SPCS2022 distortion map and zone design datasets

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The FTP folder at ftp://www.ngs.noaa.gov/pub/SPCS/MapData/ contains distortion map datasets for zone designs by state, along with datasets used for design and analysis of zones in the "ZoneDesignData" folder.

The map datasets are in zipped folders organized by state for the most current SPCS2022 designs, along with existing systems for comparison (e.g., SPCS 83, UTM 83, state systems). Datasets can be added by request at NGS.SPCS@noaa.gov.

Each zipped state folder contains the datasets listed below. Background data used for creating the map images are not included (e.g., topography, cities, county boundaries, etc.).

Zone Distortion Datasets by State

- ***"ArcMapDocs_v10_7" folder*.** Contains version 10.7.1 ArcMap documents (*.mxd files) with datasets corresponding to each map image. If an earlier ArcMap version is needed, email NGS.SPCS@noaa.gov. Some older datasets may have an "ArcMapDocs_v10_6" folder containing version 10.6.1 documents.
- ***"DataCommon" folder*.** Contains zone and state boundary polygons, distortion raster for the map legend, and other data common to more than one ArcMap document. It also contains projection (*.prj) files defining the coordinate systems used for consistent display in the ArcMap documents.
- ***Individual design data folders*.** The folder names begin with the state abbreviation, similar to the distortion map image files at ftp://www.ngs.noaa.gov/pub/SPCS/DistortionMaps/. Each folder contains the following datasets:
  - Distortion raster in parts per million (ppm) in *.img format, extracted by mask to the zone boundary polygon. An additional raster may be included that is buffered to show distortion outside the zone boundary. Buffered rasters are provided upon request and are appended with "_bufferXkm", where "X" is the buffered distance in kilometers.
  - Distortion contours created from the zone raster, in Esri shapefile format.
  - Projection axis (central meridian, central parallel, or skew axis), plus local origin point for Oblique Mercator projection, in Esri shapefile format.

Datasets Used for Designing Zones

The "ZoneDesignData" folder includes zipped folders that contain some of the data used by NGS for designing zones, along with ArcMap documents and map image files of some datasets. The contents are listed below (note that some of the zipped folders are very large). All folders should be extracted directly into the same folder structure as used on the FTP site to preserve relative data paths.

