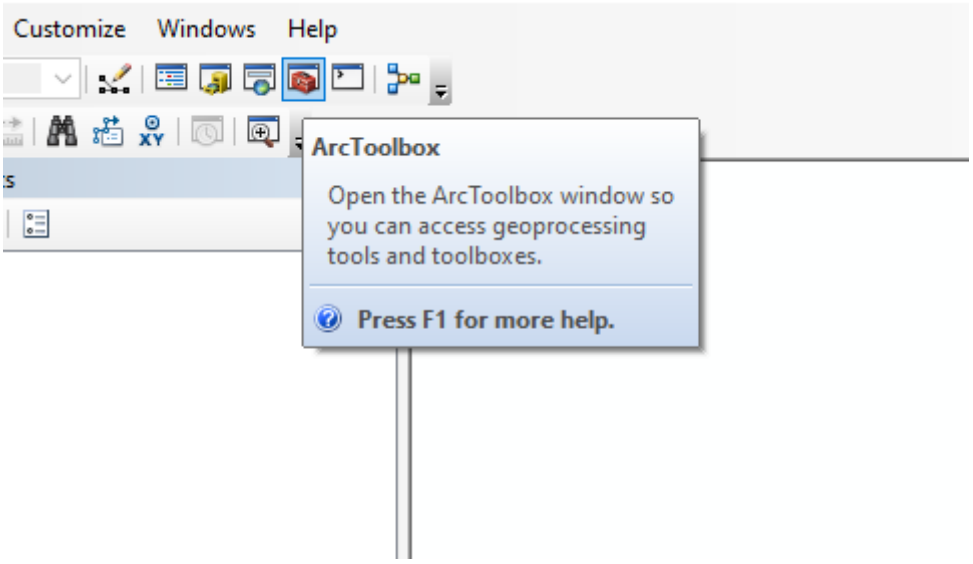
3.1.2.2 Install GHS-POPWARP ArcGIS toolbox

Once the MATLAB Runtime is installed, if you have not done so already, download the GHS-POPWARP ArcGIS toolbox from the GHSL website (Tools section):

https://ghsl.jrc.ec.europa.eu/tools.php

Unzip the file, then open ArcGIS and from the Tools panel open the ArcToolbox window:

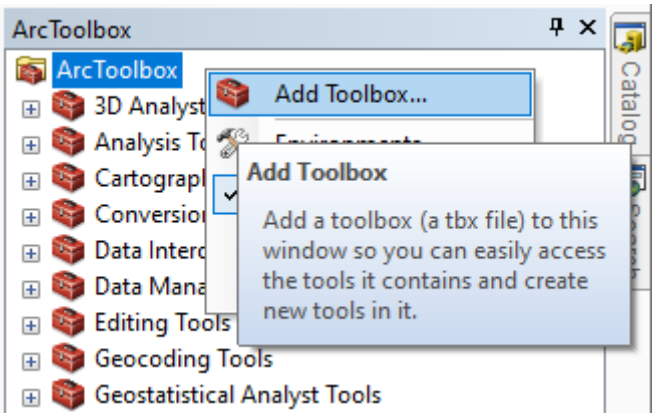
Figure 11 Show ArcToolbox window



From the the ArcToolbox window right click, press Add Toolbox and select the *GHS_Tools.pyt* file.

The toolbox will be listed under GHS Tools section.

Figure 12 Add toolbox to ArcGIS



3.1.2.3 Remove GHS-POPWARP ArcGIS toolbox

To uninstall GHS ArcGIS toolbox simply remove the toolbox from ArcGIS and delete the entire folder containing the toolbox files.

MATLAB Runtime can also be removed if not necessary for other applications.

3.2 The GHS-POPWARP toolbox user interface

The toolbox user interface includes the same input and parameters than the standalone version. The main windows cannot be split in sections, therefore all fields are listed together but in a logical order. The user should start to fill them from top to bottom, but that's not mandatory.

For a detailed description of input data and their constraints check section 4.1.

