USER GUIDE

Automated Projection Selection for ArcGIS

ESRI ArcGIS Python Add-in

Version 1.0

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Contents

Introduction

An ESRI ArcGIS Python Add-In toolbar named *Automated Projection Selection* has been created to assist ArcMap users in making appropriate map projection selection decisions. This application has been developed using Python v2.7.10 and the ArcPy site package extension provided with ESRI ArcGIS v10.6.1.

Following a brief description of the projection selection process used in the Python script this User Guide explains the procedures for loading the toolbar to the ArcMap interface, how to run the tool, and details some possibilities for future enhancements.

Projection Selection Process

The *Automated Projection Selection* toolbar provides the necessary functions to allow an ArcMap user to generate and choose between candidate map projections that are appropriate for the specific purpose and geographical area of interest for their project. The following table gives a brief description of the purposes included in the selection process.

Purpose	Description
General Reference	Location of geographical features, e.g. atlas maps, topographical maps.
Thematic Vector	Geographical distribution of phenomena rather than location, e.g. statistical maps.
Thematic Raster	Geographical distribution of phenomena based on raster data, e.g. land-use/land-cover.
Geospatial Analysis (Distance)	Analysis based on accurate measurement of distances between features, e.g. spatial distribution, nearest neighbour, spatial autocorrelation, clustering, and geostatistical methods such as Inverse Distance Weighting.
Geospatial Analysis (Area)	Analysis based on accurate measurement of the area of an object, e.g. population density.
Navigation Routes (Geodesic)	Navigation based on travelling the shortest distance between two locations, also referred to as Great Circle navigation.
Navigation Routes (Loxodrome)	Navigation primarily for maritime use based on sailing a constant bearing between two locations, also referred to as Rhumb-Line navigation.
Ranges of Activity	Visualisation of phenomena distance from single/multiple source locations.
Flow Patterns	Display of symbolised arrows highlighting object movement between locations, e.g. migration, commercial distribution, airline routes.
World Index	Global overlay of information on basic geographical outlines, e.g. time zones, climate zones.

Projection selection diagrams have been created for each purpose, detailing the particular projections that are recommended in academic literature as being suitable for different geographical footprint characteristics based on size, location and extent (see Appendix A).

The diagrams also outline the types of data which are required to provide the definition of the footprint of interest, and these are also relevant to the specific purpose and designed around the data that the user is likely to have when carrying these out. In some cases these are a single feature defined by a vector polygon or raster dataset, whilst in others the footprint is defined by a set of vector point, line or polygon features.

Users should note that the input dataset must be referenced to a geographical coordinate system (GCS), using any GCS available within ArcGIS including other celestial bodies. The tool design is based on employing the ArcMap project-on-the-fly capability, which can lead to improper results for displaying data layers based on one projected coordinate system (PCS) when using a data frame set to a different PCS. It is also likely that if a user is running the tool and already has data referenced to a PCS then this is likely to be the most appropriate choice for their project.

The area characteristics are determined using real-world geographical values:

- *Size* – for an individual feature the ArcMap *Area_Geodesic* geometry attribute is used. For a set of features, the tool determines whether all features are completely within certain buffer sizes.
- *Location* – employs an iterative process using the Azimuthal Equidistant projection to calculate an approximate geographic centroid.
- *Extent* – uses an Azimuthal Equidistant projection based on this centroid location to determine whether the footprint extends equally in all directions or is greater in either the North-South or East-West directions.

Using the selection diagrams the tool generates a list of candidate projection options, determines the initial parameter settings from the geographic characteristics, and creates a set of .prj files for the candidates.

The tool assesses projection distortion for each PCS candidate using finite techniques with indices calculated for different types of distortion:

- *Distance* – the tool calculates an average distortion value for a randomly generated set of distances within the area of interest by comparing the geodesic to corresponding Euclidean distance.
- *Area* – similar to distance, the tool calculates an average distortion value for a randomly generated set of geodesic buffers within the area of interest by comparing the geodesic area to corresponding plane area.
- *Shape* – using the same randomly generated set of geodesic buffers within the footprint of interest, the tool calculates an average distortion value by comparing geometric intersection and union areas of each geodesic buffer with a plane circular buffer created using the same distance in projected space.

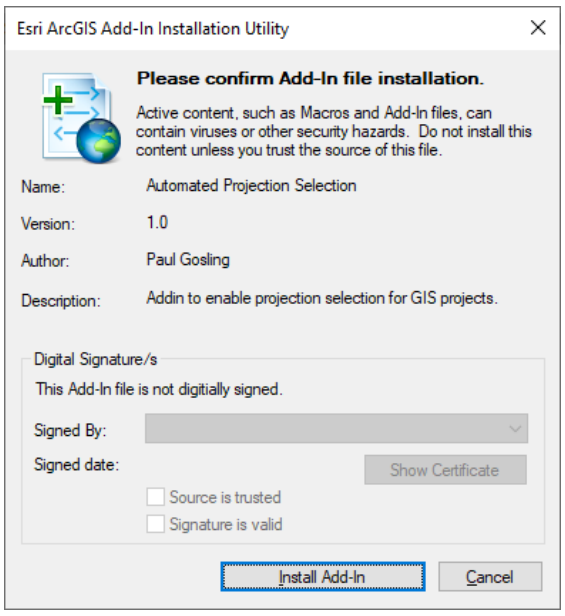
Distortion assessment points are generated using a method based on Fibonacci lattices, and the chosen purpose determines the weighting of the distortion type. For example the thematic and area-based analysis weight area as 1 and distance / shape as zero, whereas for general reference all types are weighted as 1.

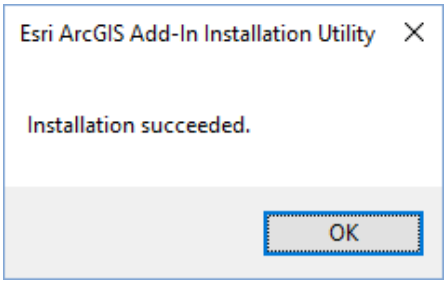
A Combined Index is calculated to give an overall indicator which can be used to compare the candidates. For some projections, optimisation methods are employed to modify parameters and further reduce the Combined Index where possible. This relates to determination of standard parallels for conic projections, and some projections which use scale factors for the line or point of zero distortion (i.e. Transverse Mercator and Stereographic).

A text file is generated with all of the results to enable evaluation of the candidates. These can also be viewed graphically by using a toolbar function to apply to the ArcGIS data frame properties, ideally employing Layout View with a graticule displayed to better interpret the shape of the Earth. The user now has the necessary quantitative and qualitative results to determine their preferred projection selection.