- ***ArcMapDocs_v10_7.zip*** *(1 MB)*. Version 10.7.1 ArcMap documents (*.mxd files) of the population raster datasets (CONUS_Census2010_shared.mxd) and datasets used for design (Design_CONUS_SPCS2022_ITRF2014_zones_EqArea_shared.mxd).
- ***DataCommon.zip*** *(308 MB).* Datasets common to more than one ArcMap document. Includes detailed 2018 state and county polygon features obtained from the U.S. Census Bureau (features ending in "coast" were clipped to the ocean and Great Lakes coastlines). Also includes more generalized U.S. and world boundaries and lake polygons.
- ***ElpsdHtRasterCONUS.zip*** *(898 MB).* Raster of topographic ellipsoid heights for all of CONUS at 9 arcsecond spatial resolution (approximately 270 meters or 900 feet). Ellipsoid heights are with respect to ITRF2014 at epoch 2020.00 (the best available estimate of NATRF2022).
- ***ExportMaps.zip*** *(3.4 MB).* Two maps exported from "CONUS_Census2010_shared.mxd", one of the kernel density population density raster, and one of the population count raster.
- ***PopulationRasters.zip*** *(32 MB).* Equal area population rasters derived from 2010 U.S. Census 2010 block data by state, both at 1 km resolution. One is a population density raster of CONUS, created for visualization**.** The others are population count rasters, one per CONUS state, where each cell gives the number of people in 1 km^2 (cells with no population are null). The 2010 block data were obtained for each state from https://www2.census.gov/geo/tiger/TIGER2010BLKPOPHU/. Projected using a CONUS Albers equal area projection (parameters included with the data).
- ***ZoneDesignPoints.zip*** *(349 MB).* Point dataset shapefiles with ITRF2014 epoch 2010.0 ellipsoid heights. All heights were derived from 1 arcsec USGS 3DEP digital elevation models (https://www.usgs.gov/core-science-systems/ngp/3dep/data-tools), converted to NAD 83 (2011) epoch 2010.0 ellipsoid heights using GEOID18, and transformed to ITRF2014 epoch 2020.0 using Horizontal Time Dependent Positioning (HTDP) software.
  - ***Population counts.*** "PopEhtPoints_CONUS_ITRF2014_EqArea_1km.shp" (1,893,441 points). Points derived from population count raster, projected using a CONUS Albers equal area projection (parameters included with the data).
  - ***U.S. Cities and towns.*** "US_cities_all_2017_ITRF2014_eht.shp" (38,193 points). Cities and towns of the U.S. with 2010 population estimates (named locations with no population estimate have population of -999). Product of the National Atlas of the United States as "Cities and Towns of the United States, 2014", available from https://earthworks.stanford.edu/catalog/stanford-bx729wr3020 and in Esri Data and Maps (2017). Augmented with cities in exterior U.S. territories.
  - ***Ellipsoid height grids.*** Four equal area grids of points with ellipsoid heights, at spacings of 1, 2, 3, and 5 km. Files named "xCONUS_*N*km_ITRF2014_EqArea_eht_grid.shp", where "*N*" is the grid spacing in km. The number of points in the datasets are 7,824,232 (1 km); 1,956,069 (2 km); 869,380 (3 km), and 312,967 (5 km). Projected using a CONUS Albers equal area projection (parameters included with the data).

- ***ZoneDesignSpreadsheets.zip*** *(81 MB).* Spreadsheets for performing map projection computations and designing zones. ***IMPORTANT:*** These spreadsheets were developed for internal NGS use and only provided here as a courtesy for customers. Some are very complex, and NGS does not have the resources to provide support for assisting in their use. Many of the cells include equations and cross-reference cells on other worksheets. None of the cells are protected, so care should be used to avoid modifying the spreadsheets except for cells intended for input, otherwise incorrect results may be obtained. If non-input areas of a spreadsheet is altered, it can be replaced by re-downloading an original version.
  - ***Map projection spreadsheets.*** Spreadsheets for performing map projection computations. These spreadsheets are fairly simple and should be mostly self-explanatory.
    - There are four spreadsheets, two for Lambert Conformal Conic (LC) projections, and one each for Transverse Mercator (TM) and Oblique Mercator (OM) projections. The "LC-general.xlsx" spreadsheet handles the general case (1- or 2-parallel), but the 1-parallel version should be easier to use for SPCS2022. The OM spreadsheet is specifically for the "center" or "local" version of this projection, as required by SPCS2022 policy.
    - Each spreadsheet has the following four worksheets, where all input cells are yellow (computation/cross-reference cells are blue and green):
      - Parameters. Defining parameters for the projection, including selection of ellipsoid and linear units.
      - Direct-DecDeg. Direct computation (lat/lon to northing/easting). Input of points with latitude and longitude in decimal degrees, plus ellipsoid height.
      - Direct-DMS. Direct computation (lat/lon to northing/easting). Input of points with latitude and longitude in degree-minute-second format, plus ellipsoid height.
      - Inverse. Inverse computation (northing/easting to lat/lon). Input of points in northings and eastings, plus ellipsoid height.
    - Note that the zone parameters and test points use positive east longitudes. Negative west longitudes can be used, but the parameters and points must both use the same convention.
    - All the computation sheets are set for a maximum of 100 points. Simply drag-copy the rows down to handle a larger number.
    - The data in the spreadsheets corresponds to the data used in the three zone design spreadsheets (described next).
  - ***"ZoneDesign" folder.*** Three spreadsheets for designing zones in each of the three projection types used for SPCS2022: LC (1-parallel), TM, and OM ("center" or "local" version). These spreadsheets are far more complex and much larger than the map projection spreadsheets. They are provided as a courtesy because of requests from

customers, but NGS does not have the resources to provide tutorials on their use. So it will require considerable effort to learn to use them effectively for design. What follows are generalized descriptions of their data and functionality.