Figure 13 ArcGIS toolbox window

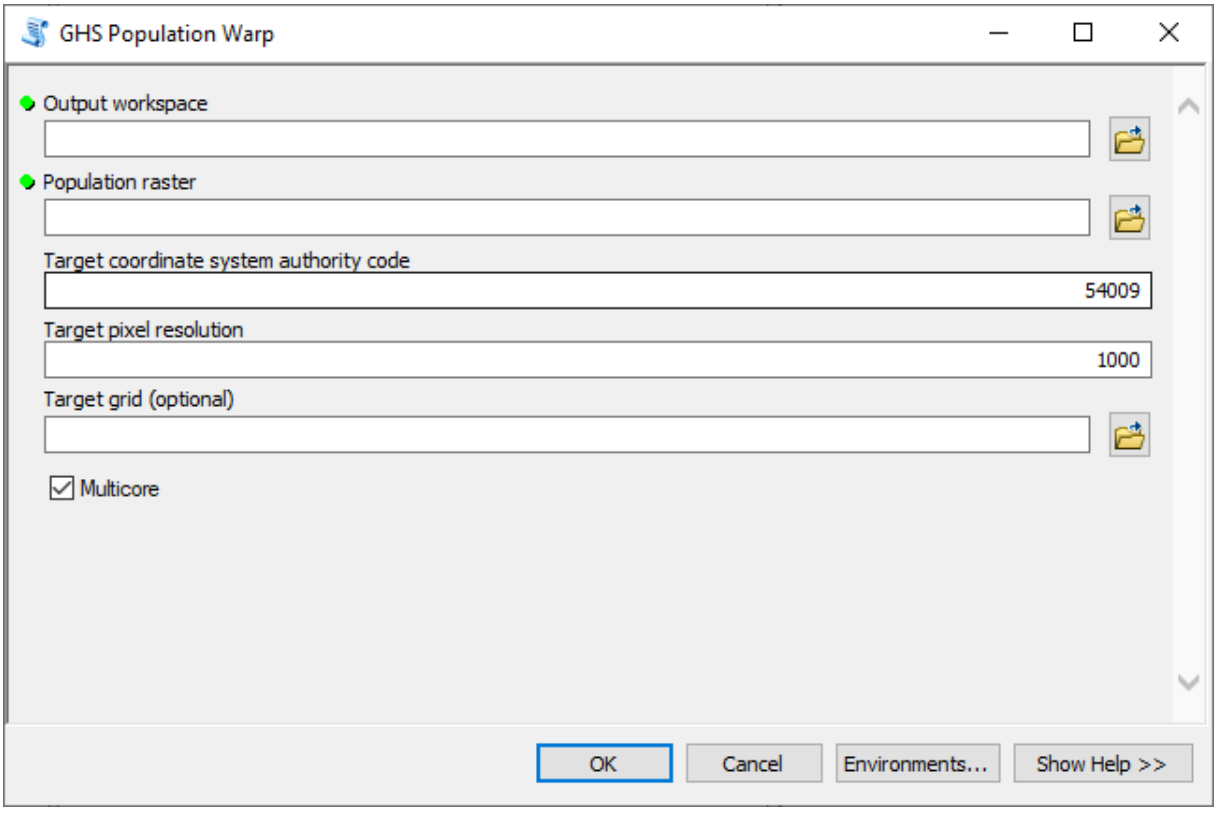


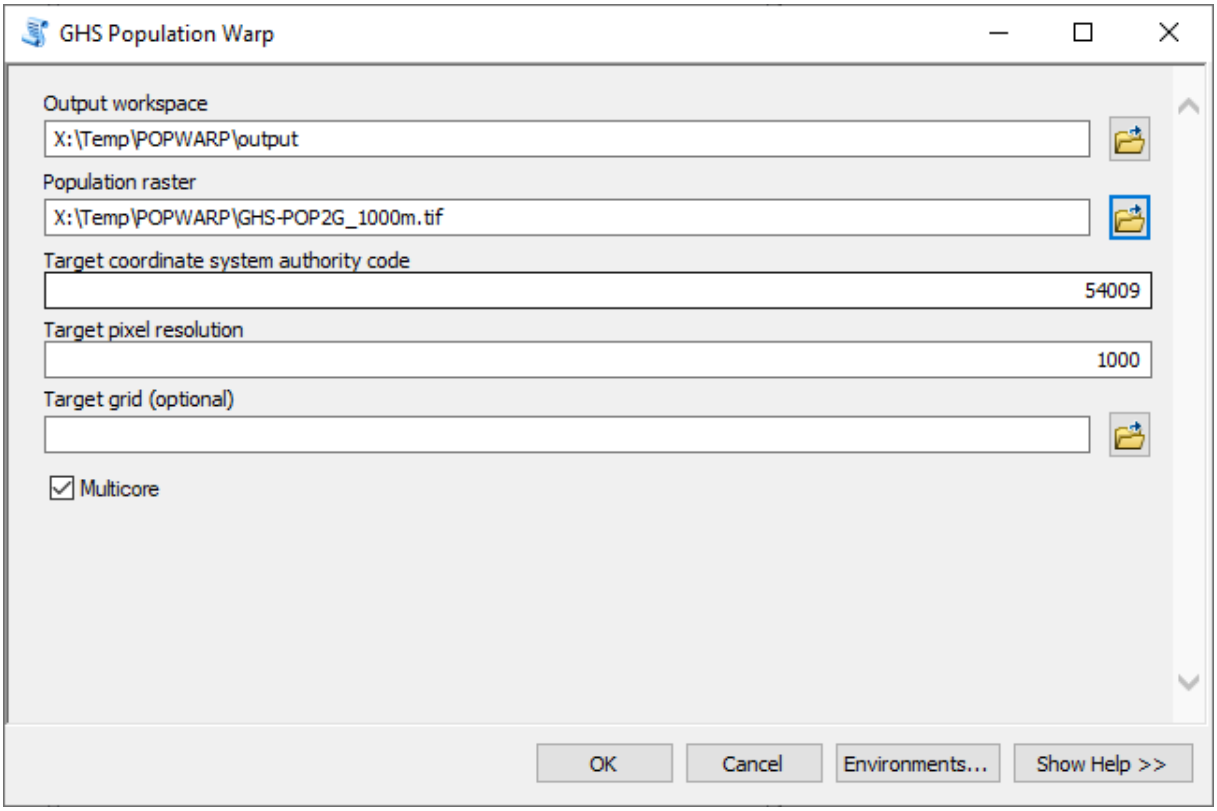
Table 9 Toolbox items description

Item	Description
Output workspace	Set the output folder. This is the output path where results and intermediate files are saved. The user needs to have write permission to this folder.
Population raster	Select and load the input population raster that will be warped
Target coordinate system authority code	Choose the output coordinate system using authority code (a.k.a. EPSG code) See www.epsg.io for EPSG codes definitions
Target pixel resolution	Choose the output pixel size, taken as meters or degrees according to the units of the target coordinate system selected
Target grid	Select and load a target grid as reference to derive coordinate system and pixel resolution. The warped result will also be aligned to this grid.
Multicore	Use all available machine cores. By default is deactivated (single core).