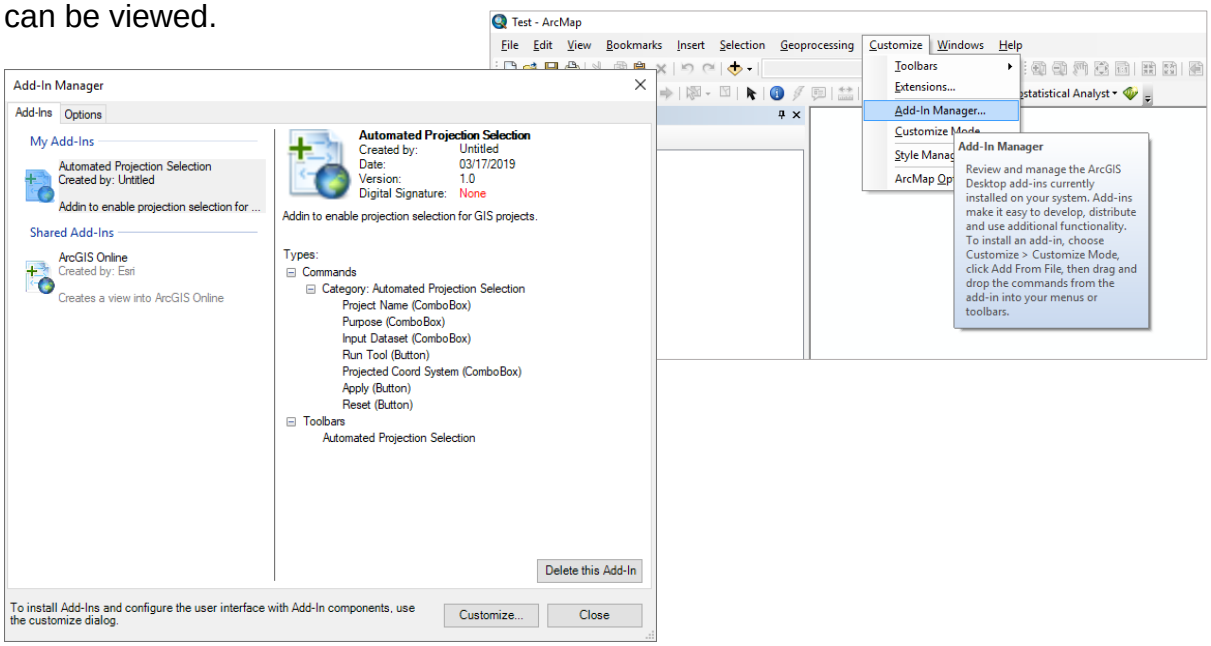
Loading the ArcMap Add-In

The *AutomatedProjectionSelection* folder contains all of the necessary files to install and run the *AutomatedProjectionSelection* Add-In toolbar. Copy the folder to any relevant location and double-click on the ***ProjectionSelection*** Esri AddIn File. View the details and confirm installation by clicking ***Install Add-In***, then ***OK*** to 'Installation succeeded'.

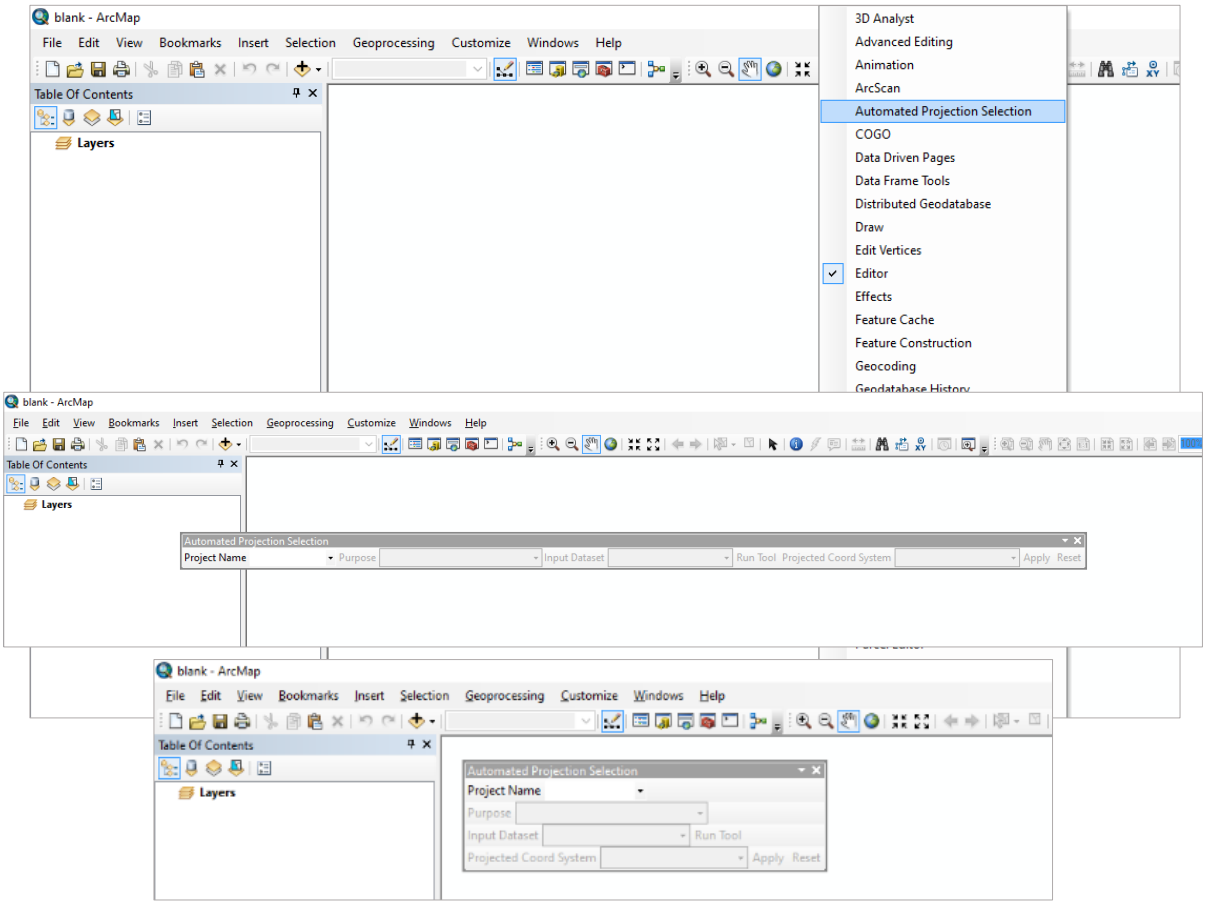




Open an ArcMap MXD Map Document. The Add-In Manager can be used to verify that the Automated Projection Selection Add-In is installed and further details can be viewed.



Right-click on the toolbar area in ArcMap (or click *Customize…Toolbars*) and select ***Automated Projection Selection*** to load the toolbar to the interface. The toolbar can float over the map or be docked as per normal functionality. The initial toolbar is wide but can be resized to provide a better user experience.



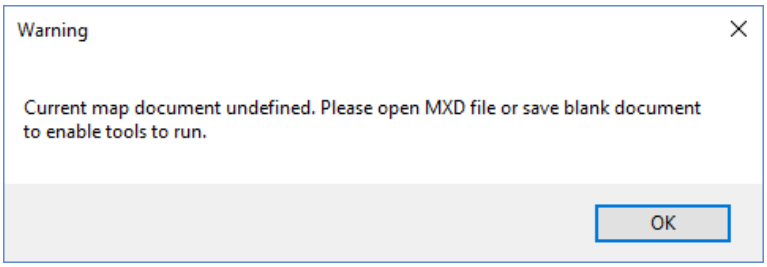
User Interface

The toolbar contains a number of user input selections and buttons:

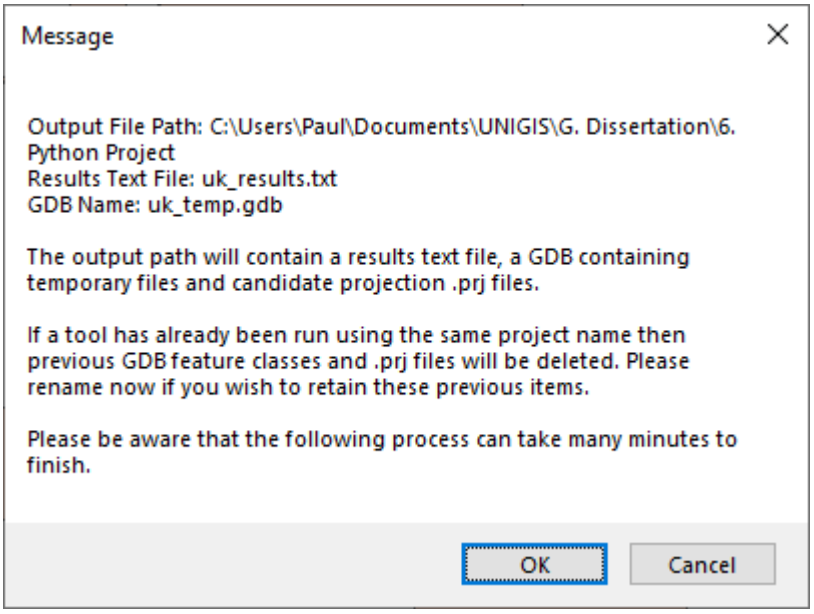
- Project Name – free text field with maximum 10 characters used to identify files created by the tool.
- Purpose – drop-down list containing different types of mapping or analysis purposes which relate to the reason why the projection selection is required.
- Input Dataset – drop-down list of layers in the active data frame which are referenced to a geographic coordinate system and are of the appropriate type for the selected Purpose. Once selected the data frame zooms to the extents of this layer.
- Run Tool – click button to run selection tool.
- Projected Coord System – drop-down list of candidate .prj files created by the tool ranked in order of least combined distortion index.
- Apply – click button to apply projected coordinate system from candidate .prj file selection. The data frame coordinate system property is modified, but note that layers are not re-projected and are simply displayed using the project-on-the-fly capability.
- Reset – click button to reset all input fields and buttons ready to start afresh.

Running the Selection Tool

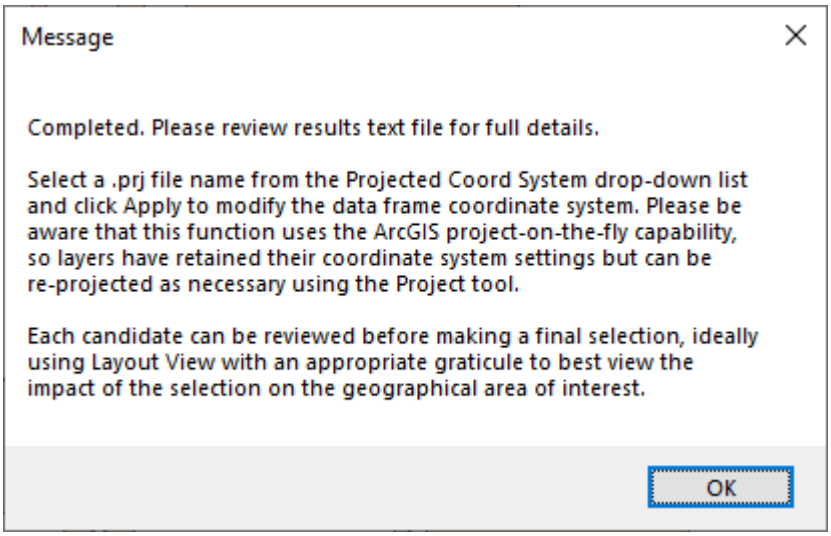
The tool can only run inside a saved MXD map document and a warning message is displayed for an unsaved MXD.



Each input field is enabled in turn and the *Run Tool* button can only be clicked once the *Project Name*, *Purpose* and *Input Dataset* have been defined. A message provides information about the outputs that will be generated, and also warns the user that the processing can take considerable time to complete. Click *OK* to confirm or *Cancel* to return to the toolbar.



Once the tool has completed processing a message explains how the user should proceed to review the results text file, which contains full details of the projection candidates and the distortion assessment, and view each of the candidates graphically before making their final selection.



Using the textual and graphical results the user can make a decision as to their preferred candidate. The text file also includes various notes depending on the situation to aid understanding of the outputs, or pointing the user to other options not directly included in the results.

The *Reset* button can be used at any time to refresh the input fields, and must be used after the tool has been run before attempting to run the tool again. In some cases the inputs are reset automatically, e.g. when selecting a new *Purpose* the *Input Dataset* list refreshes to enforce selection of a dataset of the appropriate type.

Possible Future Developments

The Purpose drop-down list provided will be sufficient for most mapping and GIS applications, but is not comprehensive as it is limited by appropriate projection selection research and advice for other possible options, e.g. climate and meteorological mapping. More practically, the projection selection diagrams (see Appendix A) can only include projections which are available in ArcGIS, so these may be updated in future when additional options become available.

Additional research would aid the Geospatial Analysis (Distance) purpose in better definition of the appropriate size limits and improved understanding of the impact of using projected XY coordinates in place of true Cartesian coordinates in certain GIS tools. More broadly GIS analysis techniques would benefit from increased use of geographical methods which do not require projected coordinate system input.

The distortion weighting scheme of assigning a binary zero or one to each type (distance, area and shape) is currently hardcoded depending on the purpose, so a planned update to the tool will see these values included as input fields. Therefore, a user will be able to modify from the default position and also use non-binary values, based on their particular requirements or further research which suggests a different approach. For example, the area-dependent purposes have the area distortion set to one and distance / shape to zero, so as all candidate projections are equal area this means that the returned distortion index in all cases is effectively zero apart from some minor rounding errors introduced by the calculation. The ranking of the candidates is therefore essentially arbitrary, and amending the distance and shape weights might prove beneficial to assist the user in making their final selection.

The distortion assessment process currently includes randomisation functions which in certain situations impacts the ranked order of candidate projections when running the tool multiple times for the same input purpose and footprint of interest, so a planned improvement will remove these random procedures and lead to repeatable results.

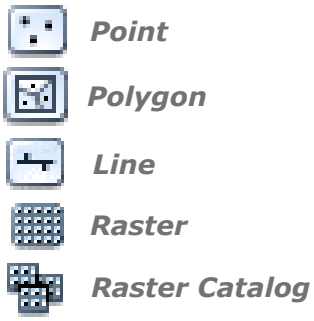
The visualisation of distortion distribution would be a clear benefit to user understanding of projection properties, but requires addition of complicated mathematical formulae for each projection in the selection process. In addition, the tool does not currently include a separate process for assessing the unique distortion challenges when using raster datasets and this warrants further study.

Finally, subjectively chosen limits and ratio factors could benefit from further study, and it may be possible to widen the extent calculations beyond the cardinal directions. The tool could also easily include pre-defined geographical footprints of interest such as countries / regions / continents.

Appendix A: Projection Selection Diagrams

The following pages provide the conceptual diagrams used to visualise the candidate projections for each purpose based on different geographic area characteristics in terms of size, location and extent (see Section 2.6 for details).