- The spreadsheets contain actual data and results for zone designs. The TM spreadsheet is for the Minnesota statewide zone. The OM spreadsheet is for the Florida statewide zone. Both LC spreadsheets are for the Florida West zone (panhandle).
- The spreadsheets have the following worksheets. Data for populating the worksheets are obtained from GIS datasets in the "ZoneDesignPoint.zip" archive described above. As with the map projection spreadsheets, input cells are yellow and computation/cross-reference cells are blue and green.
  - Design. Entry fields for projection and design parameters, and output fields for design statistics, along with a table for storing results for comparing design alternatives. The content shows actual design iterations for the three SPCS2022 zones stated above.
  - Grid. Input worksheet for equally spaced grid of points for the design area. The data are obtained from the "xCONUS_*N*km_ITRF2014_EqArea_eht_grid.shp" GIS dataset, were "*N*" is the grid spacing in km (1, 2, 3, and 5 km).
  - Population. Input worksheet for 1-km grid of points with population and ellipsoid heights, obtained from the "PopEhtPoints_CONUS_ITRF2014_EqArea_1km.shp" GIS dataset.
  - Cities. Input worksheet for city ellipsoid heights, obtained from the "US_cities_all_2017_ITRF2014_eht.shp" GIS dataset. Typically these are sorted by descending population, so that the largest cities appear first in the list on the "Design" worksheet.
  - Extent. Automatically populated and computes various statistics for the zone extents, as well as the grid spacing.
  - Coords. Computes projected coordinates and distortion for test points. Automatically does this for the first 10 cities from the "Cities" worksheet, but user-entered points can be added.
  - Inverse (OM spreadsheet only). Computes various coordinates on the skew axis for OM projections.
- The grid and population datasets are equal area so that number of points can be used to calculate area percentages.
- The spreadsheet is limited to 100,000 grid and population points, and 2000 city points. These limits are why a 2-km grid spacing was used for the MN and FL statewide zones, and 1-km for the FL W zone. These maximum numbers can be increased by copying the computation cells down on their respective worksheets. If the number of points exceeds the maximum, the "Design" worksheet will display a warning and will not compute results.

- GIS or other geospatial software is necessary to select point sets for populating the three data worksheets. For example, points can be "selected by location" using a group of county polygons.

NGS Design Process

Below is a generalized description of how the zone design spreadsheets are used by NGS design (note that these are for zones designed by NGS and do not necessarily apply to zones designed by stakeholders):

1. Initial approach is to minimize linear distortion range for a zone by modifying the projection axis location (and orientation for OM projections).
2. Once the projection type and axis location/orientation corresponding to a minimum range have been determined, the projection scale is modified to achieve specific performance criteria (this has essentially no effect on the range, because it is nearly independent of scale).
3. The main performance objective is to achieve a "distortion design criterion", which is selected from specific pre-defined distortion ranges of ±5, ±10, ±20, ±30, ±40, ±50, ±75, ±100, ±150, ±200, ±300, or ±400 ppm (see SPCS2022 Procedures at https://geodesy.noaa.gov/INFO/Policy/files/SPCS2022-Procedures.pdf).
4. An initial scale and distortion design criterion are selected so that at least 90% of the population, 75% of cities (by location only), and 50% of the total zone area are within the design criterion.
5. Other considerations in the design process (some consistent with traditional map projection design) include:
    a. Approximately 60-80% of the total design area should have negative distortion.
    b. The ratio of the absolute value of minimum distortion to maximum distortion for the entire zone should be > ~0.5 (with a preference for > ~0.9).
    c. Positive distortion on either side of the projection axis should be relatively balanced. Design objectives are that the ratio of positive distortion on either side of the axis should be > ~0.8, and the ratio of positive distortion area on opposite sides of the zone should be > ~0.5.