3.2.1 Run the toolbox

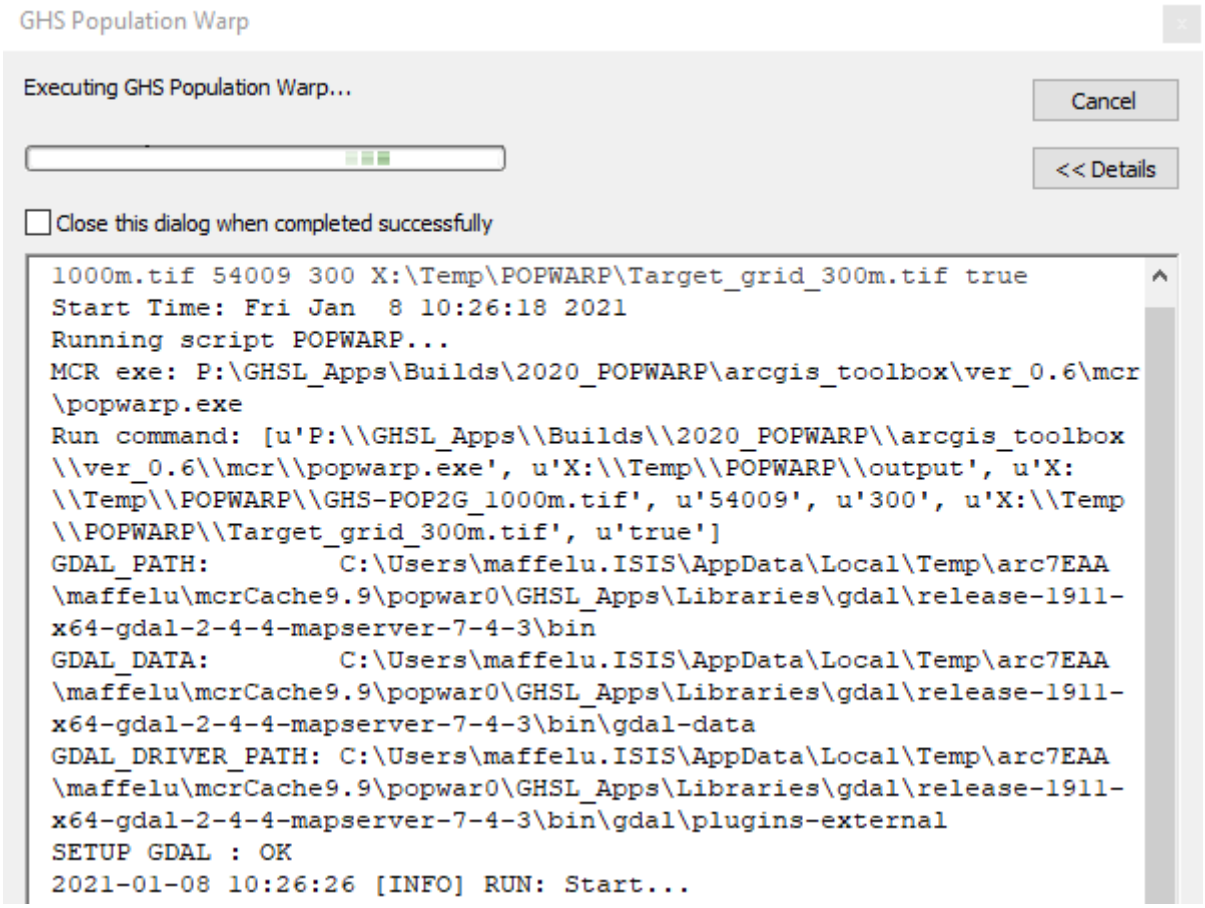
Before running the toolbox all inputs and parameters must be filled. The toolbox performs internal checks to ensure the values are correct. In case of doubt, the help section contains a short description about each field.