Alongside the purpose heading, the following ArcGIS icons are used to show what types of input data are valid for this purpose:

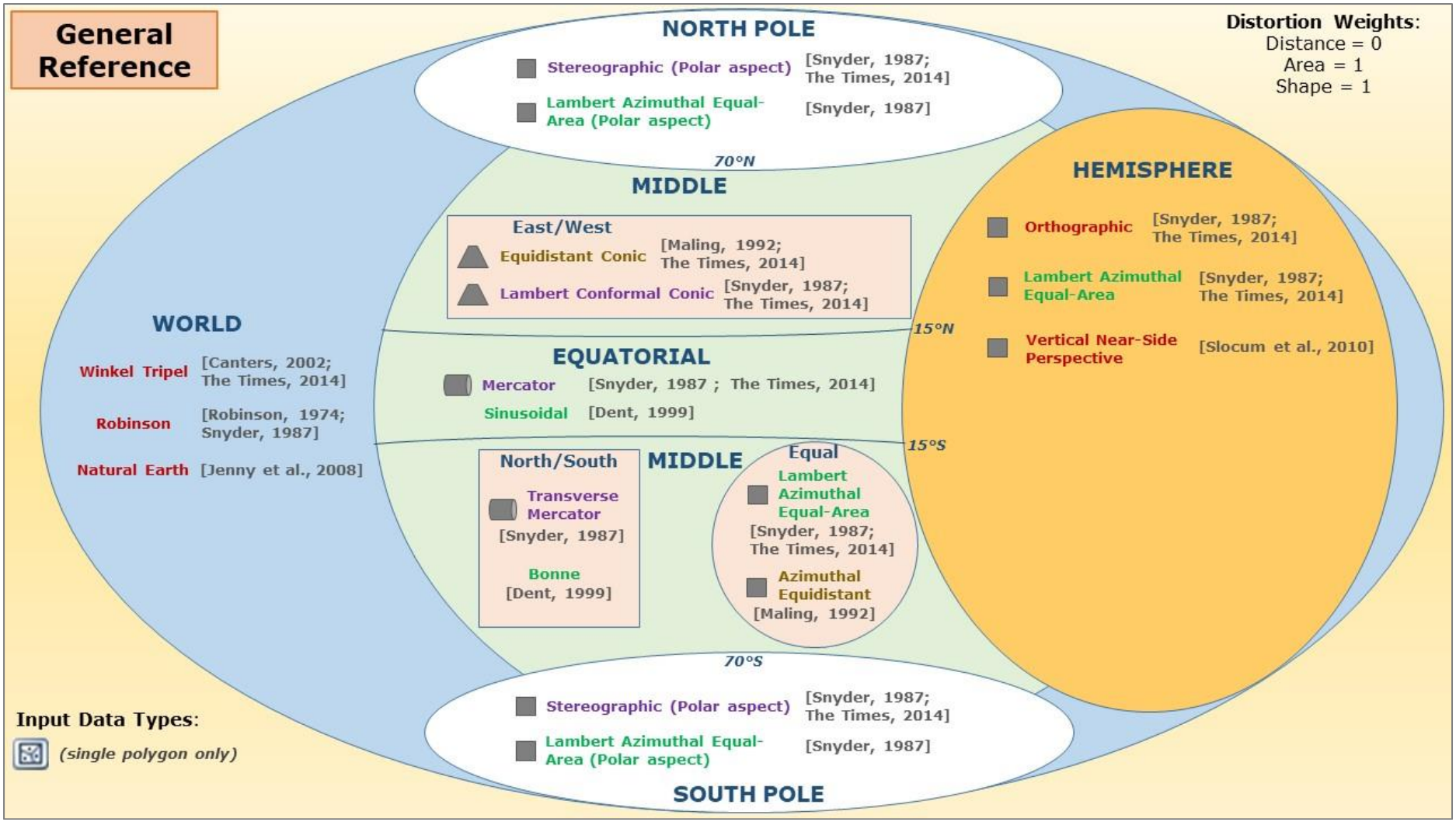


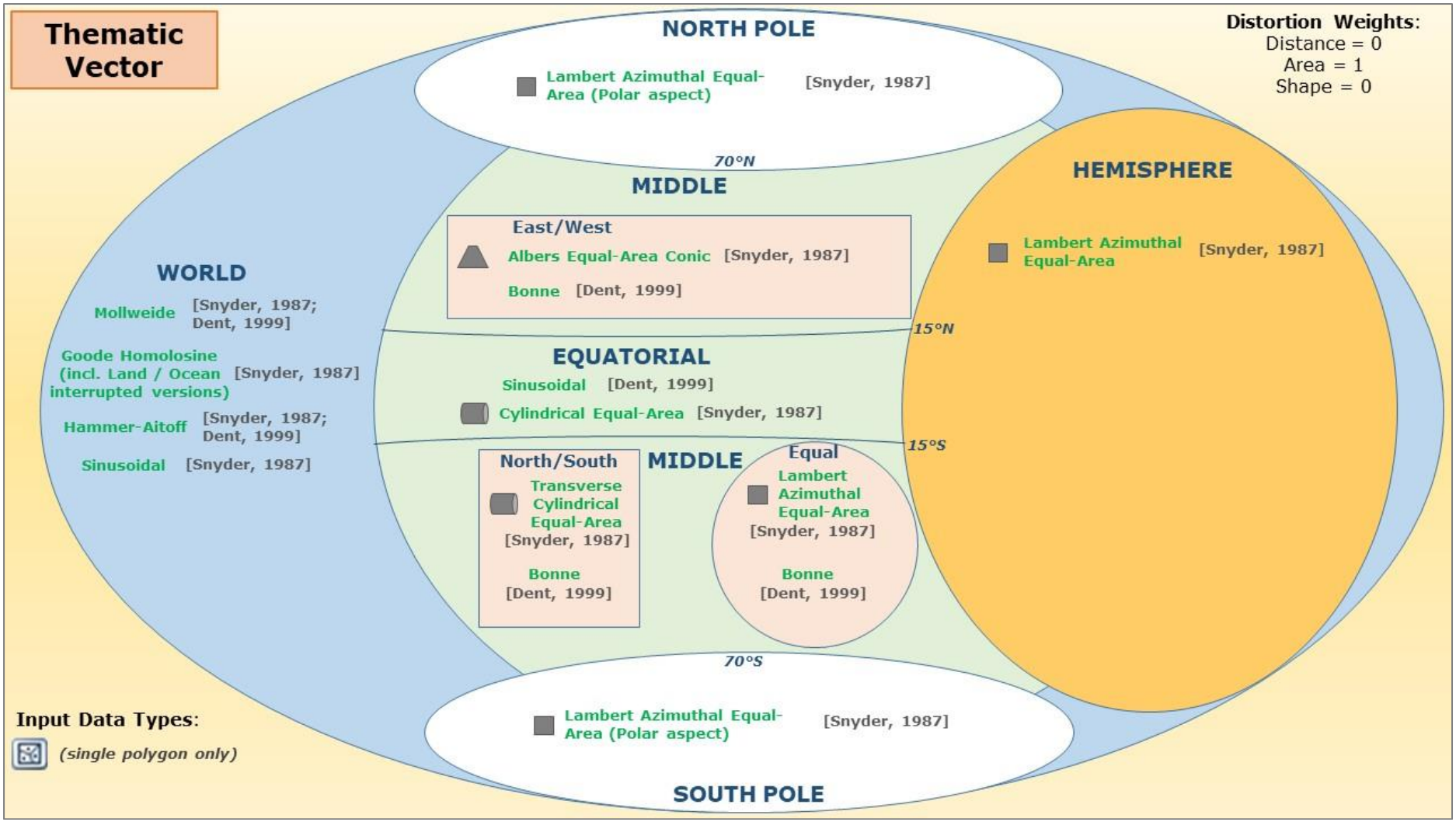
The following icons are used to highlight the projection's graphical construction, omitted if the projection is not of the perspective type:

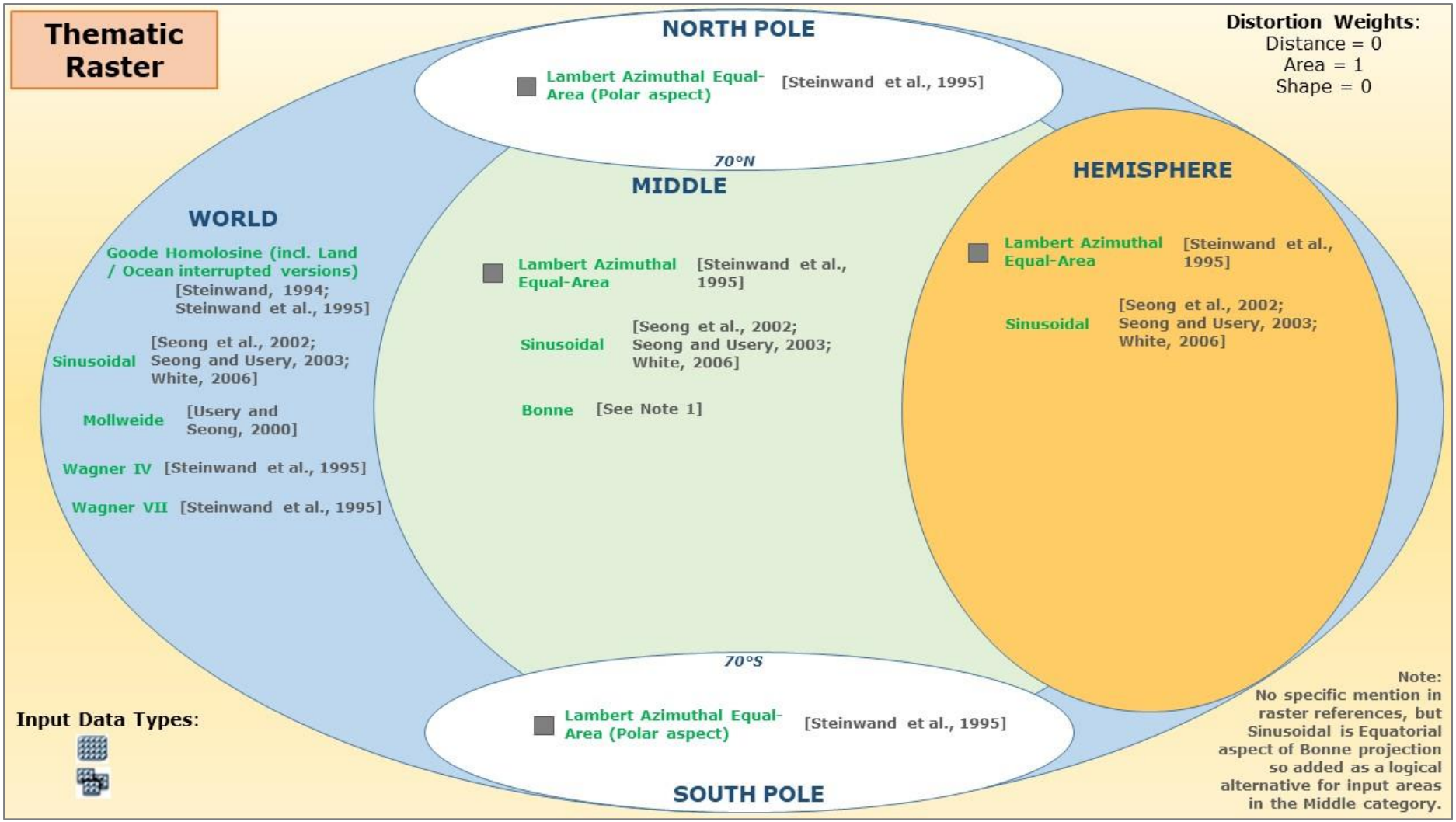
The projection name text is coloured depending on the appropriate distortion property:

Conformal
Equal-Area
Equidistant
Compromise

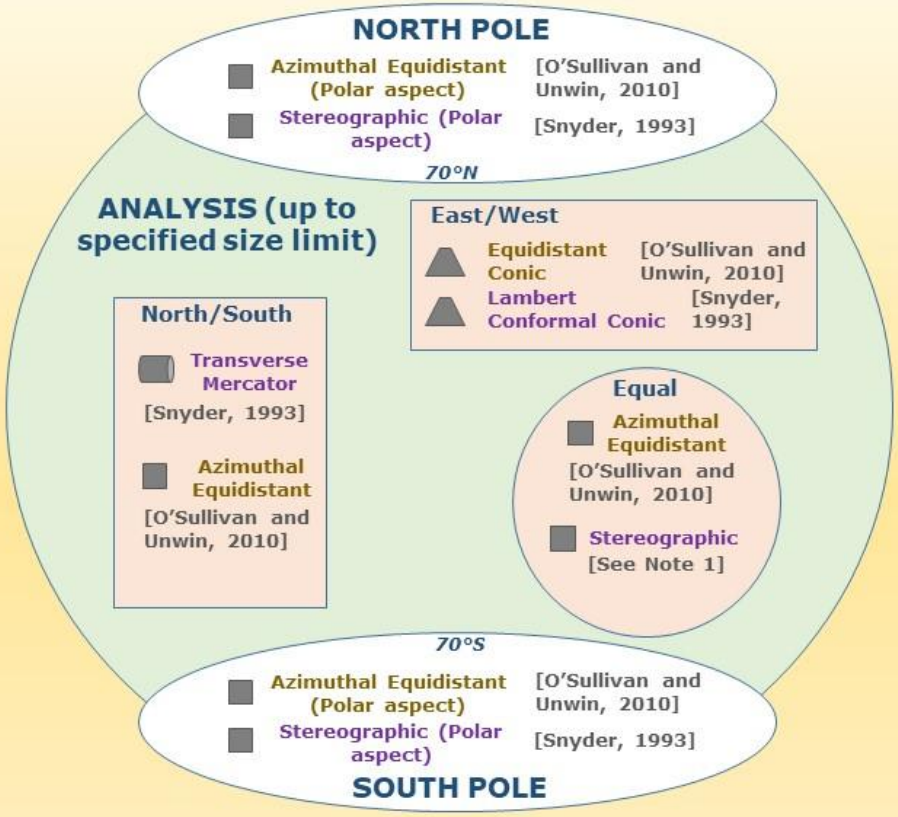
In the upper right-hand corner the distortion weights that are applied for this purpose are listed.