Note that it is not always possible to satisfy all of the above criteria when designing zones. Judgment is required in selecting a final set of parameters. However, for zones designed by NGS, SPCS2022 policy and procedures require that the distortion criterion assigned to a zone must always satisfy the aforementioned minimum 90% of population, 75% of cities, and 50% of zone area.

Additional information

Feature symbology. The "_Symbology.zip" file at the root of the FTP folder the contains Esri layer files (*.lyr) for symbolizing features and distortion rasters in the same manner as the map image files. The same symbology is used for the datasets in the included distortion map ArcMap documents

Distortion accuracy. For SPCS2022 zone designs, distortion values are based on ITRF2014 epoch 2020.0 ellipsoid heights, which are identical to 2022 Terrestrial Reference Frame (TRF) ellipsoid heights for all four TRFs at that epoch. Distortion rasters for existing NAD 83 zones are usually based on NAD 83 epoch 2010.0 ellipsoid heights, but in some cases they are based on ITRF2014 epoch 2020.0 ellipsoid height. However, the maximum difference in ellipsoid height between these frames in the NSRS is less than ±2 m, which is smaller than the accuracy of the digital elevation models used to compute distortion. The resulting maximum difference in distortion is within ±0.3 ppm between NAD 83 and ITRF2014 (i.e., the 2022 TRFs).

Folder and file naming conventions. The names used for the data folders, rasters, contour shapefiles, and ArcMap documents correspond to the names used for the map image files. For SPCS2022 designs of individual zones, the names include abbreviations for the state, zone (if applicable), projection type, projection axis scale, and parameters that affect distortion. For files created by combining rasters from two or more zones, a descriptive name that includes "SPCS2022" is used rather than projection parameters. The names include the following items:

- *Projection type.* "lc" or "lcc" for Lambert Conformal Conic, "tm" for Transverse Mercator, "om" for Oblique Mercator.
- *Projection axis scale.* Digits with implied decimal point after first digit (1 to 7 digits)
- *Projection parameters.* Packed degrees-minutes for LCC central parallel (4 digits, positive north) or TM central meridian (5 digits, positive east). For OM, local origin latitude and longitude given in same format, along with skew axis azimuth (degrees), preceded by "p" for positive and "n" for negative. Any systems where origin is not defined to nearest arc-minute is given as packed degrees-minutes-seconds (6 digits for latitude, 7 digits for longitude).
- *Examples of distortion raster file names.* The "x" at the beginning of the name indicates that the raster was extracted by mask using the zone boundary, and "ppm*N*s" means the raster is in parts per million at a resolution of *N* arcseconds (usually 9 or 15):
  - "xVA_N_lcc1_3836_ppm15s.img" for Virginia North Lambert Conformal Conic zone with scale of exactly 1 and central parallel of 38°36'N.
  - "xNM_C_tm100022_25354_ppm15s.img" for New Mexico Central Transverse Mercator zone with scale of 1.00022 and central meridian of 253°54'E.
  - "xMI_om09999_4500_27400_n26_ppm15s.img" for Michigan statewide Oblique Mercator zone with scale of exactly 0.9999, origin latitude and longitude of 45°0'N and 274°00'E, and skew axis azimuth of -26°.

- "xID_all_9zones_selected_ppm09s.img" for all nine SPCS2022 Idaho zones that were selected for the final design, combined into a single distortion raster.

For existing coordinate systems, the names indicate the system type and zone (e.g., "GA_E_SPCS83" for Georgia East SPCS 83 zone, "FL_UTM_17N" for UTM 17 North used as a statewide zone for Florida).