Figure 14 Toolbox setup with all inputs and parameters



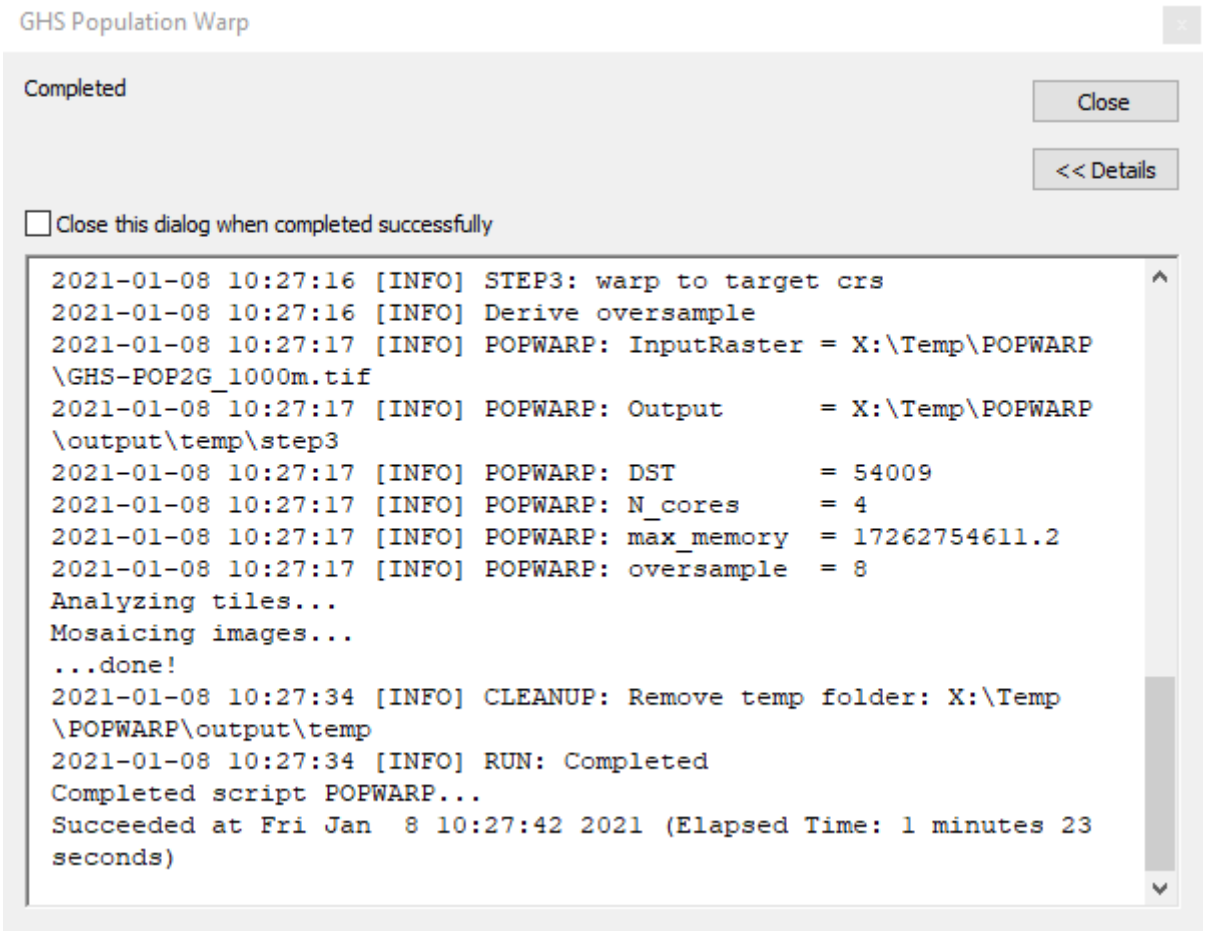
If no error messages appear while selecting the input data and the parameters the user can hit OK and start the computation. The user can follow the run progress by checking the computation logs.

Figure 15 Toolbox running



Once the process is completed the windows can be closed and the results can be loaded in ArcGIS or any other GIS to be inspected.