General Reference
Distortion Weights:
Distance = 0
Area = 1
Shape = 1
NORTH POLE
Stereographic (Polar aspect) [Snyder, 1987; The Times, 2014]
Lambert Azimuthal Equal-Area (Polar aspect) [Snyder, 1987]
70°N
MIDDLE
East/West
Equidistant Conic [Maling, 1992; The Times, 2014]
Lambert Conformal Conic [Snyder, 1987; The Times, 2014]
HEMISPHERE
Orthographic [Snyder, 1987; The Times, 2014]
Lambert Azimuthal Equal-Area [Snyder, 1987; The Times, 2014]
Vertical Near-Side Perspective [Slocum et al., 2010]
15°N
WORLD
Winkel Tripel [Canters, 2002; The Times, 2014]
Robinson [Robinson, 1974; Snyder, 1987]
Natural Earth [Jenny et al., 2008]
EQUATORIAL
Mercator [Snyder, 1987 ; The Times, 2014]
Sinusoidal [Dent, 1999]
15°S
MIDDLE
North/South
Transverse Mercator [Snyder, 1987]
Bonne [Dent, 1999]
Equal
Lambert Azimuthal Equal-Area [Snyder, 1987; The Times, 2014]
Azimuthal Equidistant [Maling, 1992]
70°S
Stereographic (Polar aspect) [Snyder, 1987; The Times, 2014]
Lambert Azimuthal Equal-Area (Polar aspect) [Snyder, 1987]
SOUTH POLE
Input Data Types:
(single polygon only)


Thematic Vector
Distortion Weights:
Distance = 0
Area = 1
Shape = 0
NORTH POLE
Lambert Azimuthal Equal-Area (Polar aspect) [Snyder, 1987]
70°N
MIDDLE
East/West
Albers Equal-Area Conic [Snyder, 1987]
Bonne [Dent, 1999]
WORLD
Mollweide [Snyder, 1987; Dent, 1999]
Goode Homolosine (incl. Land / Ocean interrupted versions) [Snyder, 1987]
Hammer-Aitoff [Snyder, 1987; Dent, 1999]
Sinusoidal [Snyder, 1987]
HEMISPHERE
Lambert Azimuthal Equal-Area [Snyder, 1987]
15°N
EQUATORIAL
Sinusoidal [Dent, 1999]
Cylindrical Equal-Area [Snyder, 1987]
15°S
North/South
Transverse Cylindrical Equal-Area [Snyder, 1987]
Bonne [Dent, 1999]
MIDDLE
Equal
Lambert Azimuthal Equal-Area [Snyder, 1987]
Bonne [Dent, 1999]
70°S
Input Data Types:
(single polygon only)
Lambert Azimuthal Equal-Area (Polar aspect) [Snyder, 1987]
SOUTH POLE


Thematic Raster
NORTH POLE
Lambert Azimuthal Equal-Area (Polar aspect) [Steinwand et al., 1995]
70°N
MIDDLE
WORLD
Goode Homolosine (incl. Land / Ocean interrupted versions) [Steinwand, 1994; Steinwand et al., 1995]
Sinusoidal [Seong et al., 2002; Seong and Usery, 2003; White, 2006]
Mollweide [Usery and Seong, 2000]
Wagner IV [Steinwand et al., 1995]
Wagner VII [Steinwand et al., 1995]
Lambert Azimuthal Equal-Area [Steinwand et al., 1995]
Sinusoidal [Seong et al., 2002; Seong and Usery, 2003; White, 2006]
Bonne [See Note 1]
HEMISPHERE
Lambert Azimuthal Equal-Area [Steinwand et al., 1995]
Sinusoidal [Seong et al., 2002; Seong and Usery, 2003; White, 2006]
Distortion Weights:
Distance = 0
Area = 1
Shape = 0
70°S
Lambert Azimuthal Equal-Area (Polar aspect) [Steinwand et al., 1995]
SOUTH POLE
Input Data Types:
Note:
No specific mention in raster references, but Sinusoidal is Equatorial aspect of Bonne projection so added as a logical alternative for input areas in the Middle category.

Geospatial Analysis - Distance



Distortion Weights:
Distance = 1
Area = 0
Shape = 0

Input Data Types:

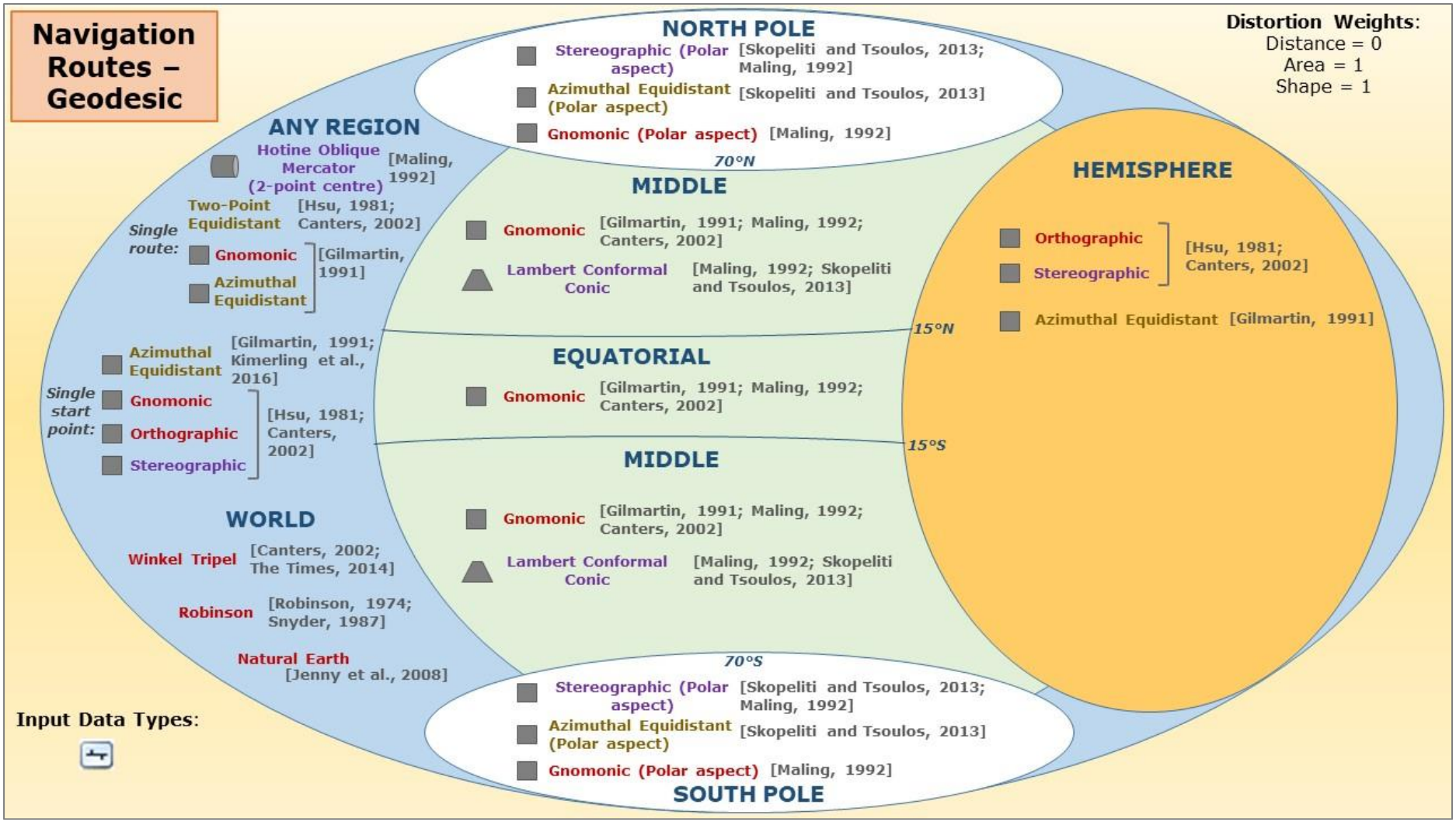
Note:
Stereographic is a conformal azimuthal projection already used for the Polar regions, so added as a logical alternative for input areas with equal extent in all directions.