Figure 16 Toolbox run successfully completed


GHS Population Warp
Completed
Close
<< Details
Close this dialog when completed successfully
2021-01-08 10:27:16 [INFO] STEP3: warp to target crs
2021-01-08 10:27:16 [INFO] Derive oversample
2021-01-08 10:27:17 [INFO] POPWARP: InputRaster = X:\Temp\POPWARP
\GHS-POP2G_1000m.tif
2021-01-08 10:27:17 [INFO] POPWARP: Output = X:\Temp\POPWARP
\output\temp\step3
2021-01-08 10:27:17 [INFO] POPWARP: DST = 54009
2021-01-08 10:27:17 [INFO] POPWARP: N_cores = 4
2021-01-08 10:27:17 [INFO] POPWARP: max_memory = 17262754611.2
2021-01-08 10:27:17 [INFO] POPWARP: oversample = 8
Analyzing tiles...
Mosaicing images...
...done!
2021-01-08 10:27:34 [INFO] CLEANUP: Remove temp folder: X:\Temp
\POPWARP\output\temp
2021-01-08 10:27:34 [INFO] RUN: Completed
Completed script POPWARP...
Succeeded at Fri Jan 8 10:27:42 2021 (Elapsed Time: 1 minutes 23
seconds)

4 Input and output

4.1 Input

4.1.1 Population grid

The population grid has to be a GeoTIFF file, with integer or float data type, in any supported GDAL projection. Each pixel value shall report the population count expressed as absolute number (e.g. "3125.9" means 3125.9 people).

Box 1 Supported projections

Check the projections supported by GHS-POPWARP through GDAL at:

https://proj.org/operations/projections/index.html

Table 10 Population grid requirements

File format	Data type	Projection	Pixel size
GeoTIFF	Any numeric (int or float)	— Any supported by GDAL	Any numeric

4.1.2 Target grid

The target grid is an optional input: when selected it will be used to derive the target's coordinate system and pixel resolution. The warped result will also be aligned to this grid.

It is a convenient way to warp and align the population grid to one that is already in the desired coordinate system.

Table 11 Population grid requirements

File format	Data type	Projection	Pixel size
GeoTIFF	Any numeric (int or float)	— Any supported by GDAL	Any numeric

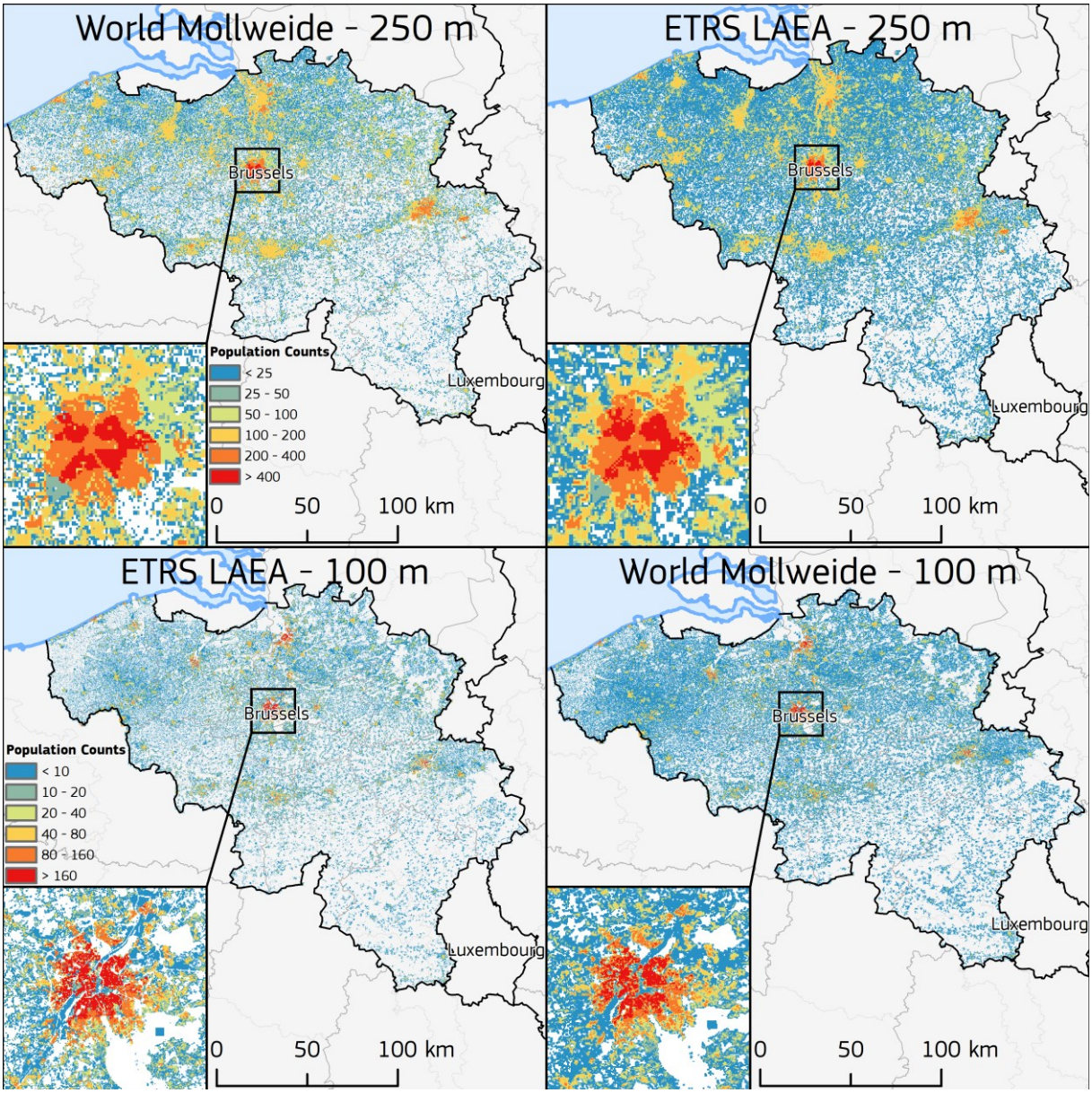
4.2 Output

4.2.1 Warped population grid

The output of the GHS-POPWARP tool is the population grid projected in the target coordinate system and with the target pixel resolution. Figure 17 shows the conversion of a World Mollweide layer of Belgium population at 250m to the ETRS LAEA projection at 250 m.

The important aspect of this warped result is that the total population volume is preserved: this means that the total population (e.g. the sum of population values in all pixels) in the warped result will be the same as the total population in the input population raster.

Figure 17 Input and output grids using GHS-POPWARP. Upper panel: original World Mollweide 250 m layer (left) of Belgium population counts grid, produced in GHS-POP, warped to ETRS LAEA 250 m (right); lower pane: original ETRS LAEA 100 m layer (left) of Belgium population counts grid, produced in ENACT-POP, warped to World Mollweide 100 m (right). All boxes show a detail of Brussels.



5 Conclusion

The GHS-POPWARP Tool adds to the family of GHSL open and free tools to enact the "open input, open method, open output" paradigm of the Global Human Settlement Layer framework. With the GHS-POPWARP Tool presented in this report the user can convert population grids at any spatial resolution to a target spatial reference preserving population volumes. This capability supports the endeavours of the European Commission and the partner Organisations of the voluntary commitment to develop a harmonised global definition of cities and settlements launched at the Habitat III conference in 2016. The tool specifically supports the capacity enhancement activities currently carried out jointly by the European Commission Directorate General for Regional and Urban Policy, the Directorate General Joint Research Centre and the United Nations Human Settlements Programme to support the application of the Degree of Urbanisation, a new global definition of cities, urban and rural areas for global monitoring of SDGs and the New Urban Agenda urban targets as recommended by the 51st Session of the United Nations Statistical Commission.

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Annexes

Annex 1. Error messages

Error	Description	Solution
Cannot create log file! Check you have write permission	The tool has no write access to the selected folder and cannot create log file	Check and change folder permission or chose another folder with write permission
The selected population raster has no spatial metadata	The input population raster is missing metadata like coordinate system or pixel resolution values	Add spatial metadata using GIS or provide another population raster
The selected target raster has no spatial metadata	The target raster is missing metadata like coordinate system or pixel resolution values	Add spatial metadata using GIS or provide another target raster
Memory is not enough for requested target raster size	The available RAM is not enough to run the warping process in a reasonable time	Increase the computer RAM or use a coarser target pixel resolution

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