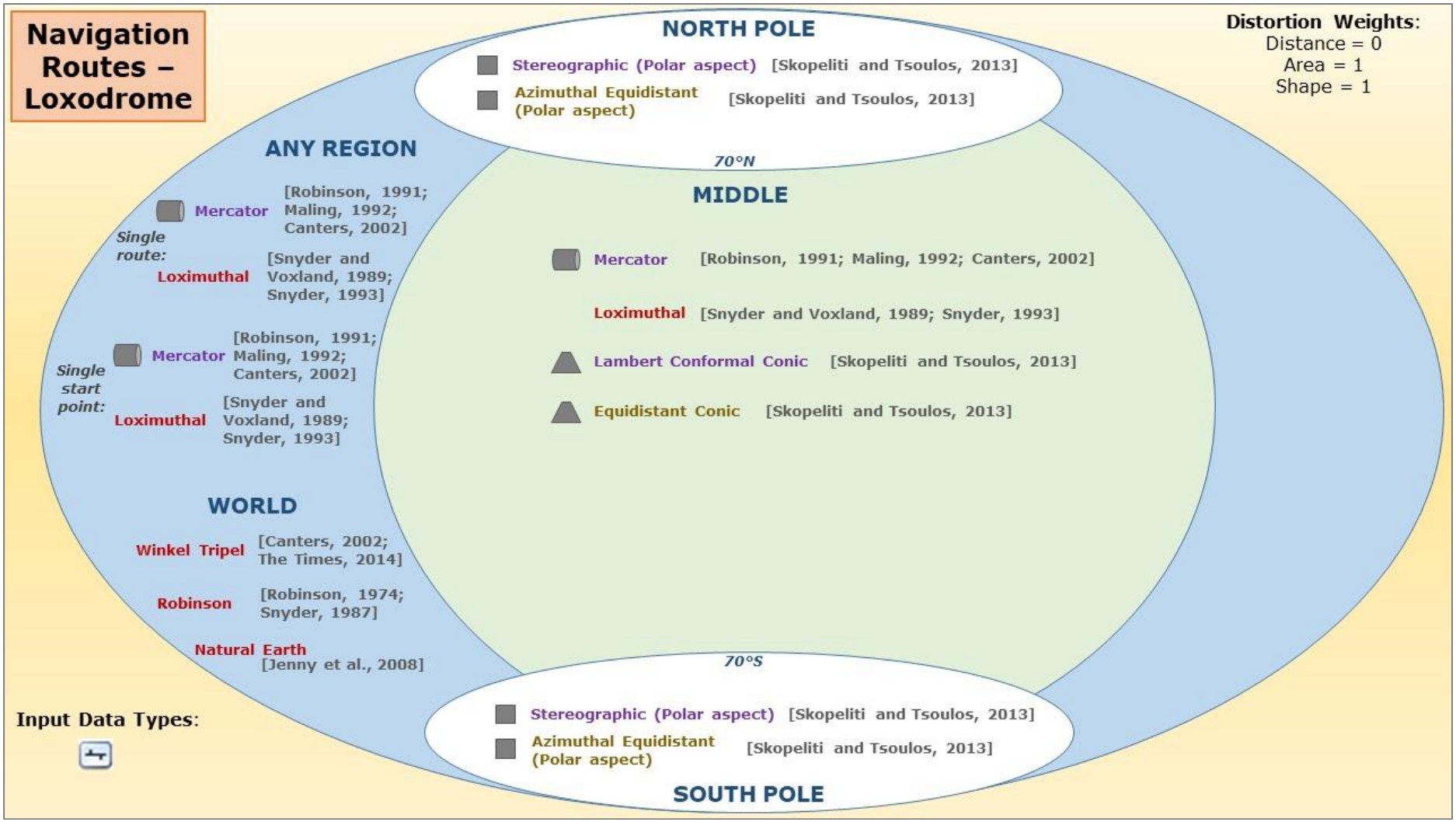
Geospatial Analysis - Area

Distortion Weights:
Distance = 0
Area = 1
Shape = 0

Uses Thematic Vector or Thematic Raster diagram depending on input data type

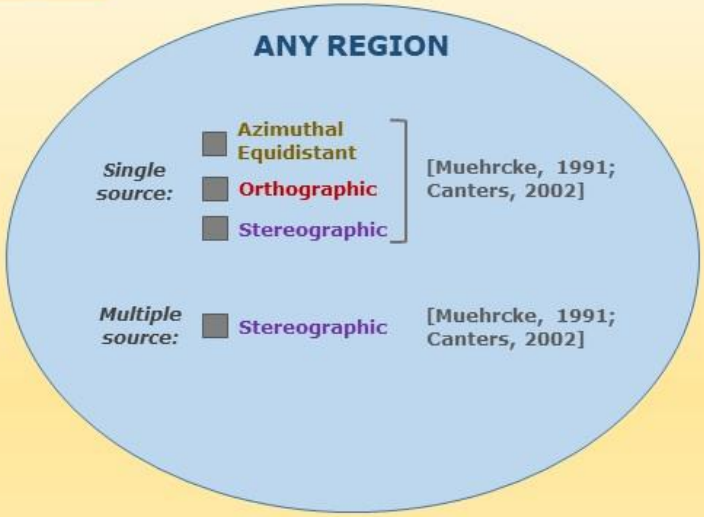
Input Data Types:


Navigation Routes – Geodesic
Distortion Weights:
Distance = 0
Area = 1
Shape = 1
NORTH POLE
Stereographic (Polar aspect) [Skopeliti and Tsoulos, 2013; Maling, 1992]
Azimuthal Equidistant (Polar aspect) [Skopeliti and Tsoulos, 2013]
Gnomonic (Polar aspect) [Maling, 1992]
70°N
ANY REGION
Hotine Oblique Mercator (2-point centre) [Maling, 1992]
Two-Point Equidistant [Hsu, 1981; Canters, 2002]
Single route:
Gnomonic [Gilmartin, 1991]
Azimuthal Equidistant
MIDDLE
Gnomonic [Gilmartin, 1991; Maling, 1992; Canters, 2002]
Lambert Conformal Conic [Maling, 1992; Skopeliti and Tsoulos, 2013]
HEMISPHERE
Orthographic
Stereographic
[Hsu, 1981; Canters, 2002]
Azimuthal Equidistant [Gilmartin, 1991]
15°N
EQUATORIAL
Gnomonic [Gilmartin, 1991; Maling, 1992; Canters, 2002]
Azimuthal Equidistant [Gilmartin, 1991; Kimerling et al., 2016]
Single start point:
Gnomonic
Orthographic
Stereographic
[Hsu, 1981; Canters, 2002]
15°S
MIDDLE
Gnomonic [Gilmartin, 1991; Maling, 1992; Canters, 2002]
Lambert Conformal Conic [Maling, 1992; Skopeliti and Tsoulos, 2013]
WORLD
Winkel Tripel [Canters, 2002; The Times, 2014]
Robinson [Robinson, 1974; Snyder, 1987]
Natural Earth [Jenny et al., 2008]
70°S
Stereographic (Polar aspect) [Skopeliti and Tsoulos, 2013; Maling, 1992]
Azimuthal Equidistant (Polar aspect) [Skopeliti and Tsoulos, 2013]
Gnomonic (Polar aspect) [Maling, 1992]
SOUTH POLE
Input Data Types:

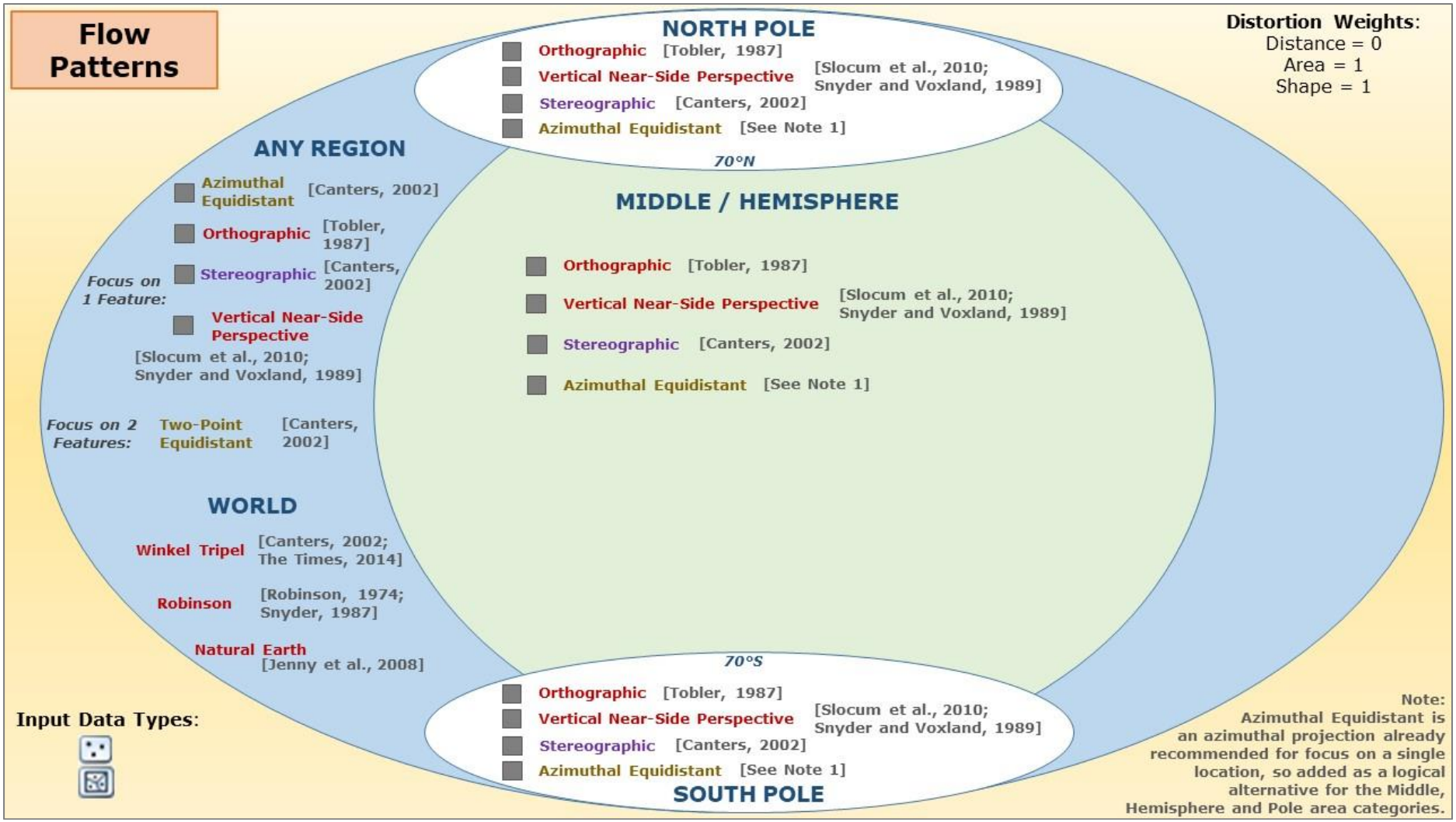

Navigation Routes – Loxodrome
Distortion Weights:
Distance = 0
Area = 1
Shape = 1
NORTH POLE
Stereographic (Polar aspect) [Skopeliti and Tsoulos, 2013]
Azimuthal Equidistant (Polar aspect) [Skopeliti and Tsoulos, 2013]
70°N
ANY REGION
Single route:
Mercator [Robinson, 1991; Maling, 1992; Canters, 2002]
Loximuthal [Snyder and Voxland, 1989; Snyder, 1993]
Single start point:
Mercator [Robinson, 1991; Maling, 1992; Canters, 2002]
Loximuthal [Snyder and Voxland, 1989; Snyder, 1993]
WORLD
Winkel Tripel [Canters, 2002; The Times, 2014]
Robinson [Robinson, 1974; Snyder, 1987]
Natural Earth [Jenny et al., 2008]
MIDDLE
Mercator [Robinson, 1991; Maling, 1992; Canters, 2002]
Loximuthal [Snyder and Voxland, 1989; Snyder, 1993]
Lambert Conformal Conic [Skopeliti and Tsoulos, 2013]
Equidistant Conic [Skopeliti and Tsoulos, 2013]
70°S
Stereographic (Polar aspect) [Skopeliti and Tsoulos, 2013]
Azimuthal Equidistant (Polar aspect) [Skopeliti and Tsoulos, 2013]
SOUTH POLE
Input Data Types:

Ranges of Activity

Distortion Weights:
Distance = 1
Area = 0
Shape = 0



Input Data Types:


Flow Patterns
NORTH POLE
Orthographic [Tobler, 1987]
Vertical Near-Side Perspective
Stereographic [Canters, 2002]
Azimuthal Equidistant [See Note 1]
[Slocum et al., 2010; Snyder and Voxland, 1989]
70°N
ANY REGION
Azimuthal Equidistant [Canters, 2002]
Orthographic [Tobler, 1987]
Stereographic [Canters, 2002]
Focus on 1 Feature:
Vertical Near-Side Perspective
[Slocum et al., 2010; Snyder and Voxland, 1989]
Focus on 2 Features:
Two-Point Equidistant [Canters, 2002]
MIDDLE / HEMISPHERE
Orthographic [Tobler, 1987]
Vertical Near-Side Perspective
[Slocum et al., 2010; Snyder and Voxland, 1989]
Stereographic [Canters, 2002]
Azimuthal Equidistant [See Note 1]
WORLD
Winkel Tripel [Canters, 2002; The Times, 2014]
Robinson [Robinson, 1974; Snyder, 1987]
Natural Earth [Jenny et al., 2008]
70°S
Orthographic [Tobler, 1987]
Vertical Near-Side Perspective
Stereographic [Canters, 2002]
Azimuthal Equidistant [See Note 1]
[Slocum et al., 2010; Snyder and Voxland, 1989]
SOUTH POLE
Distortion Weights:
Distance = 0
Area = 1
Shape = 1
Input Data Types:
Note:
Azimuthal Equidistant is an azimuthal projection already recommended for focus on a single location, so added as a logical alternative for the Middle, Hemisphere and Pole area categories.

World Index

Distortion Weights:
Distance = 0
Area = 1
Shape = 1

WORLD

- **Miller Cylindrical** [CIA, no date]
- **Plate Carrée** [Snyder, 1993; Snyder and Voxland, 1989]
- **Equidistant Cylindrical** [Snyder, 1993; Snyder and Voxland, 1989]

Input Data Types: