

Report No. UT-18.11

**SIMPLIFIED STANDARD
PENETRATION TEST
PERFORMANCE-BASED
ASSESSMENT OF LIQUEFACTION
AND EFFECTS:
UPDATED LIQUEFACTION
PARAMETER MAPPING –
ADDENDUM REPORT**

Prepared For:

Utah Department of Transportation
Research and Innovation Division

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16. Abstract The purpose of this addendum report is to document the process used to develop updated standard penetration test (SPT)-compatible liquefaction parameter maps for the states of Alaska, Connecticut, Idaho, Montana, Oregon, South Carolina, and Utah. The seismic source model developed by the US Geological Survey (USGS) and developed in 2014 was used to develop updated liquefaction parameter maps for the states of Connecticut, Idaho, Montana, Oregon, South Carolina, and Utah. The most recent USGS seismic source models available for the state of Alaska were from 2008 for mapping the hazards of liquefaction triggering, post-liquefaction settlement, and Newmark seismic slope displacement. The USGS 2002 seismic source model was the most recent model available for mapping the hazard of lateral spread displacement for Alaska. All of the completed reference parameter maps have been added to a publicly-available and interactive database. Hard copies of the developed updated reference parameter maps are also included in the appendix of this addendum report.					
17. Key Words Lateral Spread Displacements, Liquefaction Triggering, Post-Liquefaction Settlements, Seismic Slope Displacements, Performance-based Engineering Reference Maps, Simplified Models, Seismic Hazards			18. Distribution Statement Not restricted. Available through: UDOT Research & Innov. Division 4501 South 2700 West P.O. Box 148410 Salt Lake City, UT 84114-8410 www.udot.utah.gov/go/research		23. Registrant's Seal NA
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1. MAP DEVELOPMENT

1.1. Overview

This addendum report summarizes the process used to develop updated liquefaction reference parameter maps for the use with the standard penetration test (SPT). The development of liquefaction reference parameter maps is described in detail in the Final Report No. UT-16.16 for this project, dated May 2016 and published by the Utah Department of Transportation. The reader is referred to that report for detailed information on the step-by-step process applied in this research and for definitions of the terms used in this addendum. This addendum report contains an abbreviated description of the process used to create the updated reference parameter maps for the research.

In general, the development of a liquefaction parameter map requires the use of several specialized software programs. The Graphical Information System (GIS) software *ArcMap* is used to create the grid spacing and parameter maps. The software *PBLiquefy*, developed at BYU by Franke et al. (2014), is used to perform the probabilistic liquefaction initiation analysis. The program *EZ-FRISK*, created by Risk Engineering (2013), is used to perform the probabilistic lateral spread displacement analysis.

1.2. Creating the Grid Points

The first step is to divide the state into PGA hazard zones based on the USGS 2008 PGA hazard map (Figure 1). Each hazard zone is assigned a grid spacing based on the different PGA ranges. Then a grid of points, with latitudes and longitudes, can be generated for each hazard zone at the specified grid spacing in *ArcMap*. All the zones are then combined into one general grid for the state.

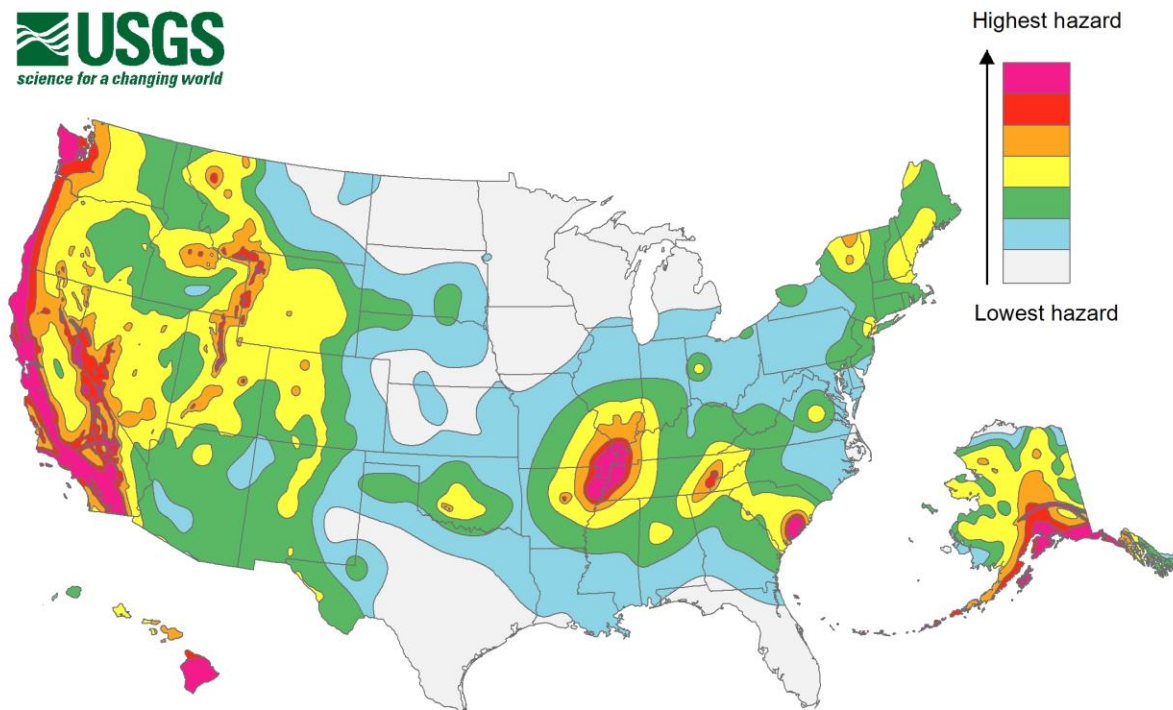


Figure 1. USGS 2008 PGA hazard map

1.3. Analysis of the Grid Points

Once the grid points are created for the state, each of the points is evaluated for liquefaction and lateral spread hazard using the reference soil profile. Each point is analyzed for the 475, 1033, and 2475 year return periods. The results are then imported back into ArcMap to begin the process of making the parameter maps.

1.3.1. Analysis of the Liquefaction Initiation, Post-Liquefaction Settlement, and Newmark Seismic Slope Displacement

The USGS 2014 deaggregation data set is used for Oregon, Montana, Utah, South Carolina, Idaho, and Connecticut to analyze liquefaction initiation, post-liquefaction free-field settlement, and Newmark seismic slope displacement; while the USGS 2008 deaggregation data set is used for Alaska. This process is performed in *PBLiquefy*.

1.3.2. Analysis of the Lateral Spread Displacement

Analyzing the grid points in *EZ-FRISK* requires that a specified seismic source model be used. For the continental states, the USGS 2014 seismic source model is used to compute the reference lateral spread displacements. However, the USGS 2014 seismic source model is not

yet available for Alaska in *EZ-FRISK*. For Alaska, the USGS 2002 seismic source model is the most current that is available at the time of mapping. Therefore, the USGS 2002 seismic source model was used for Alaska.

1.4. Creation of the Maps

Once the grid point analysis is completed, the points are imported into *ArcMap* to begin the creation of the parameter maps. The Kriging Tool in *ArcMap* converts each point into a surface raster by interpolating between each point. The result output is a raster with a value at each point. Using the output from the kriging tool, the Contour Tool is used to create contours at the desired spacing. The contour spacing will vary depending on how detailed the map needs to be. Because the goal of the parameter maps is to be user-friendly, it is important that the spacing will allow the contours to be clearly readable, while still maintaining sufficient detail and accuracy. Because data varies between each map, the contour spacings will also vary. The user can create different contour spacings based on their needs. A kriging raster and contour example is shown in Figure 2a and Figure 2b, respectively.

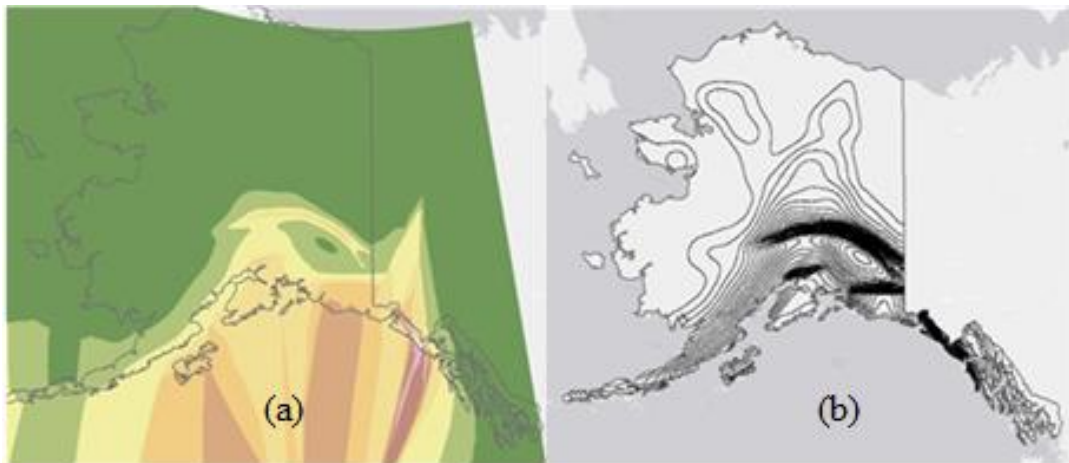


Figure 2. Examples of a (a) Kriging raster, and (b) developed contours for Alaska ($T_r = 475$ years)

Once the appropriate contour spacing is created, the contour is clearly labeled and clipped. Once completed, a basemap and reference features are added to provide more topographic details. Within the Layout View, additional formatting is performed to finalize the parameter map. An example of a completed liquefaction triggering parameter map of N_{req} , based on the Cetin et al. (2004) triggering model, is presented in Figure 3.

Each participating state has a contour map developed for each of the reference parameters at each return period. The $CSR(\%)$ parameter maps are the reference value of $CSR\%$ as

calculated using the Boulanger and Idriss (2014) model. CSR was changed from a decimal to a percentage so the maps could be easily read. The reference values for N_{req} were calculated using the Cetin et al. (2004) model and is given in units of SPT blowcounts (N). The strain parameter maps show the percent strain of using the Cetin et al. (2004) model and Ishihara and Yoshimine (1992) model. These values were also converted from a decimal to a percentage. The seismic slope displacement parameter maps are created using the Rathje and Saygili (2009) and Bray and Travasarou (2007) models. These parameter maps are in units of centimeters.

For the purpose of this addendum report, the lateral spread displacement maps for the state of Alaska were not updated because the most recent seismic source model available in *EZ-FRISK* for the state of Alaska did not change from 2016 to 2018. All other reference parameter maps were updated and are presented for each participating state in the appendix of this report.

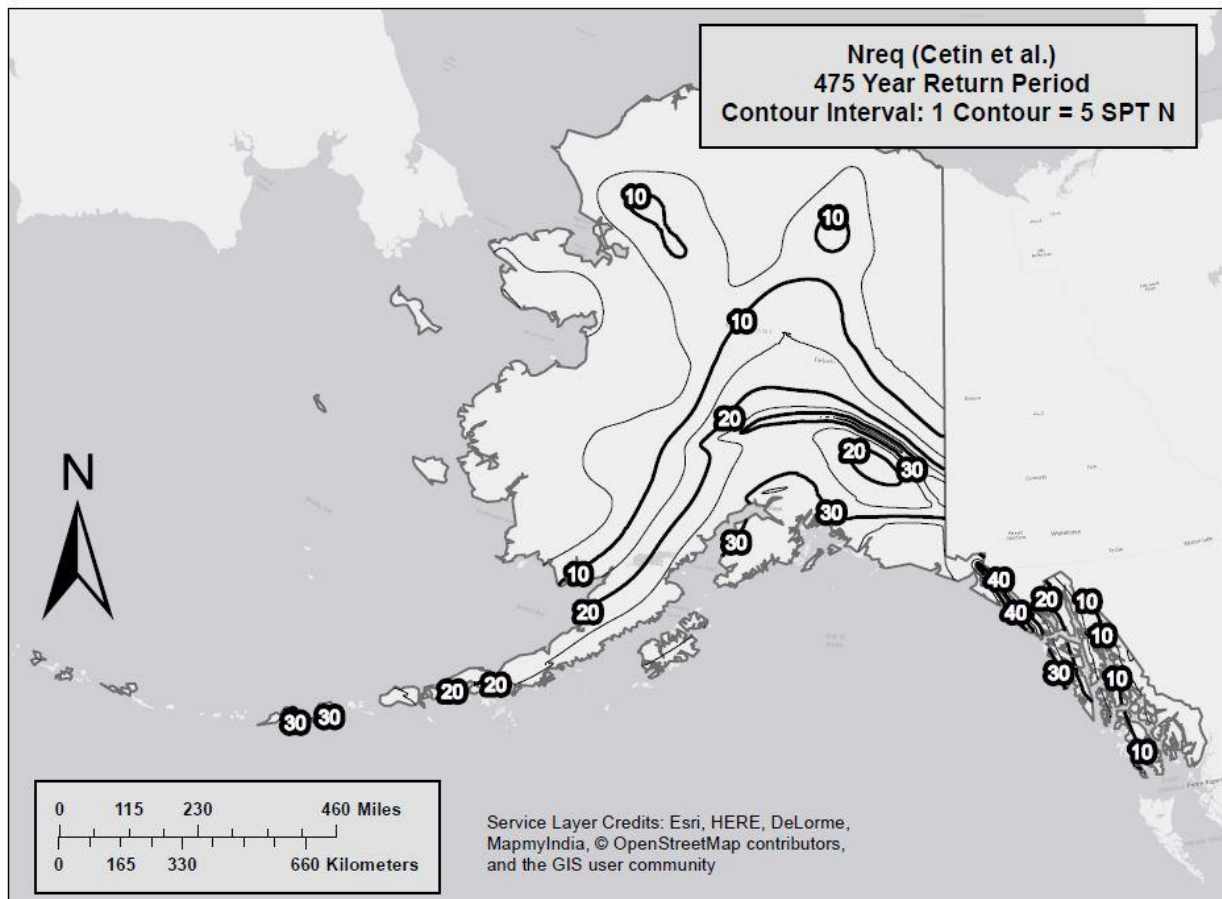


Figure 3. An example of a completed liquefaction parameter map for liquefaction triggering ($T_r = 475$ years). The map is for the reference parameter N_{req} , applicable to the Cetin et al. (2004) triggering model

2.DATABASE DEVELOPMENT

2.1. The Liquefaction Hazard App

The online Liquefaction Hazard App allows users to retrieve and view liquefaction reference parameter data according to the location and inputs specified by the user. Point values of the created maps can be retrieved from the database through the website:

<https://tethys.byu.edu/apps/lfhazard/map/>

Upon entering the website, a map of the United States will be shown with Utah highlighted as seen in Figure 4.

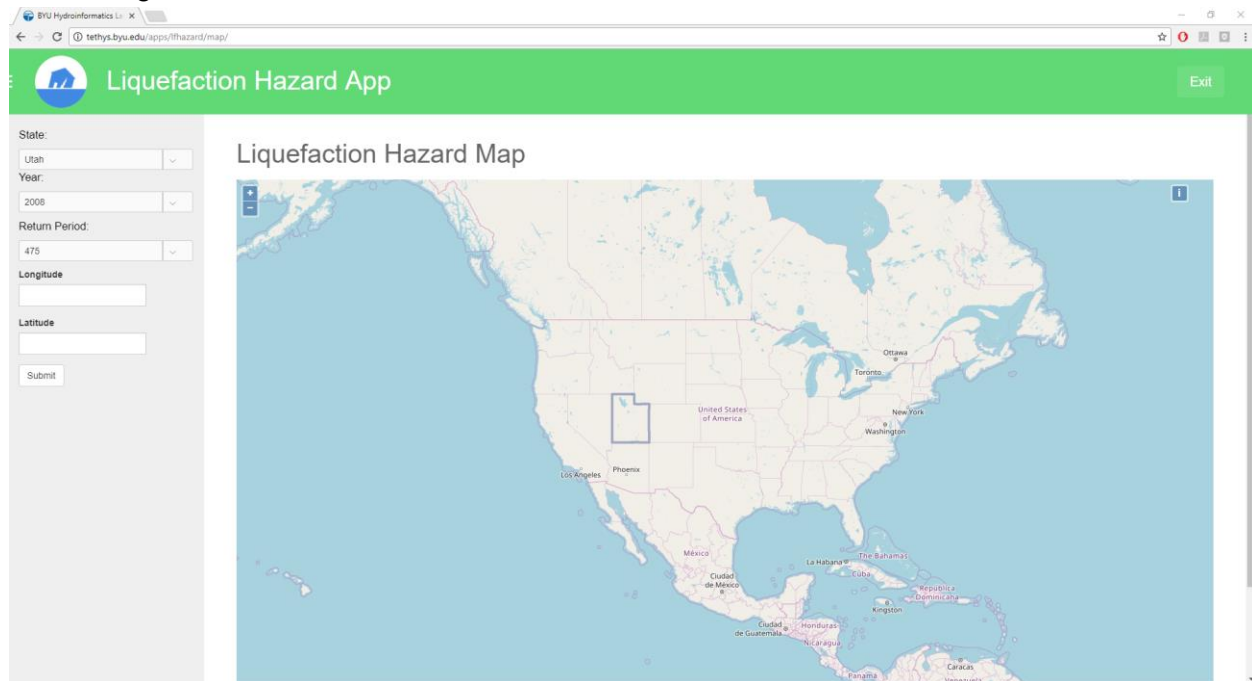


Figure 4. Liquefaction hazard app map screen

The parameters: State, Year, and Return Period can be changed on the left navigation bar as shown in Figure 5. As of 2018, there are seven states to choose from: Utah, Alaska, Idaho, Montana, South Carolina, Connecticut and Oregon. Depending on which state is chosen, the available deaggregation models for that state will appear (i.e., 2014 and 2008). The return period can also be changed to 475, 1033, or 2475 years. The data can be retrieved by either clicking on the map at the desired location or by entering a longitude and latitude coordinate within the highlighted state.

State:
Utah

Year:
2008

Return Period:
475

Longitude

Latitude

Submit

Figure 5. Navigational bar where users may change input parameters

When the user clicks anywhere within the highlighted state, a popup displays the liquefaction parameters in the Navigation Bar as shown in Figure 6. Clicking anywhere outside of the highlighted state on the map will display a warning that the selected location must be within highlighted boundaries. The data from the popup can be stored in a table (Figure 7) beneath the map by clicking on the “Add” button in the popup display shown in Figure 6. The table is organized according to the parameters mentioned above. Data from the table can be removed by clicking the “Delete Row” button, located on the right side of each data set. This table can also be downloaded as a .csv file for future use by clicking on the “Download Data” button.

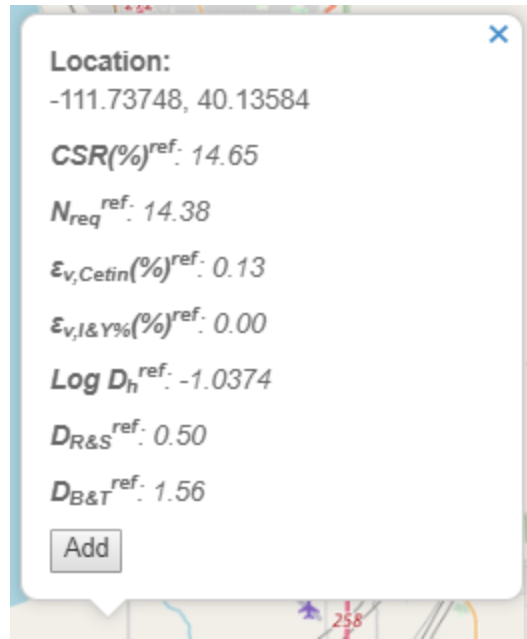


Figure 6. Map popup displaying liquefaction data retrieved and interpolated according to parameters set

Year	Return Period	Longitude	Latitude	$CSR(\%)^{ref}$	N_{req}^{ref}	$\epsilon_{v,Cetin}(\%)^{ref}$	$\epsilon_{v,I\&Y}(\%)^{ref}$	$Log D_h^{ref}$	$D_{R\&S}^{ref}$	$D_{B\&T}^{ref}$	Download Data
2014	1033	-111.72993	40.15893	36.42	27.50	1.62	1.71	0.1299	21.02	14.66	Delete Row
2008	2475	-111.92356	40.2245	32.04	25.55	1.68	1.86	-0.1718	12.52	10.18	Delete Row
2014	2475	-111.92356	40.2245	36.67	27.65	1.95	2.21	0.0318	23.23	15.72	Delete Row
2014	1033	-111.92356	40.2245	24.75	22.00	1.12	1.06	-0.2772	5.50	5.90	Delete Row
2008	475	-111.81782	40.08333	14.47	14.20	0.13	0.00	-1.0701	0.50	1.55	Delete Row
2008	475	-111.73748	40.13584	14.65	14.38	0.13	0.00	-1.0374	0.50	1.56	Delete Row

Figure 7. Table containing data collected from map

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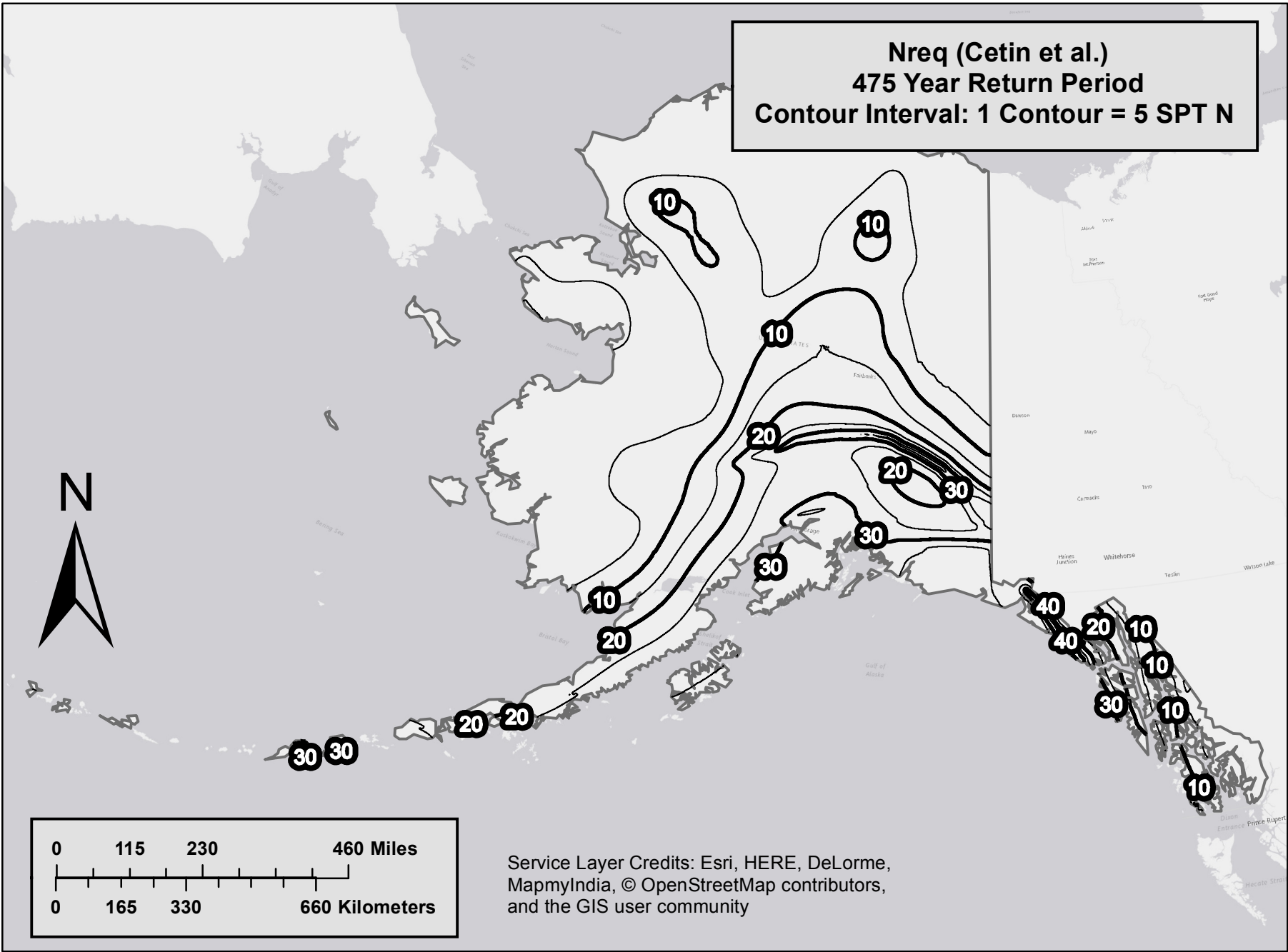
Rathje, E. M., & Saygili, G. (2009). Probabilistic Assessment of Earthquake-Induced Sliding Displacements of Natural Slopes. *Bulletin of the New Zealand Society of Earthquake Engineering*, 42(1), 18-27.

Risk Engineering. (2013). EZ-FRISK, ver. 7.60. Boulder, Colorado.

APPENDIX: UPDATED LIQUEFACTION REFERENCE PARAMETER MAPS

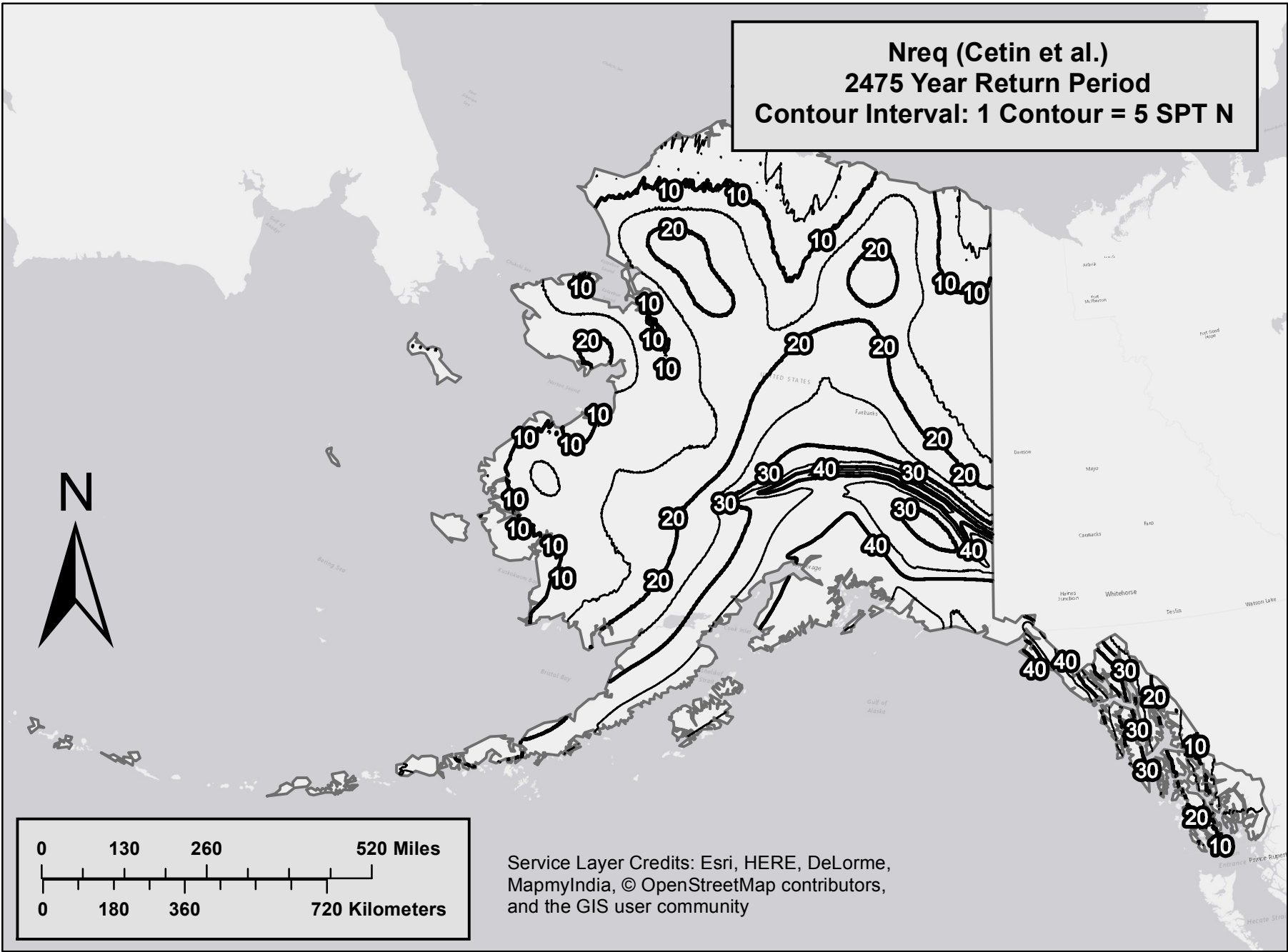
The following pages present the updated liquefaction reference parameter maps for each of the seven participating states in the study.

**Nreq (Cetin et al.)
475 Year Return Period
Contour Interval: 1 Contour = 5 SPT N**

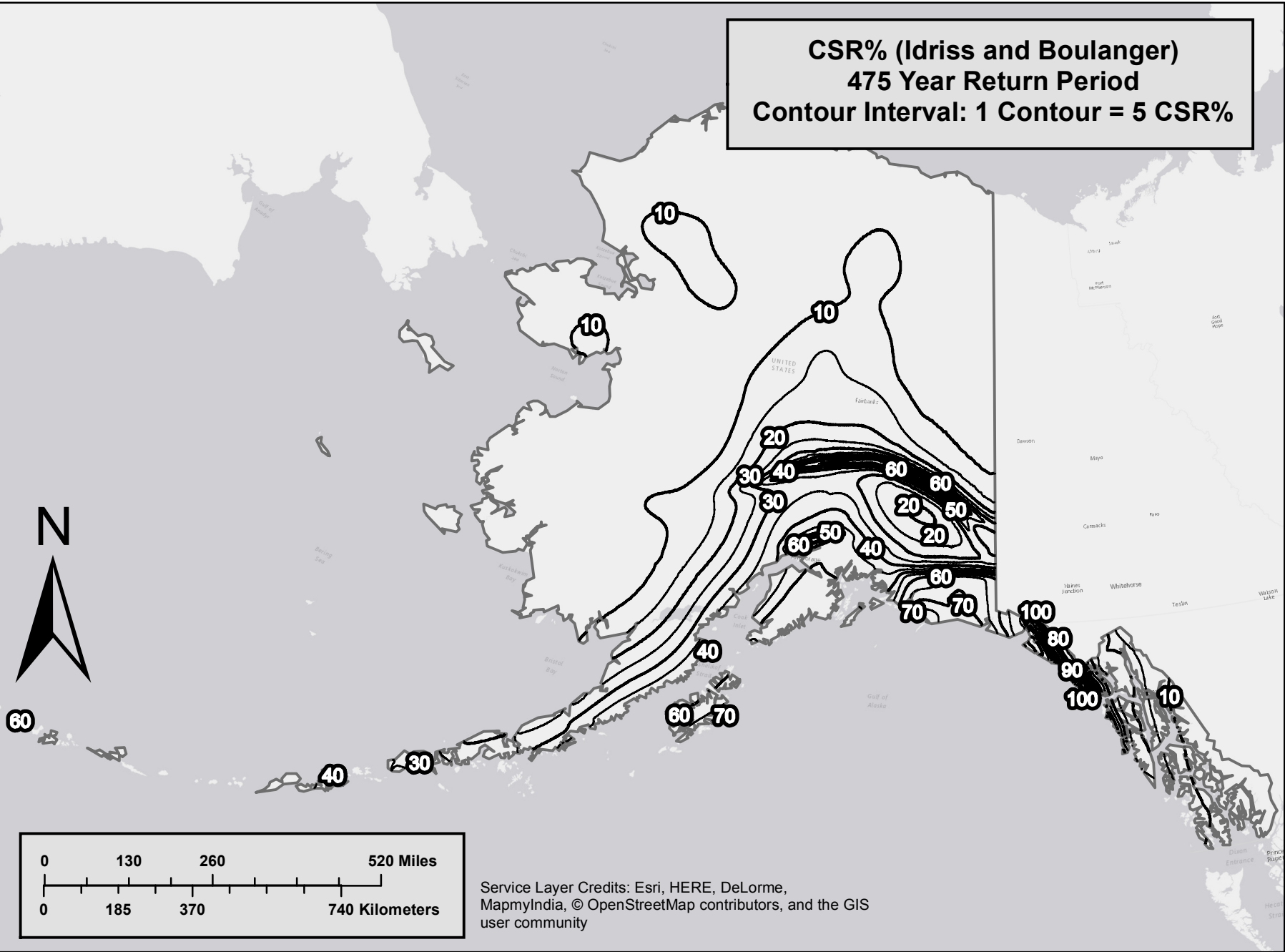


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**Nreq (Cetin et al.)
2475 Year Return Period
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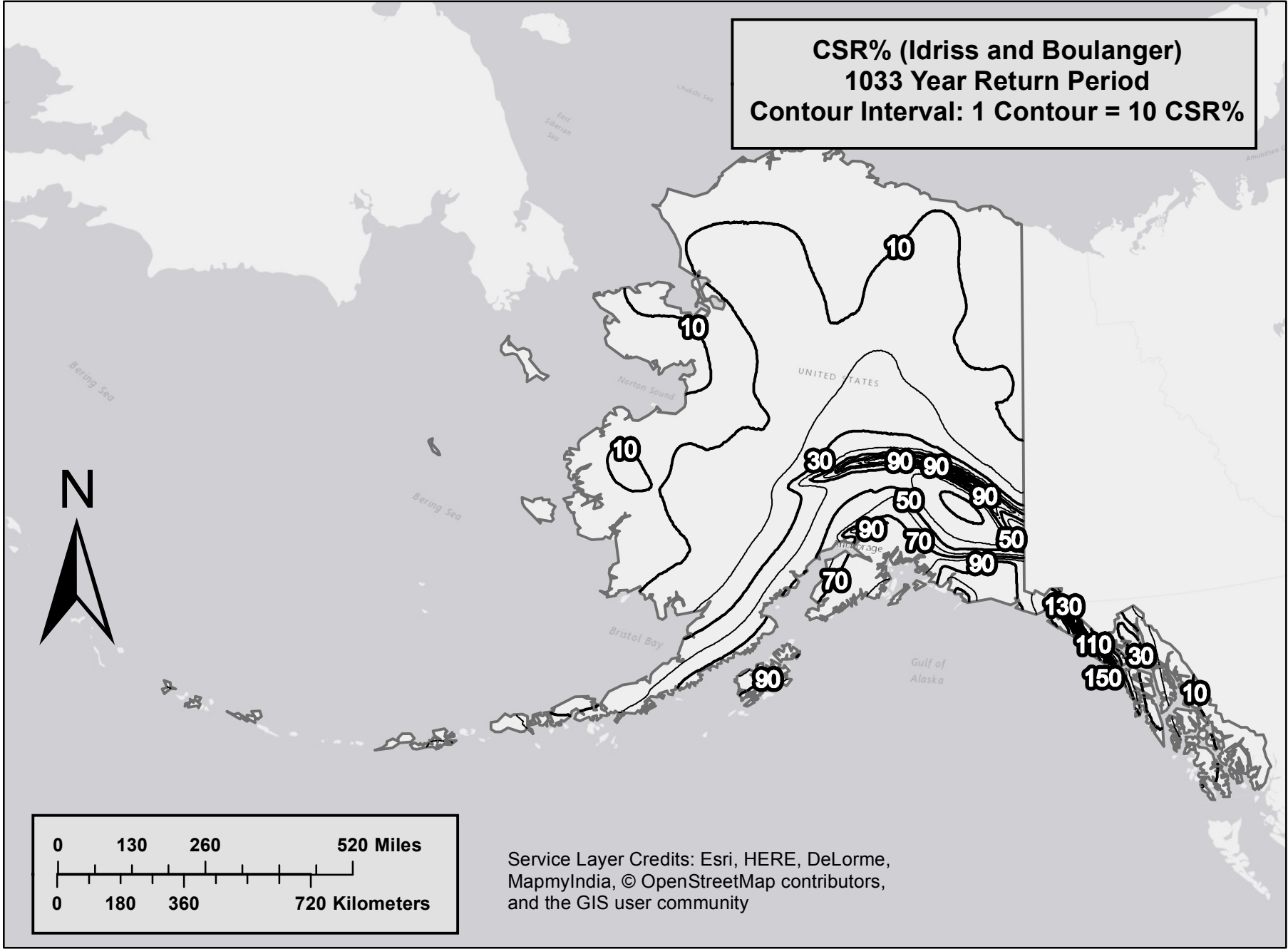


**CSR% (Idriss and Boulanger)
475 Year Return Period
Contour Interval: 1 Contour = 5 CSR%**

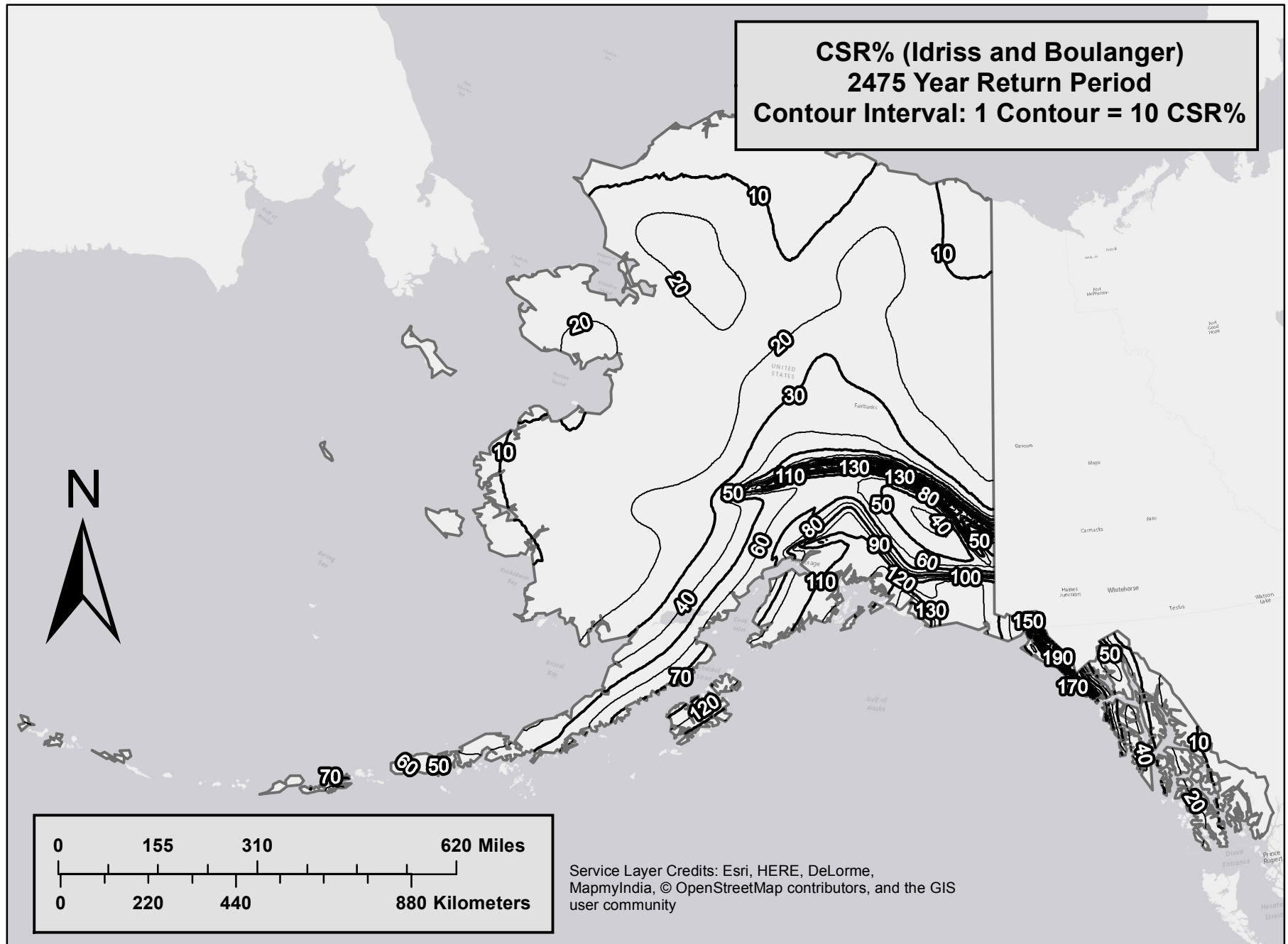


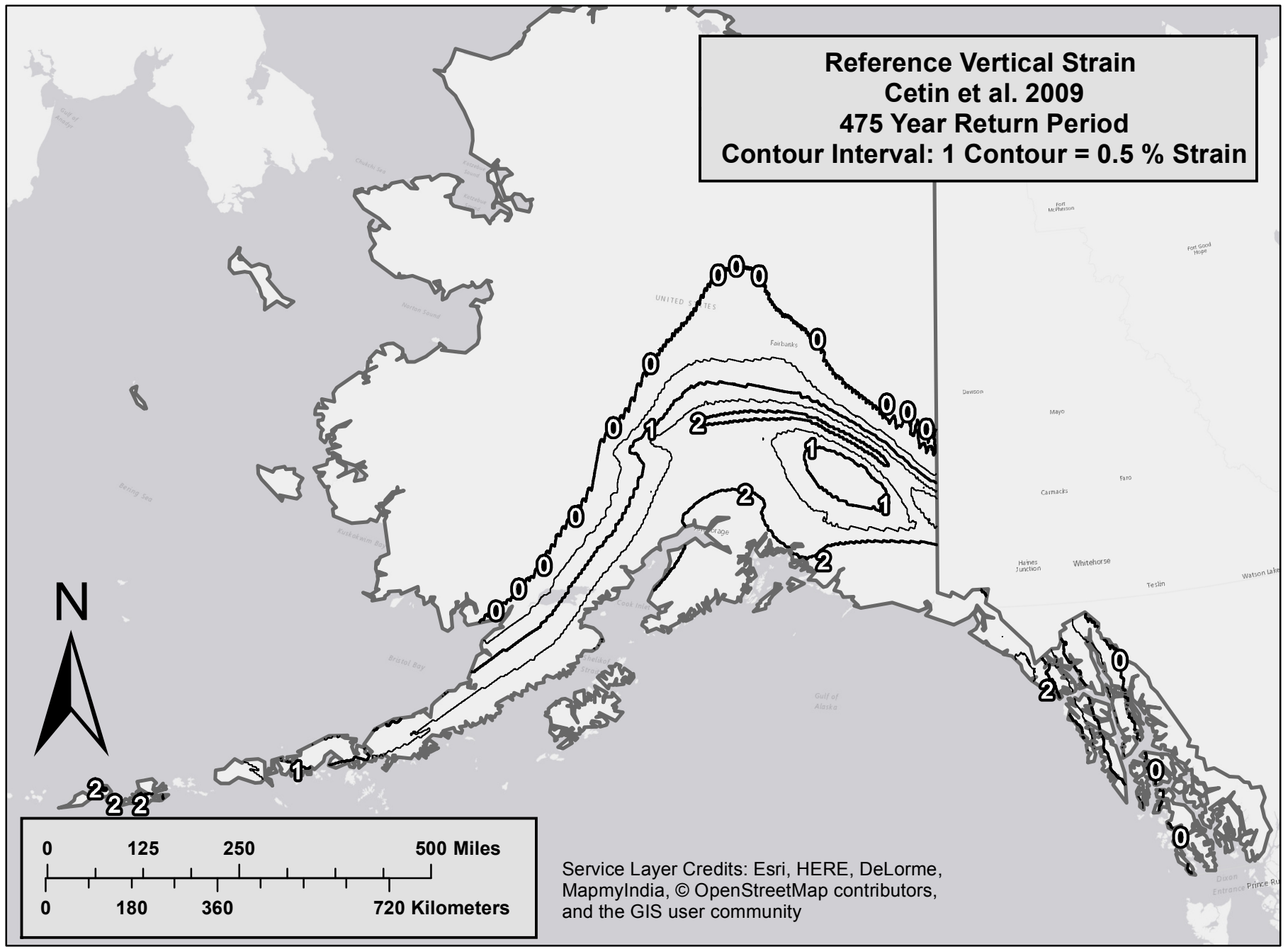
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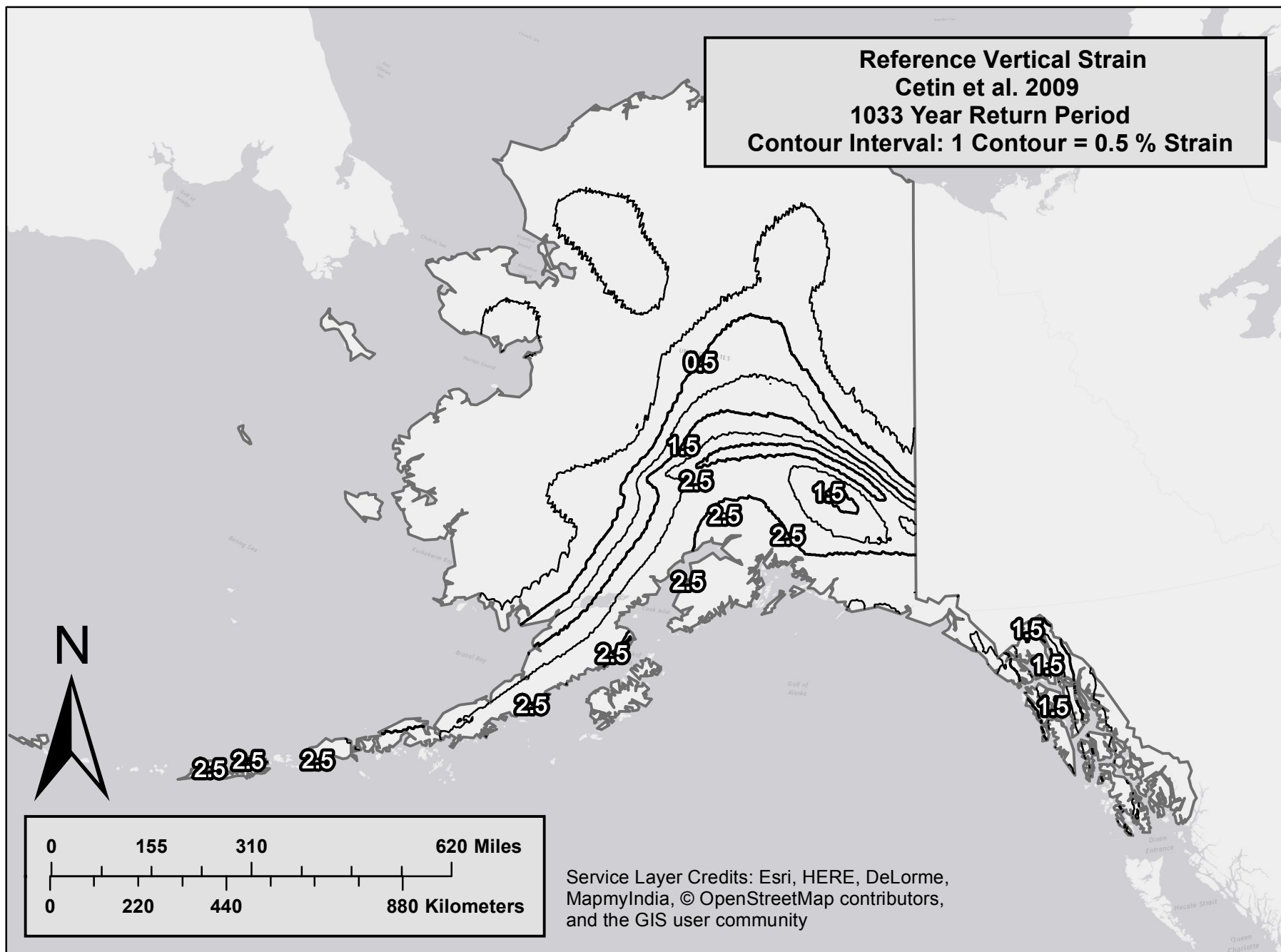
**CSR% (Idriss and Boulanger)
1033 Year Return Period
Contour Interval: 1 Contour = 10 CSR%**

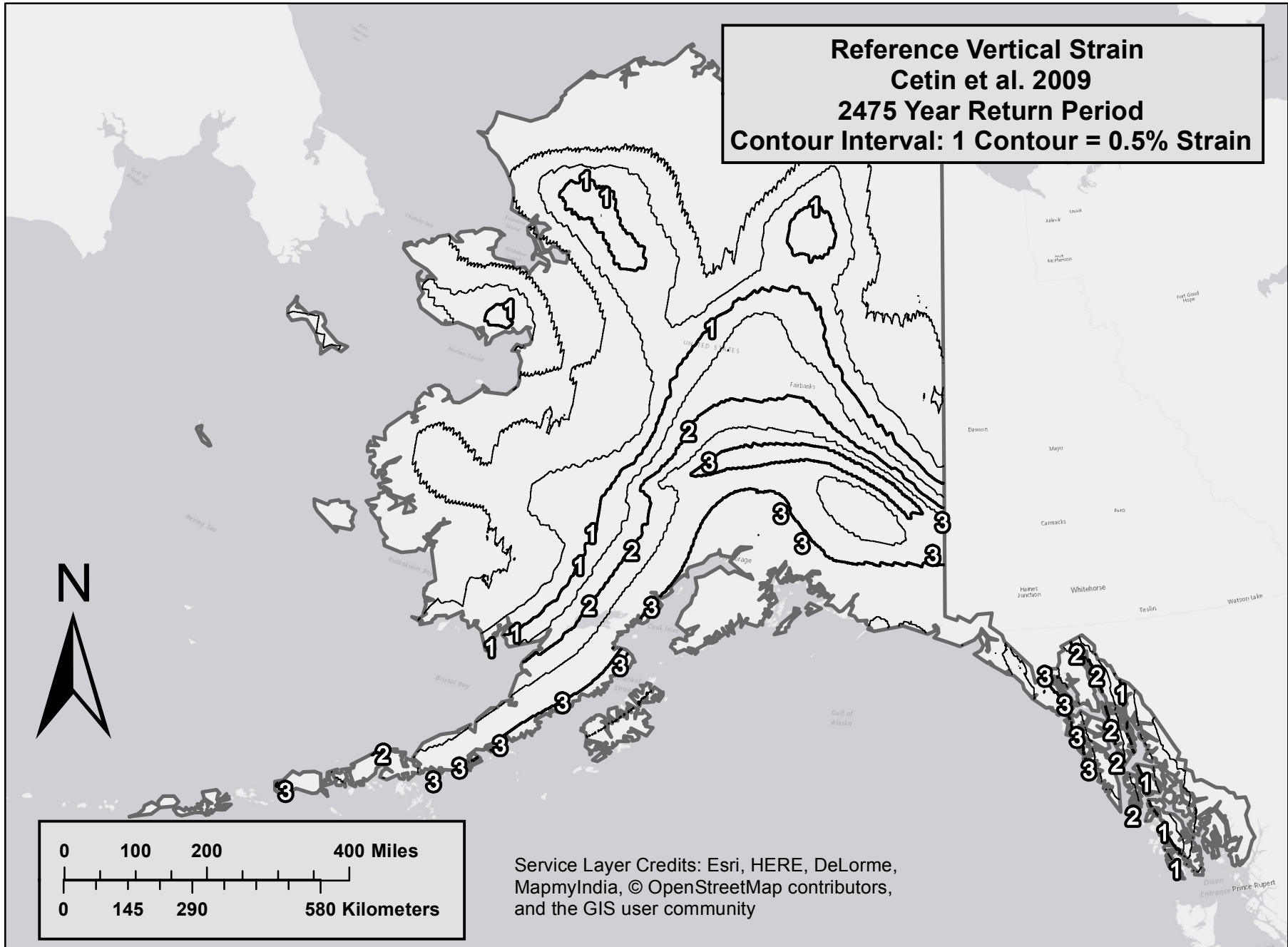


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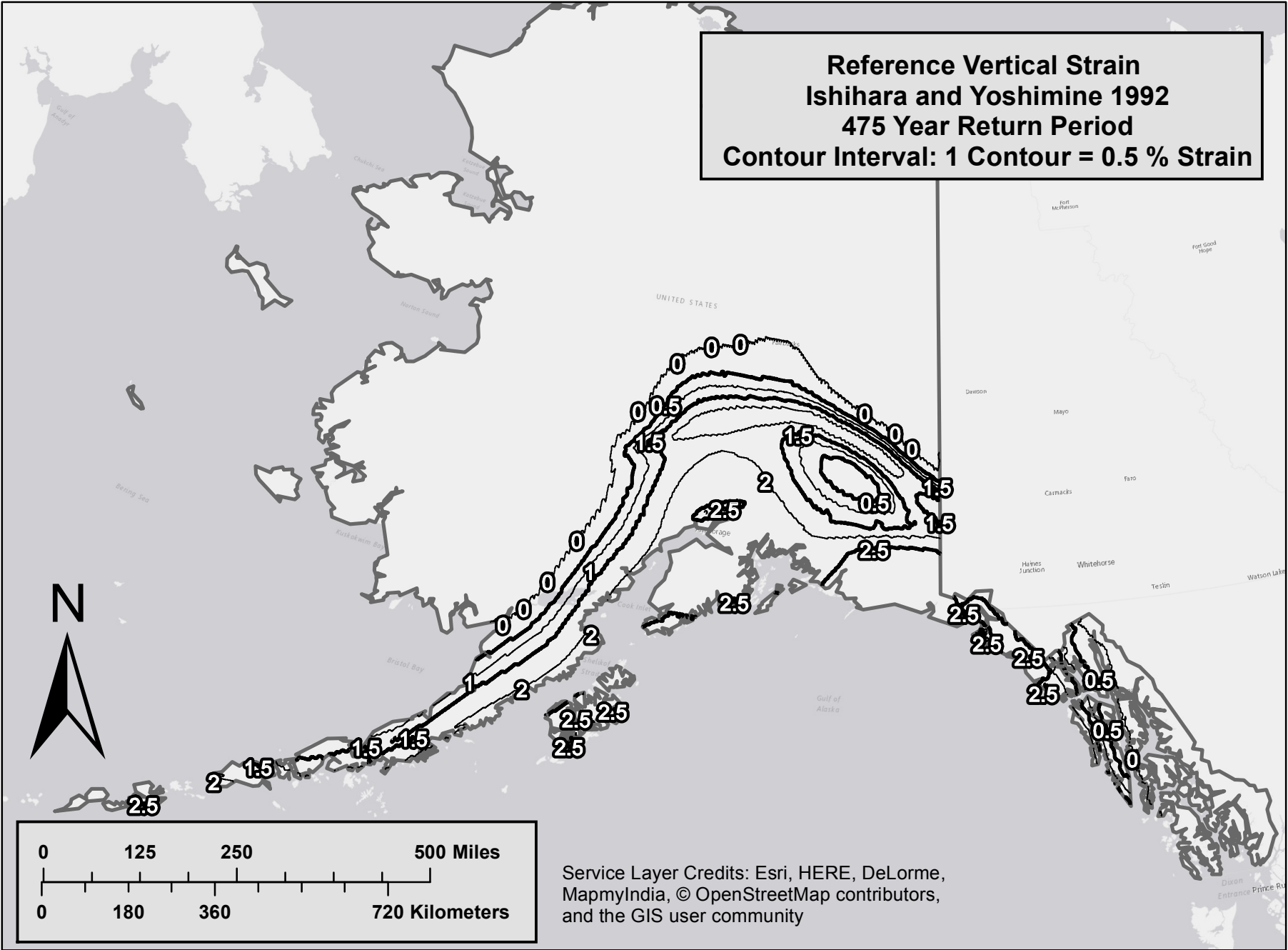


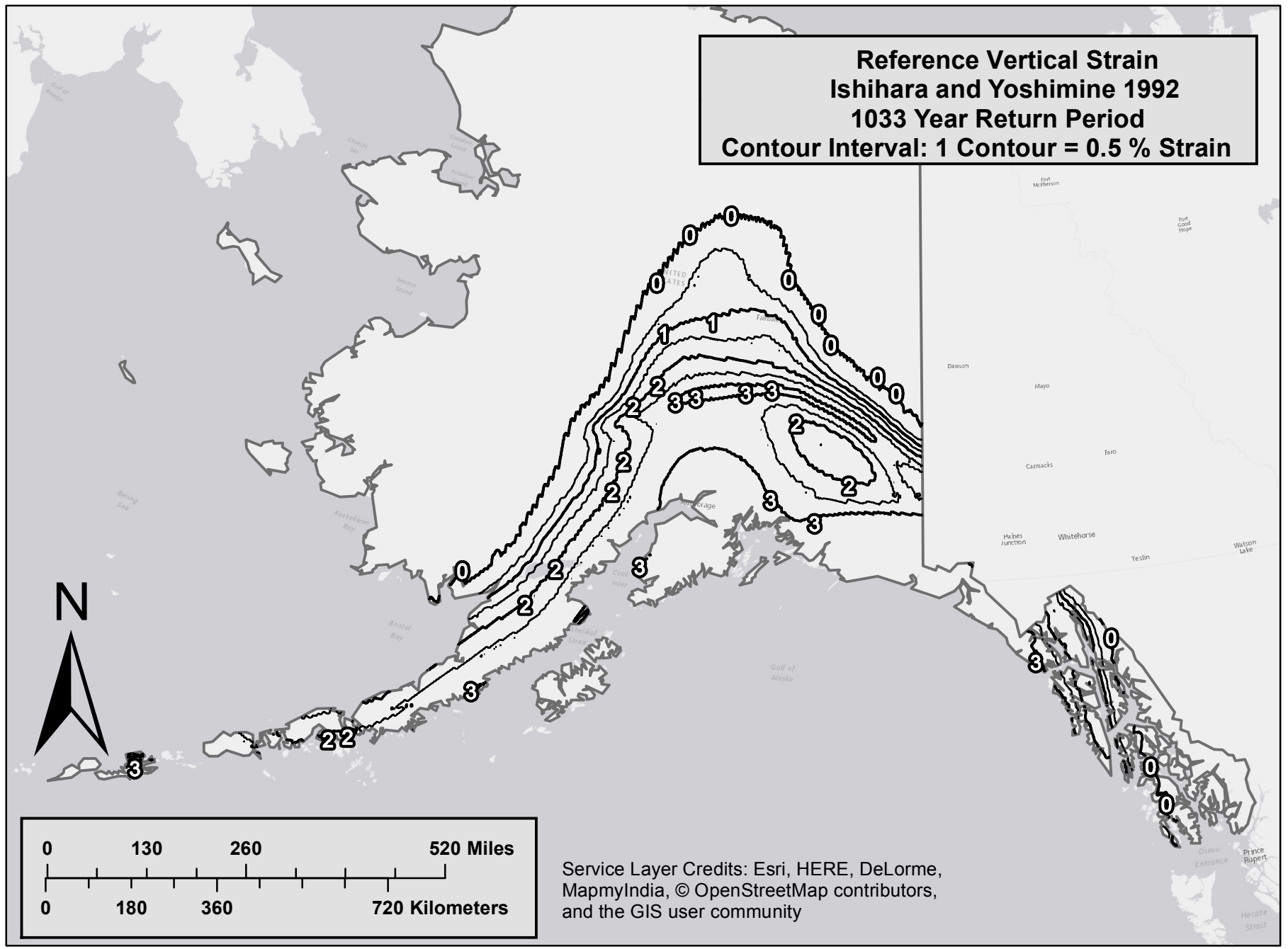




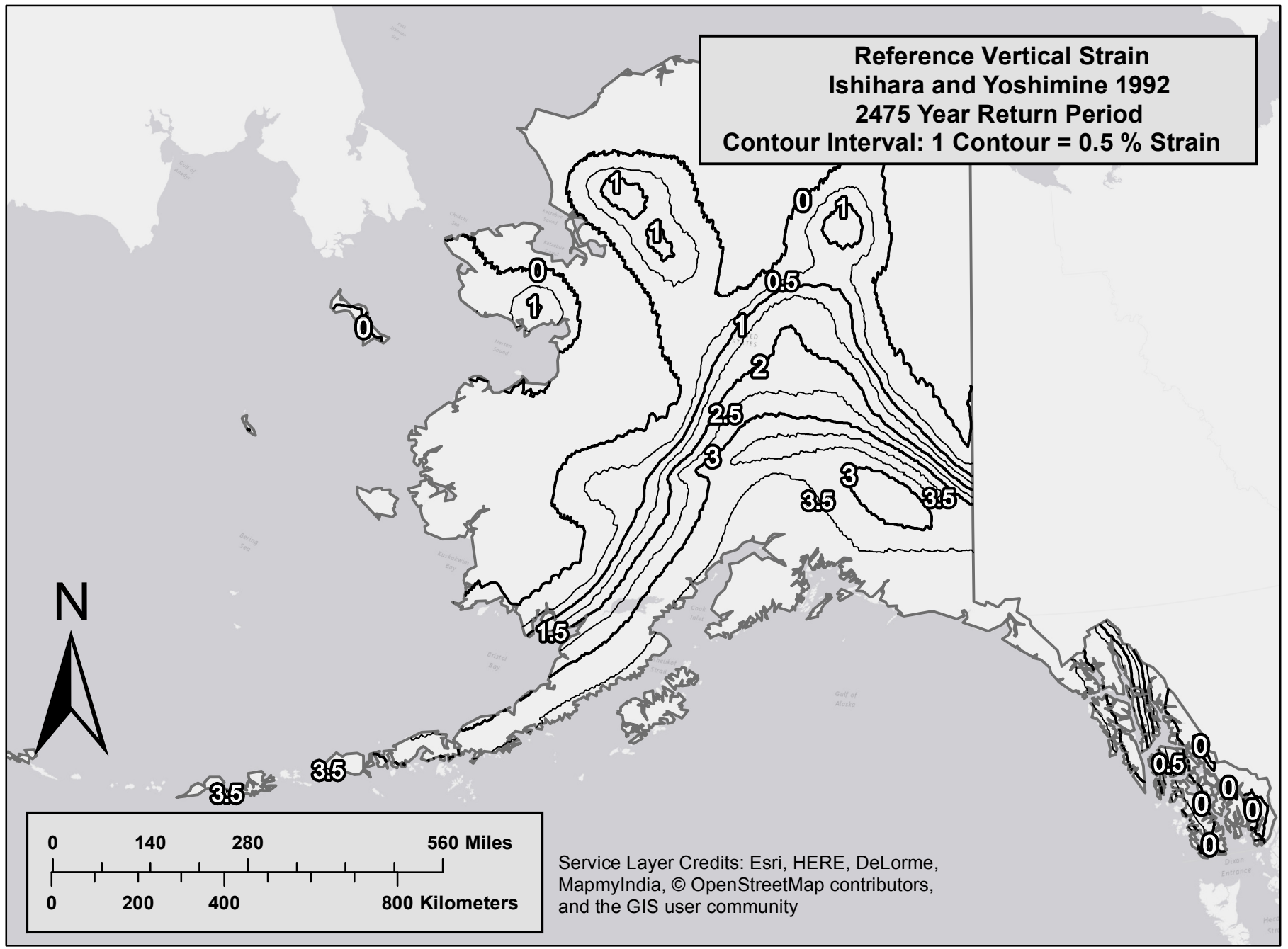


**Reference Vertical Strain
Ishihara and Yoshimine 1992
475 Year Return Period
Contour Interval: 1 Contour = 0.5 % Strain**

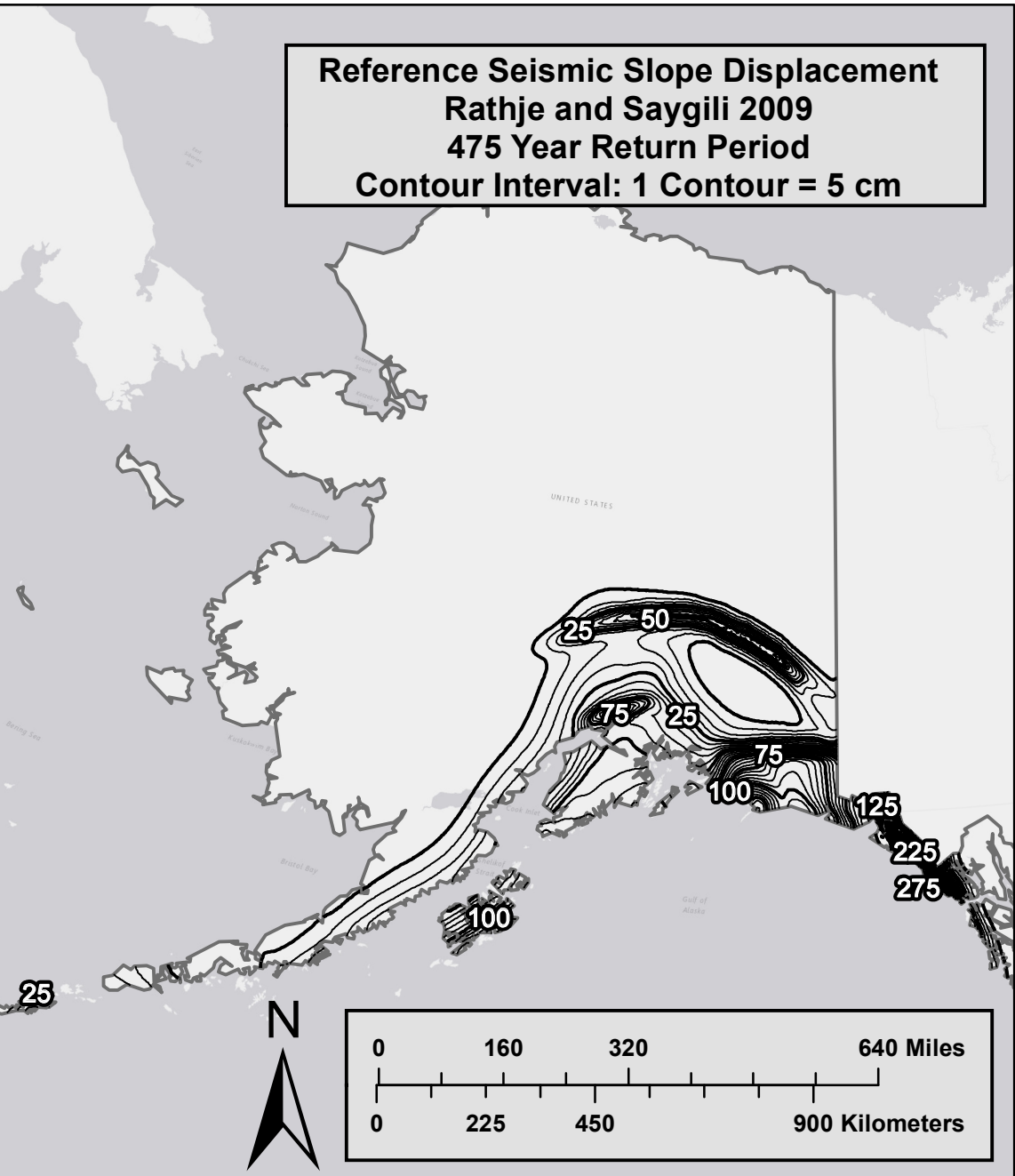
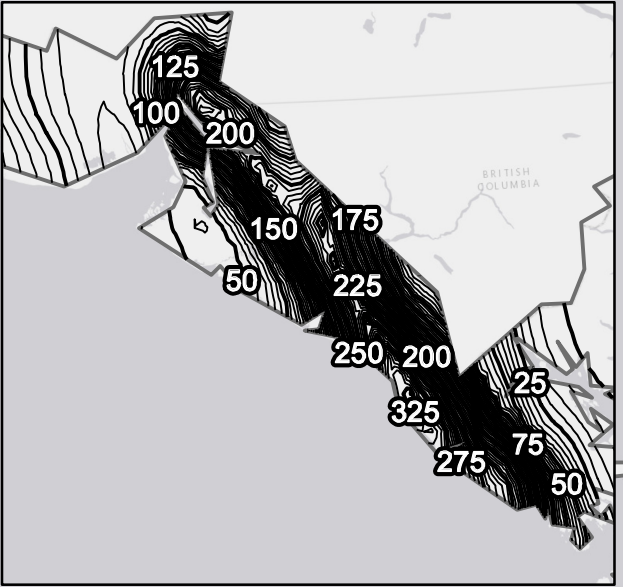
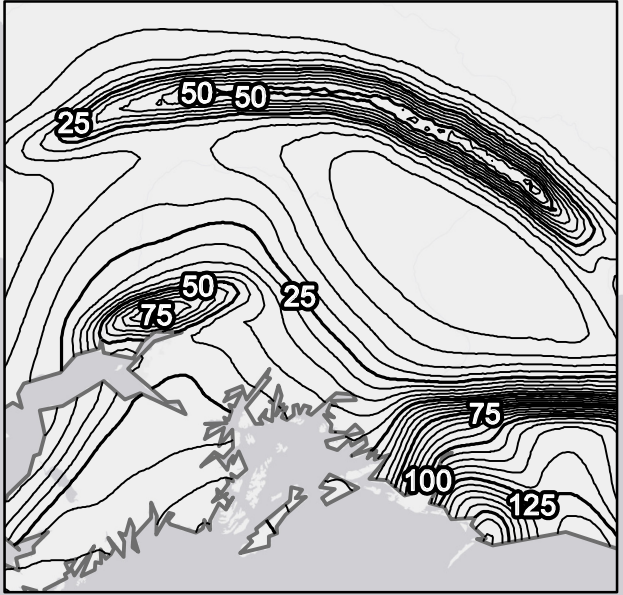




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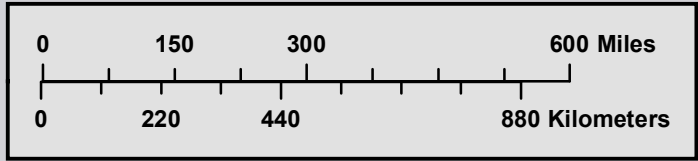
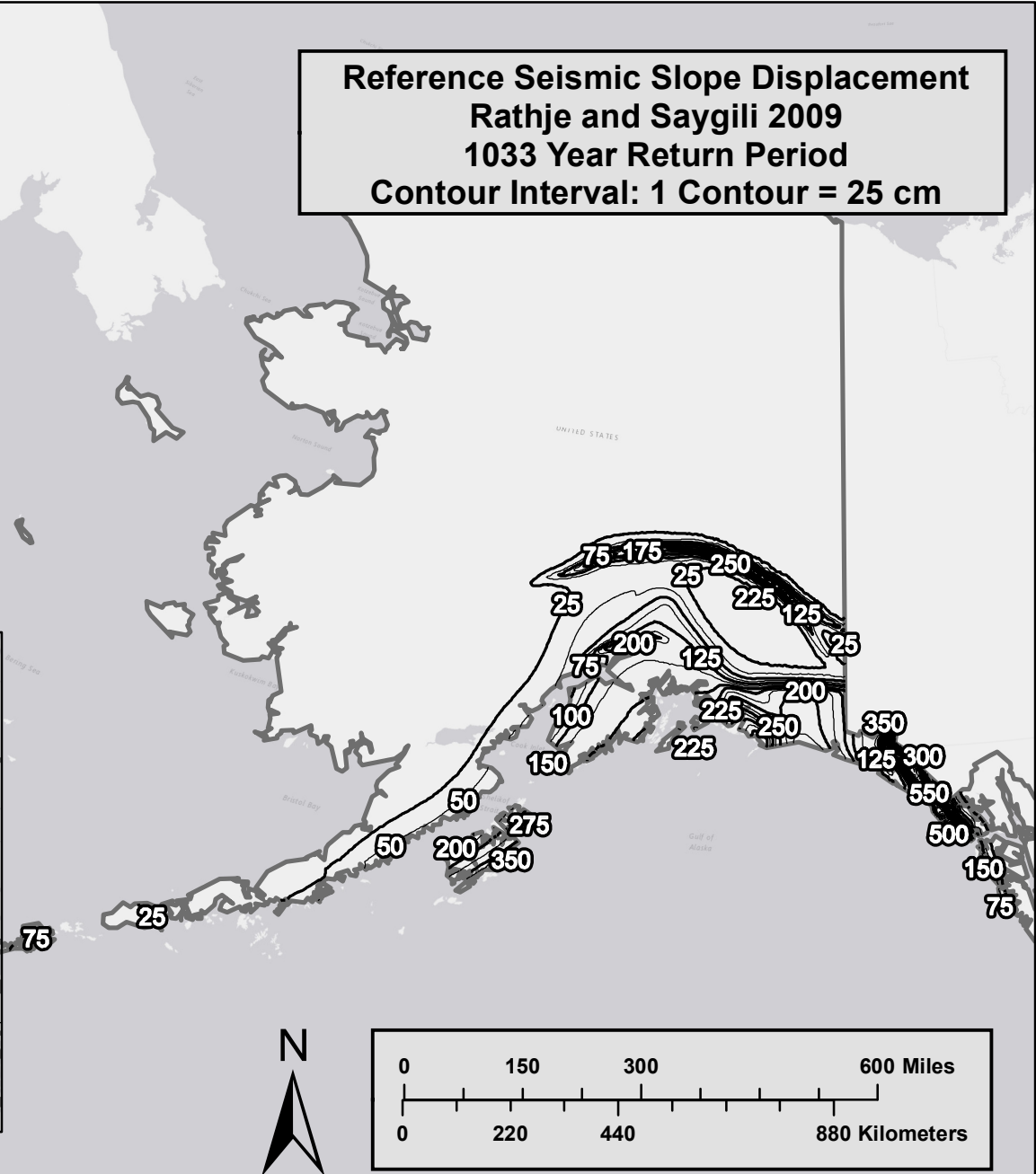
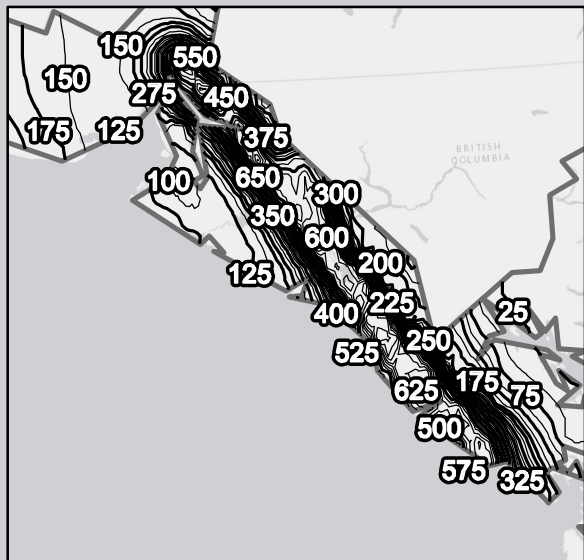
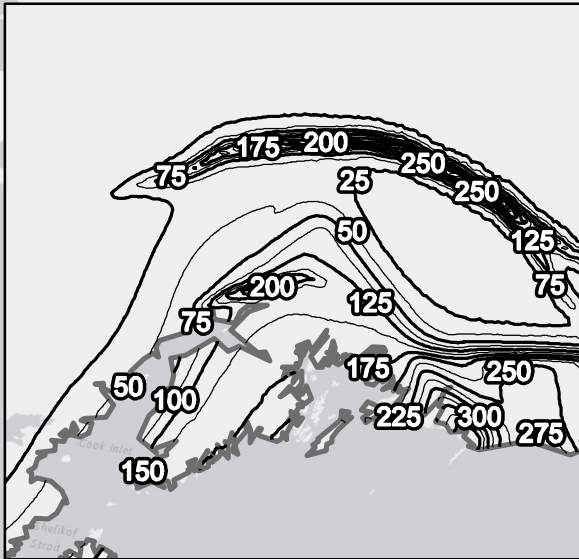


Reference Seismic Slope Displacement
Rathje and Saygili 2009
475 Year Return Period
Contour Interval: 1 Contour = 5 cm



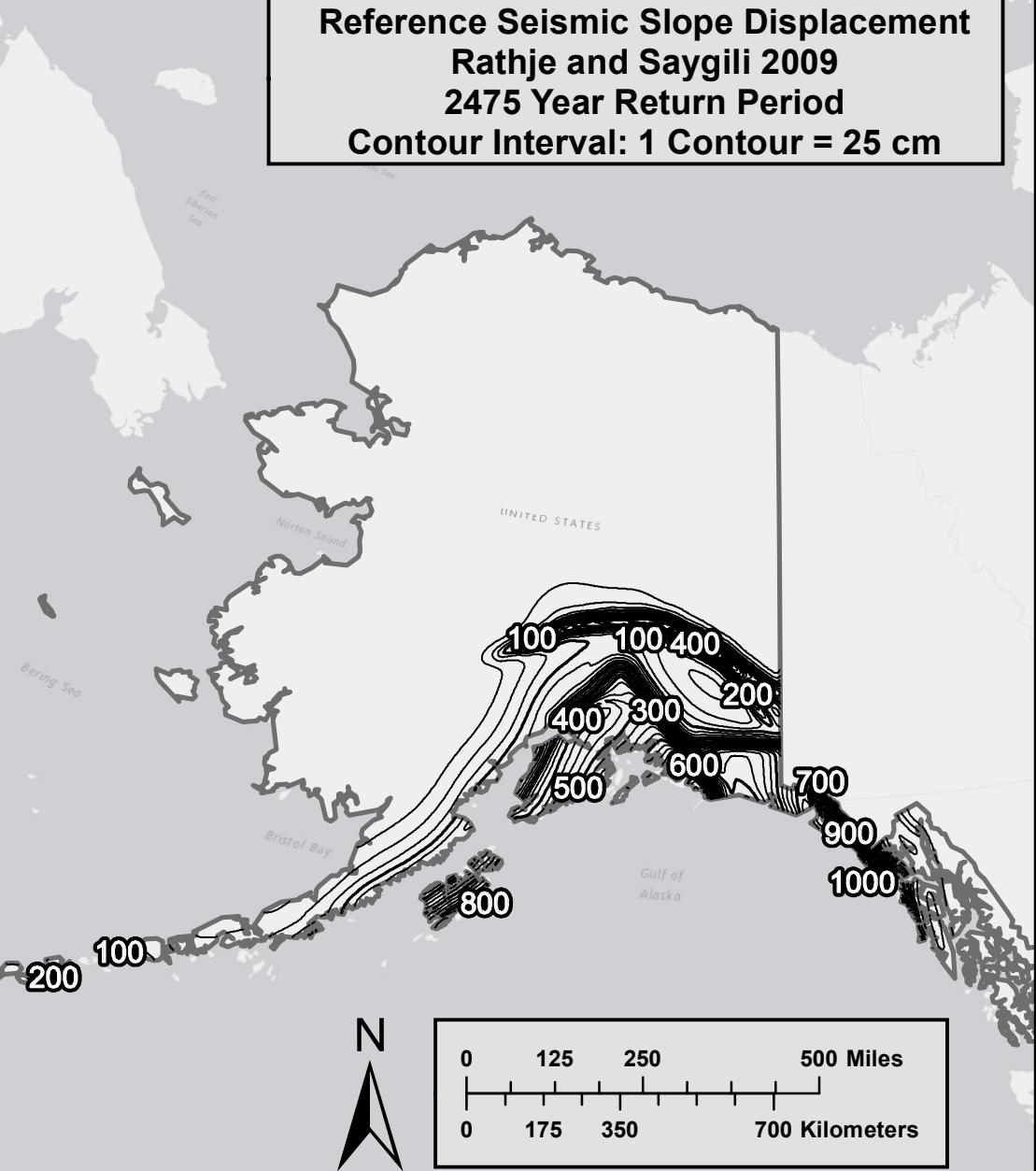
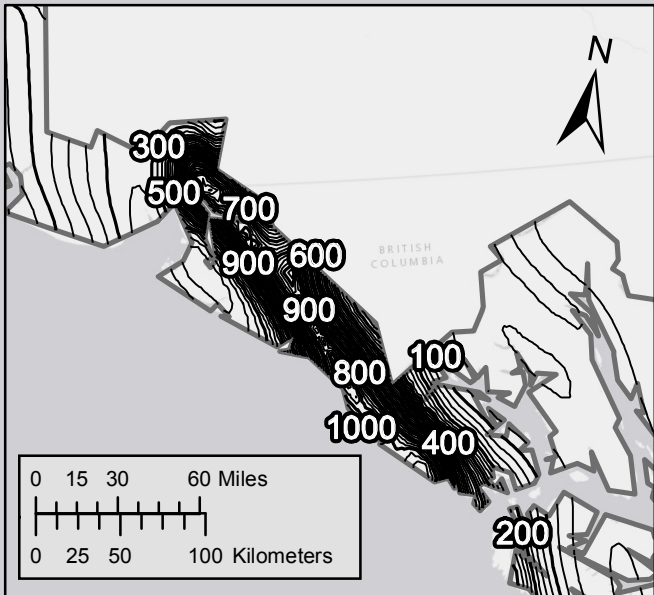
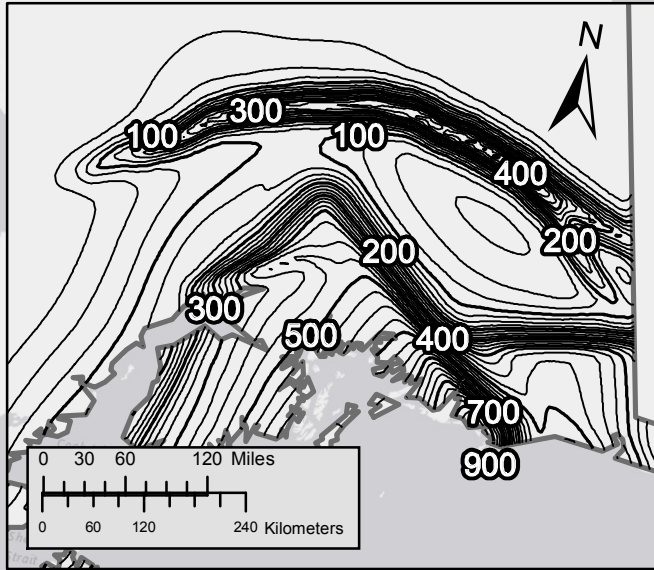
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**Reference Seismic Slope Displacement
Rathje and Saygili 2009
1033 Year Return Period
Contour Interval: 1 Contour = 25 cm**



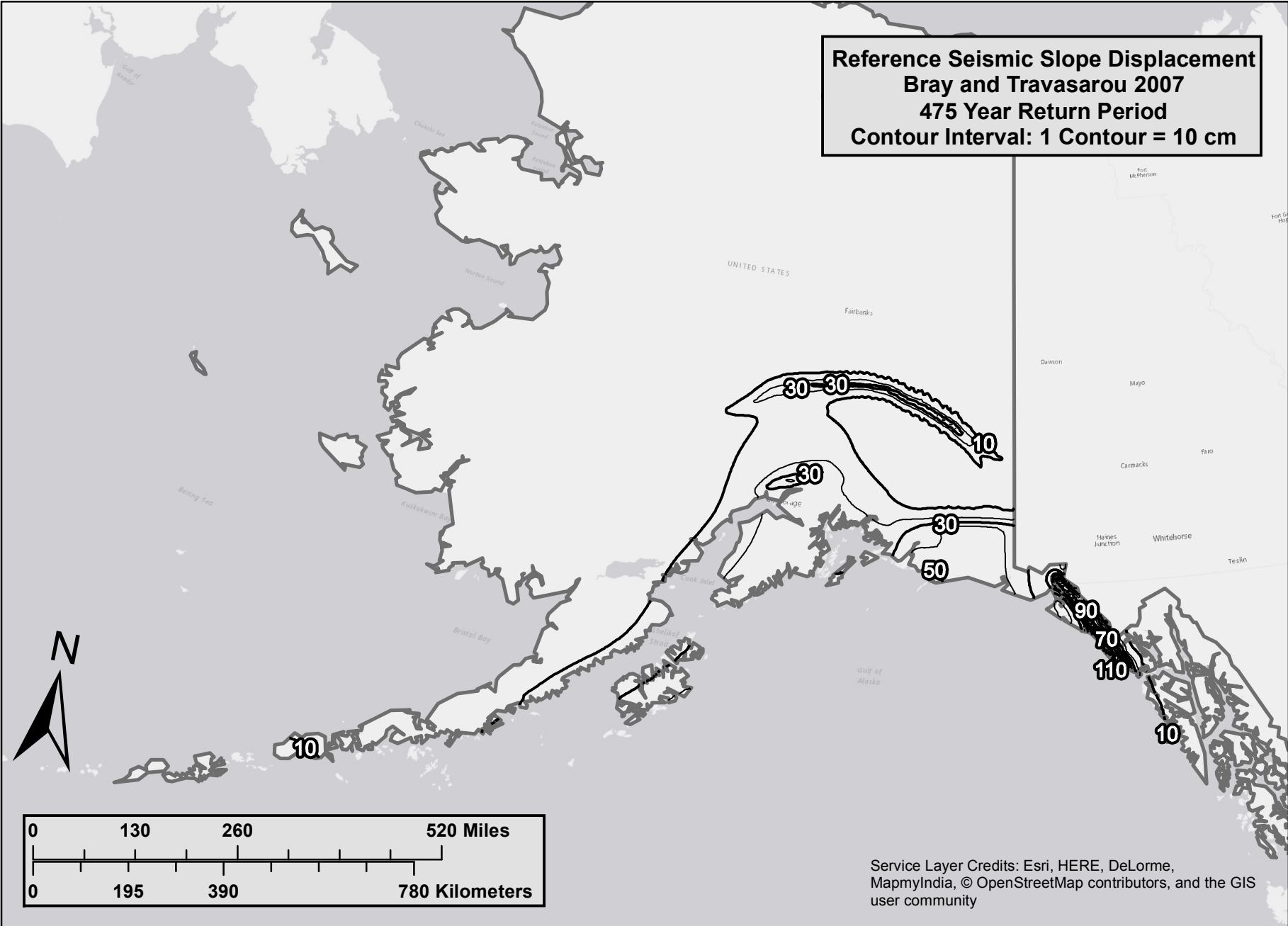
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2475 Year Return Period
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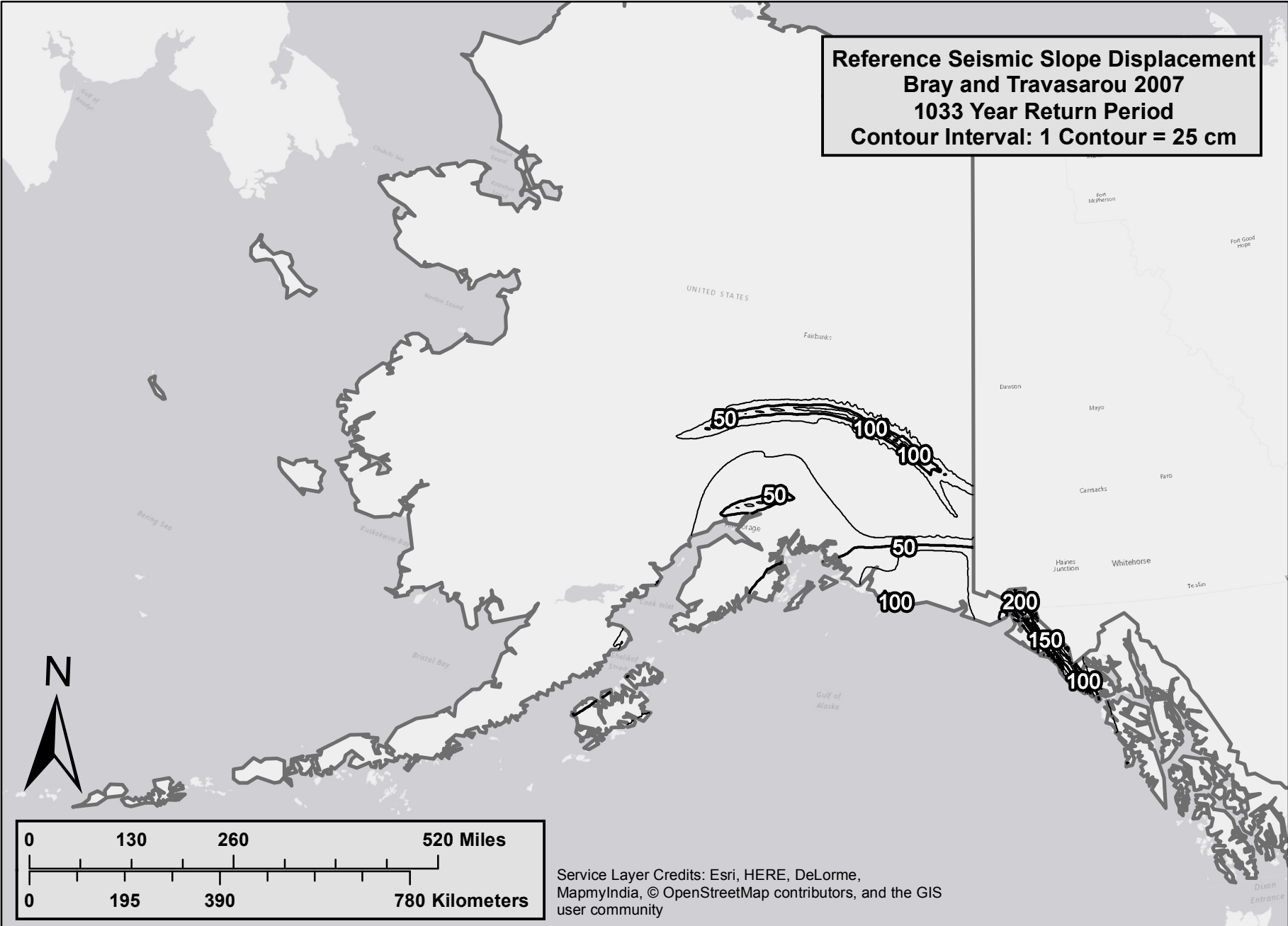
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**Reference Seismic Slope Displacement
Bray and Travasarou 2007
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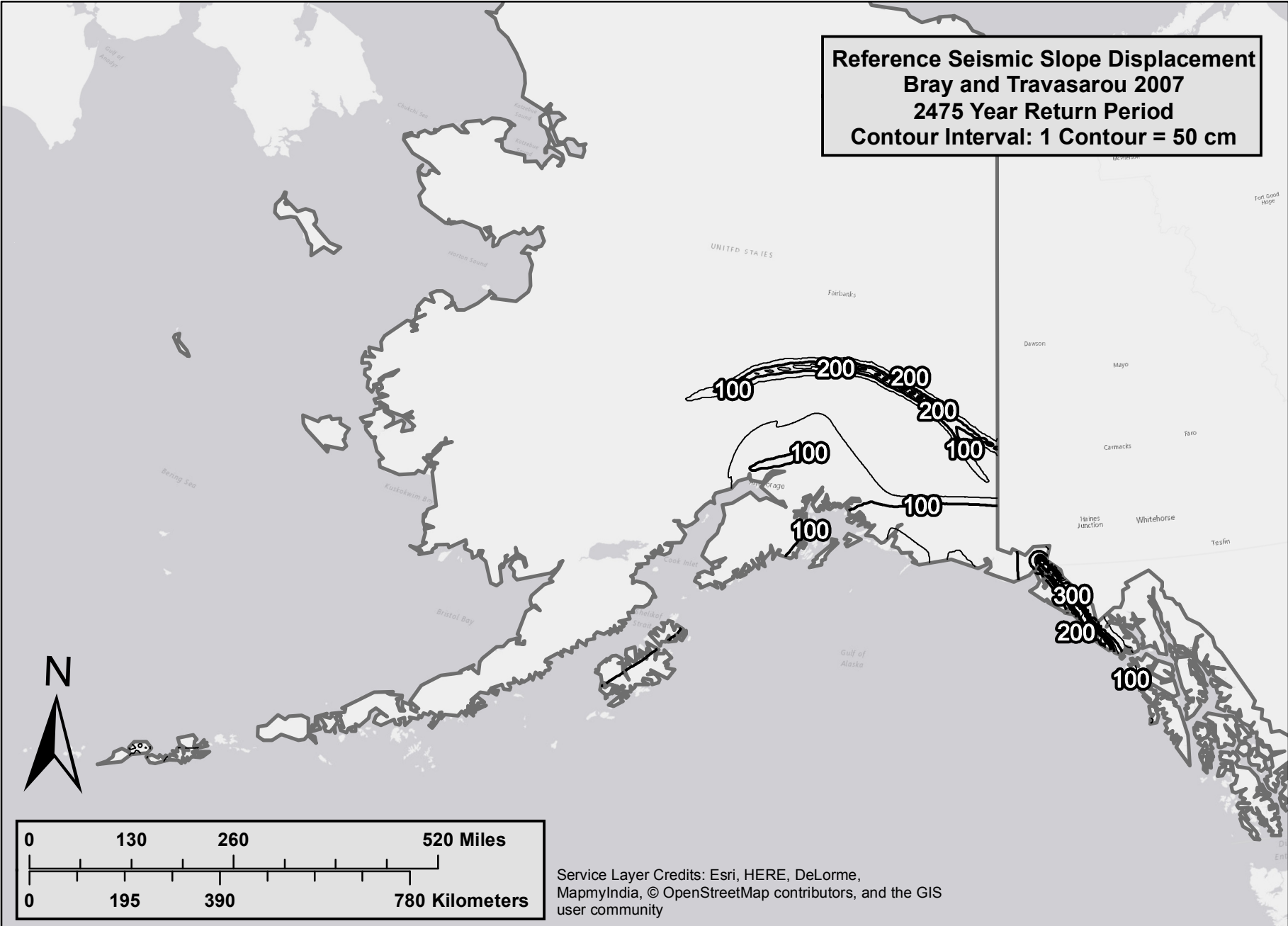
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Reference Seismic Slope Displacement
Bray and Travararou 2007
1033 Year Return Period
Contour Interval: 1 Contour = 25 cm



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**Reference Seismic Slope Displacement
Bray and Travararou 2007
2475 Year Return Period
Contour Interval: 1 Contour = 50 cm**

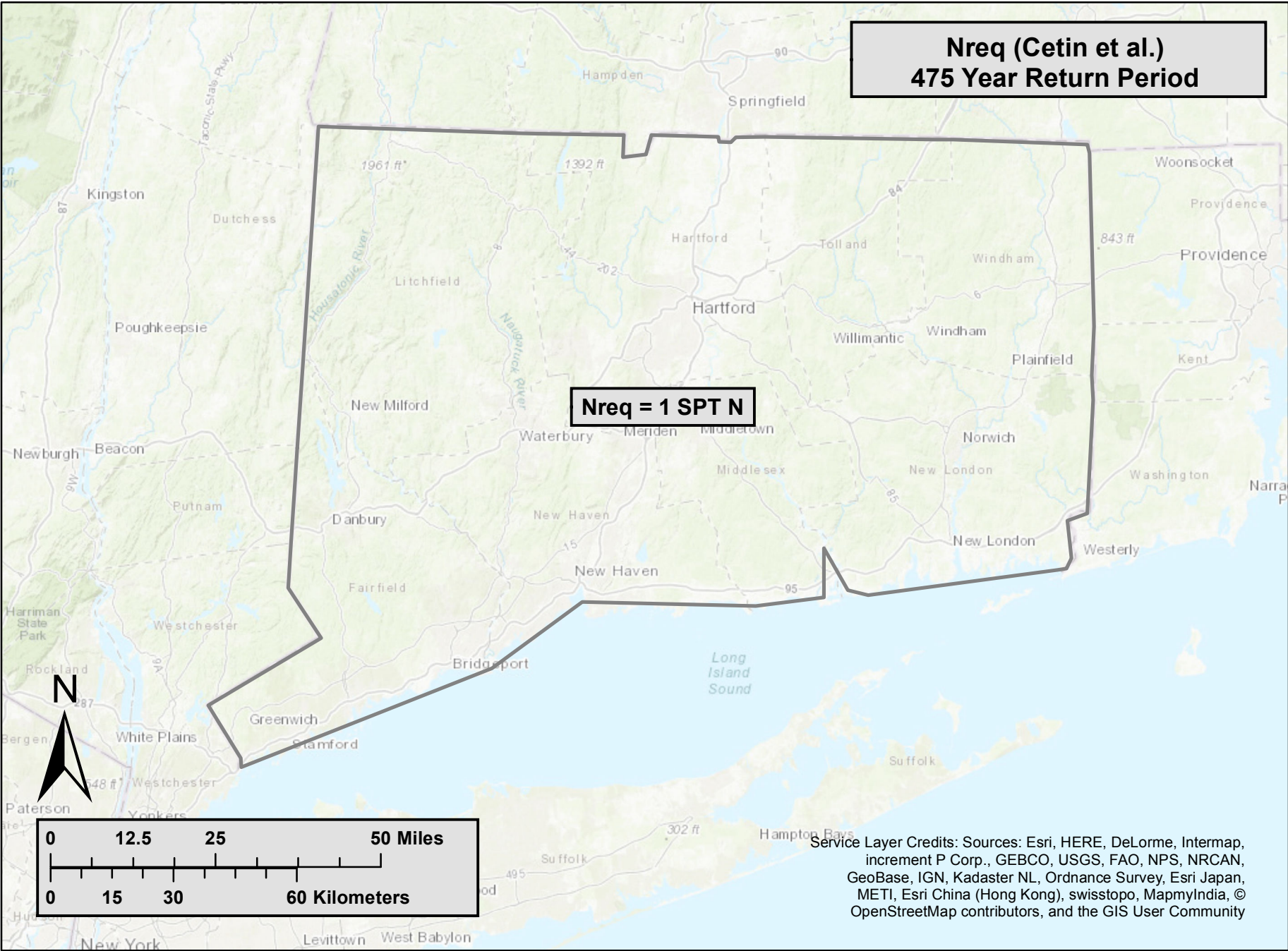
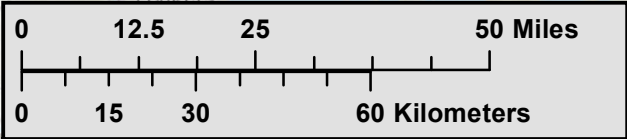


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**Nreq (Cetin et al.)
475 Year Return Period**

Nreq = 1 SPT N

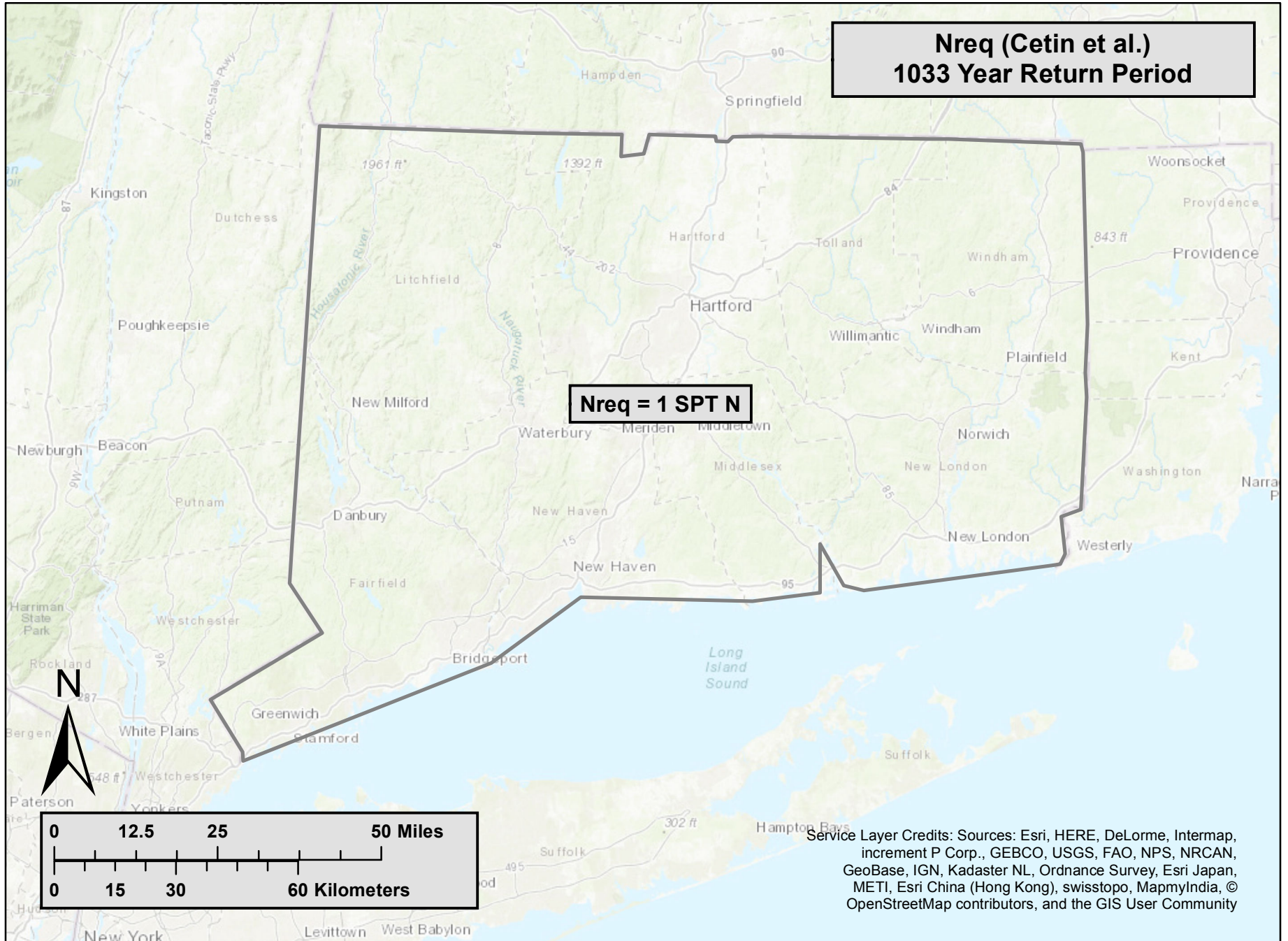
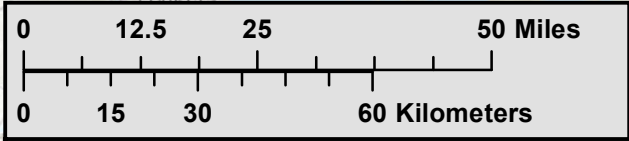
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**Nreq (Cetin et al.)
1033 Year Return Period**

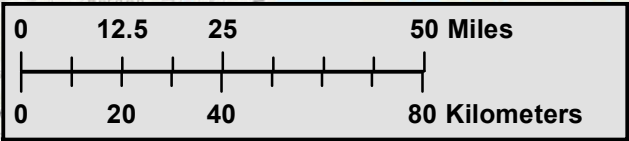
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CSR% (Idriss and Boulanger) 475 Year Return Period

CSR% = 7.434%



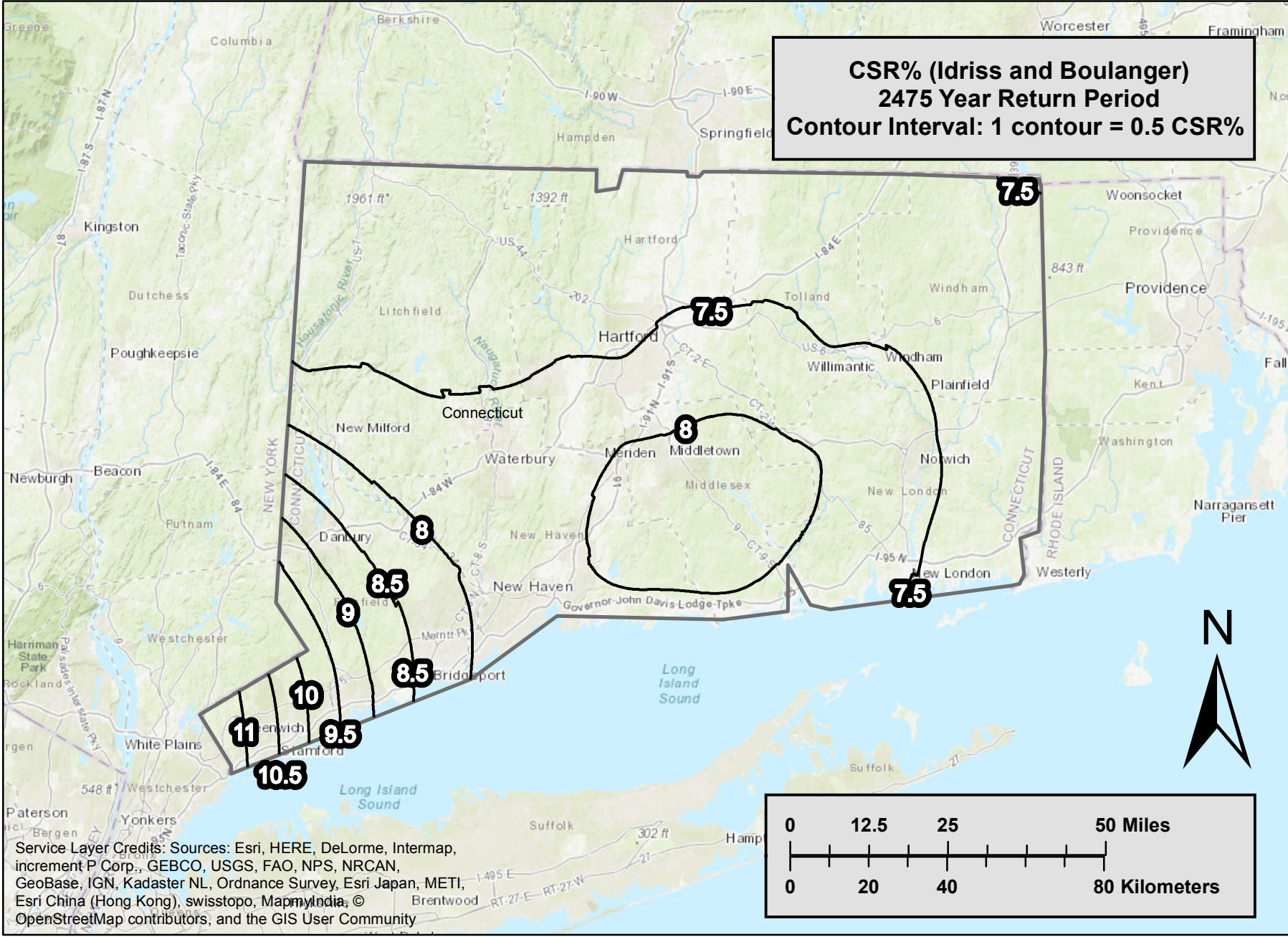
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CSR% (Idriss and Boulanger) 1033 Year Return Period

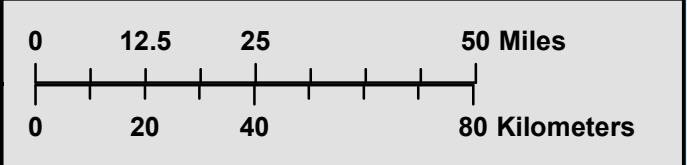
CSR% = 7.434%



Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community



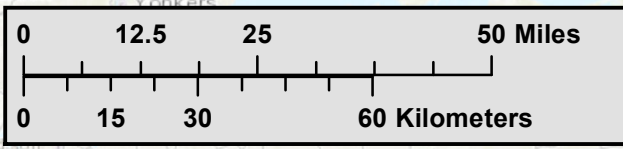
**CSR% (Idriss and Boulanger)
2475 Year Return Period
Contour Interval: 1 contour = 0.5 CSR%**



Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

**Reference Vertical Strain
Cetin et al. 2009
475 Year Return Period**

0% Strain

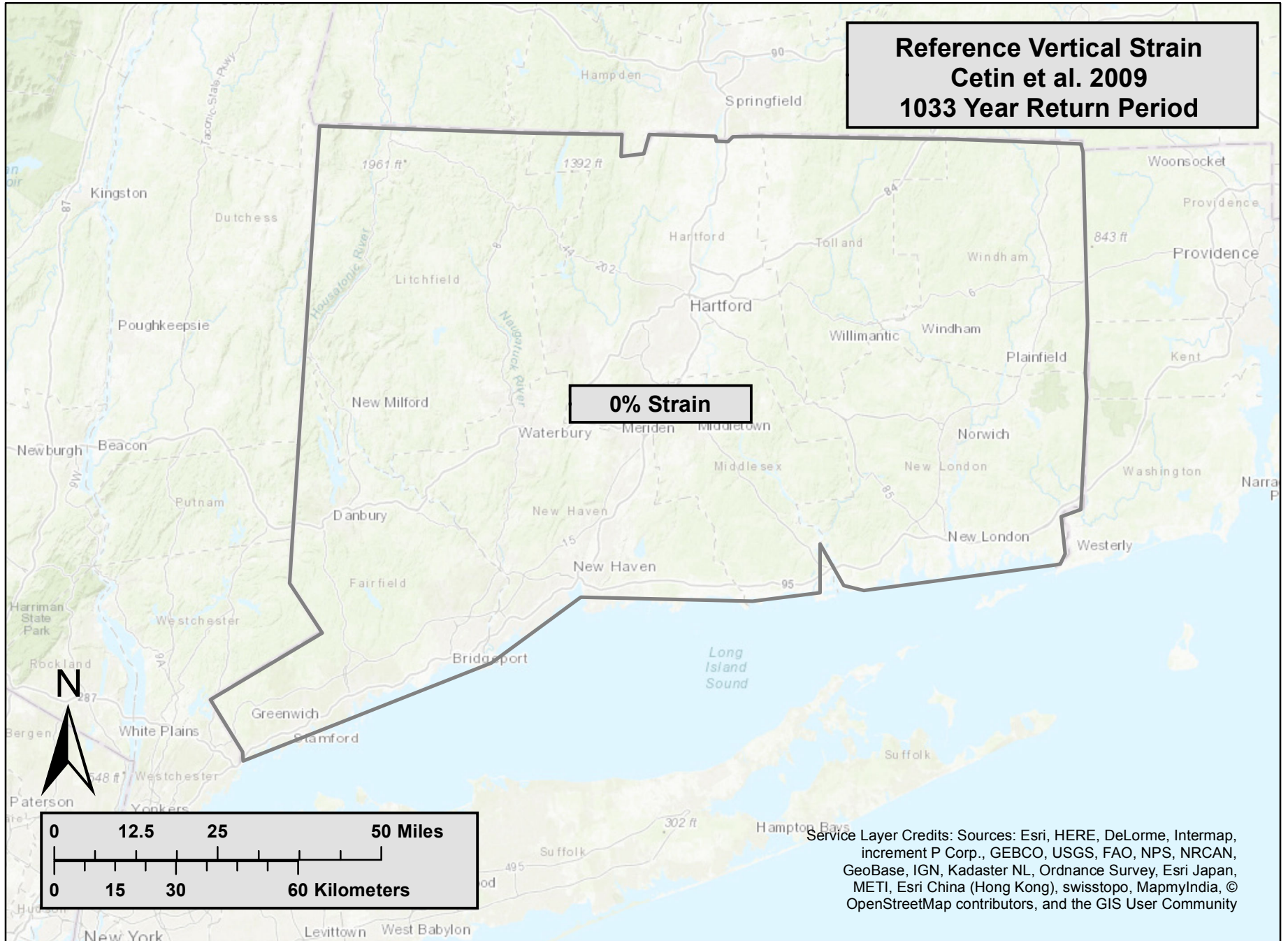
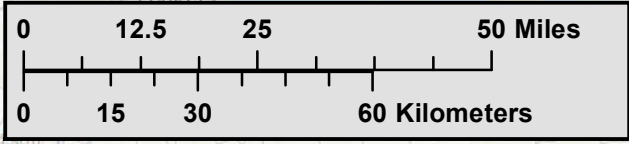


Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

**Reference Vertical Strain
Cetin et al. 2009
1033 Year Return Period**

0% Strain

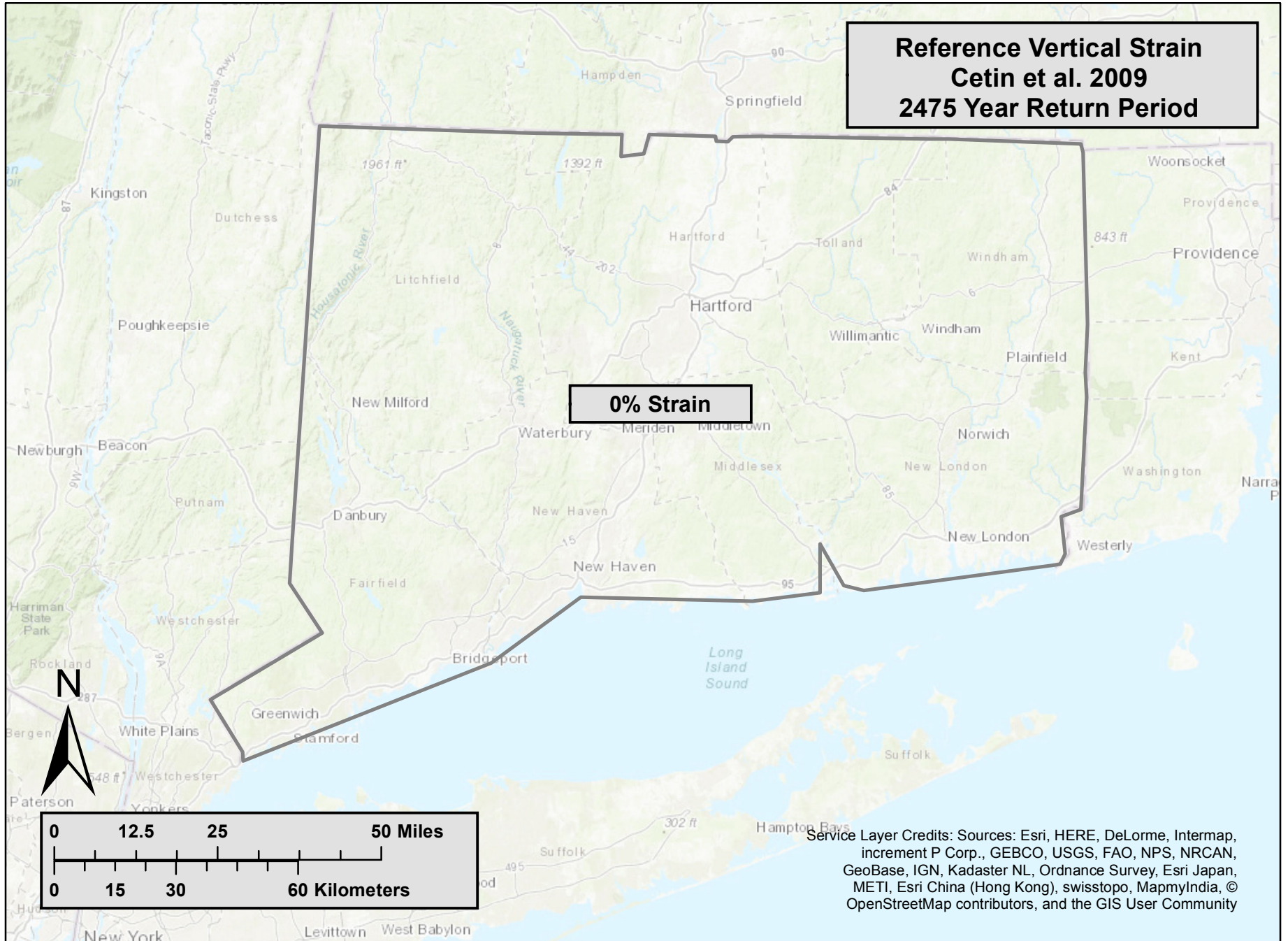
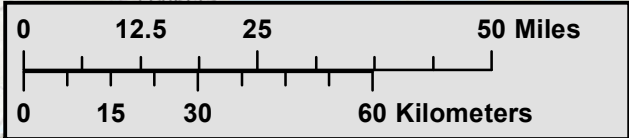
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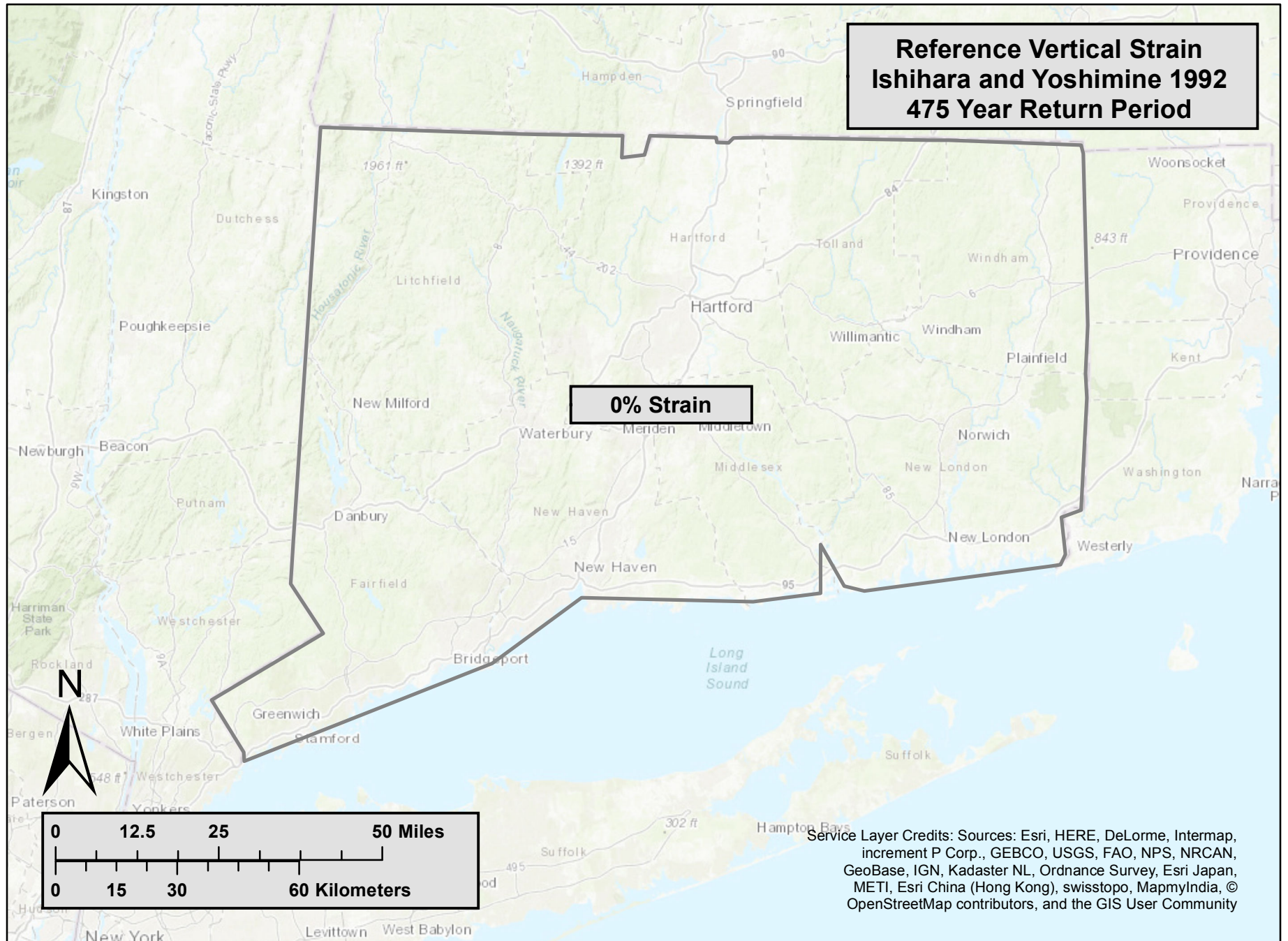


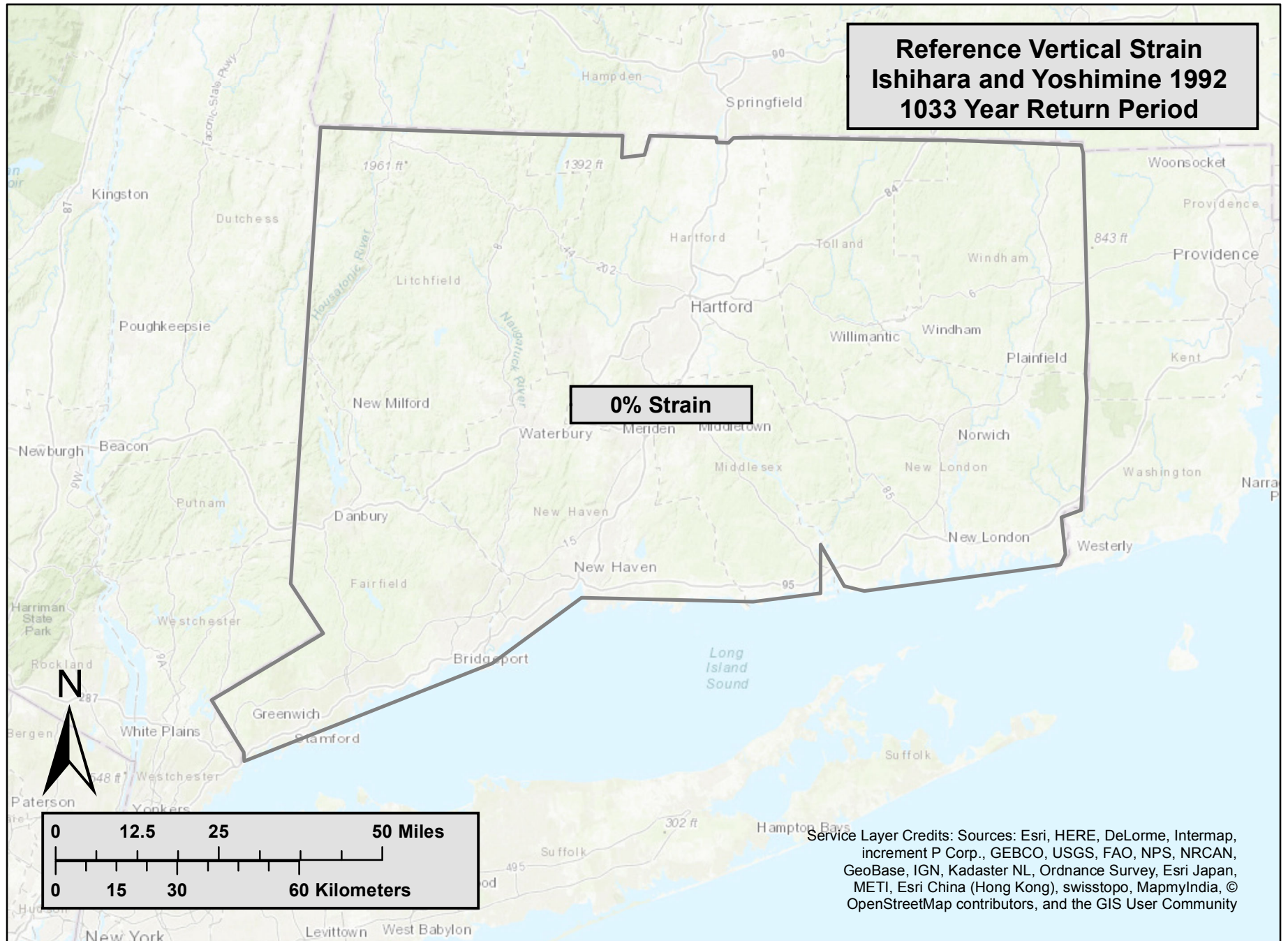
**Reference Vertical Strain
Cetin et al. 2009
2475 Year Return Period**

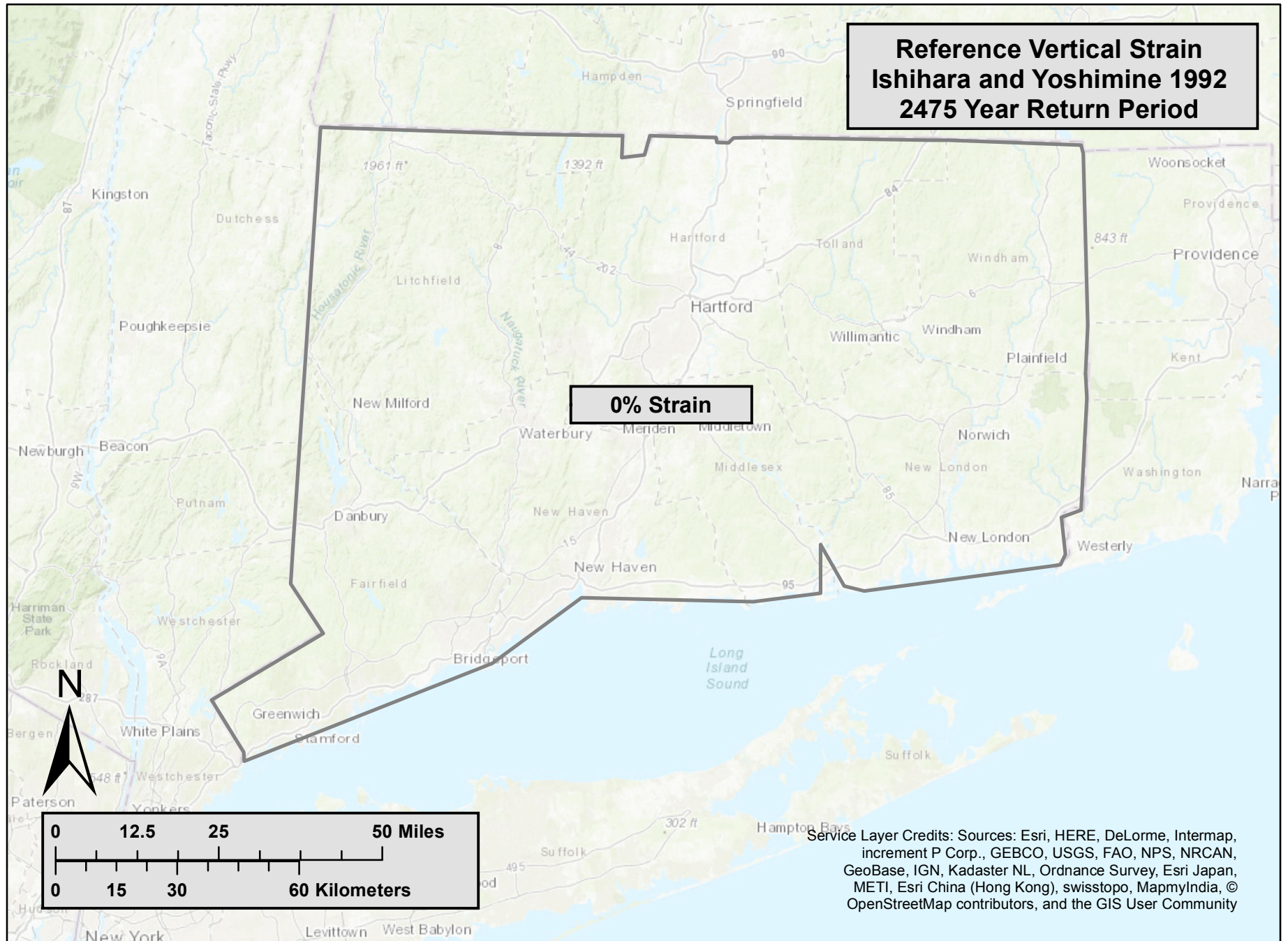
0% Strain

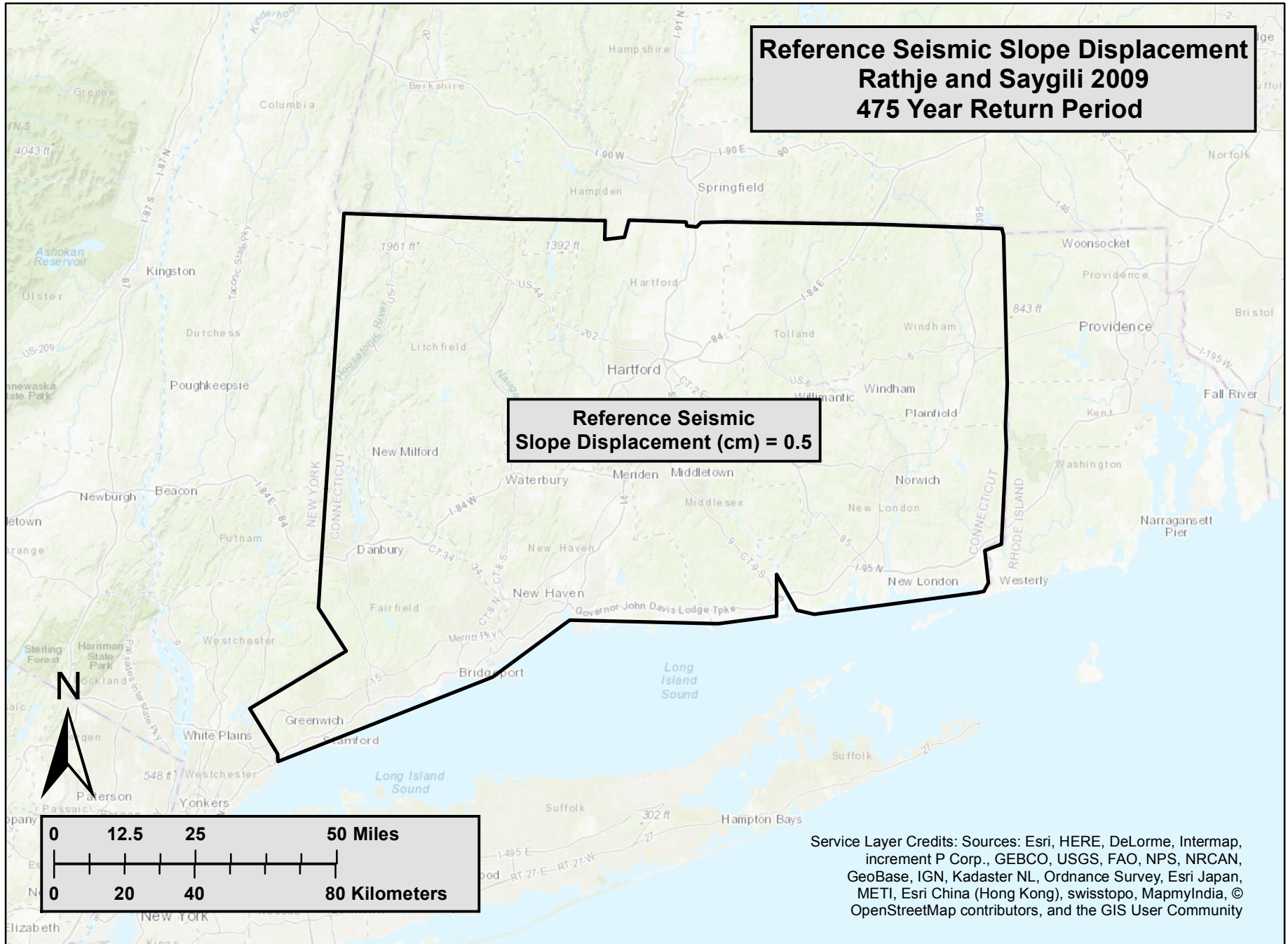
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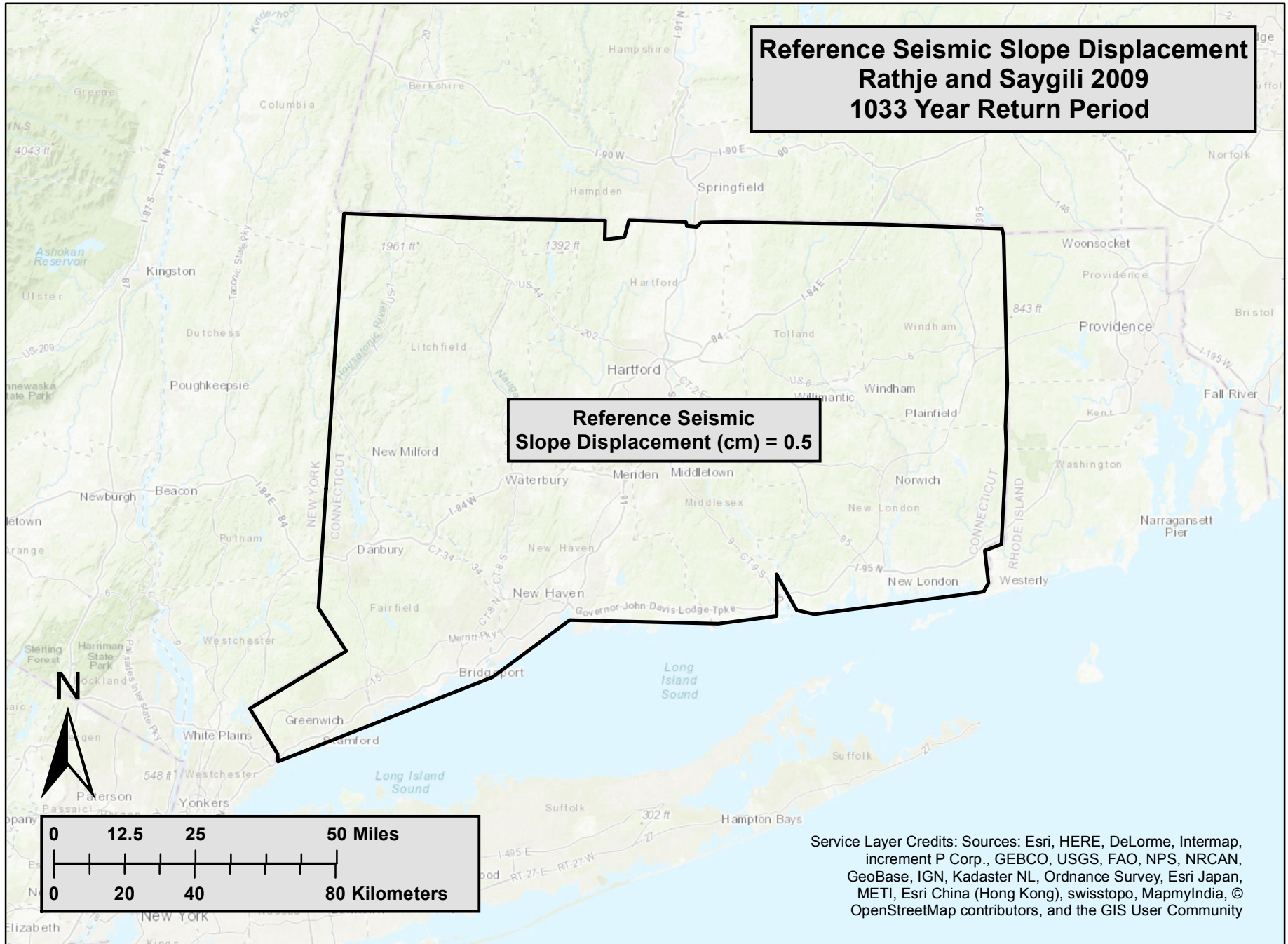


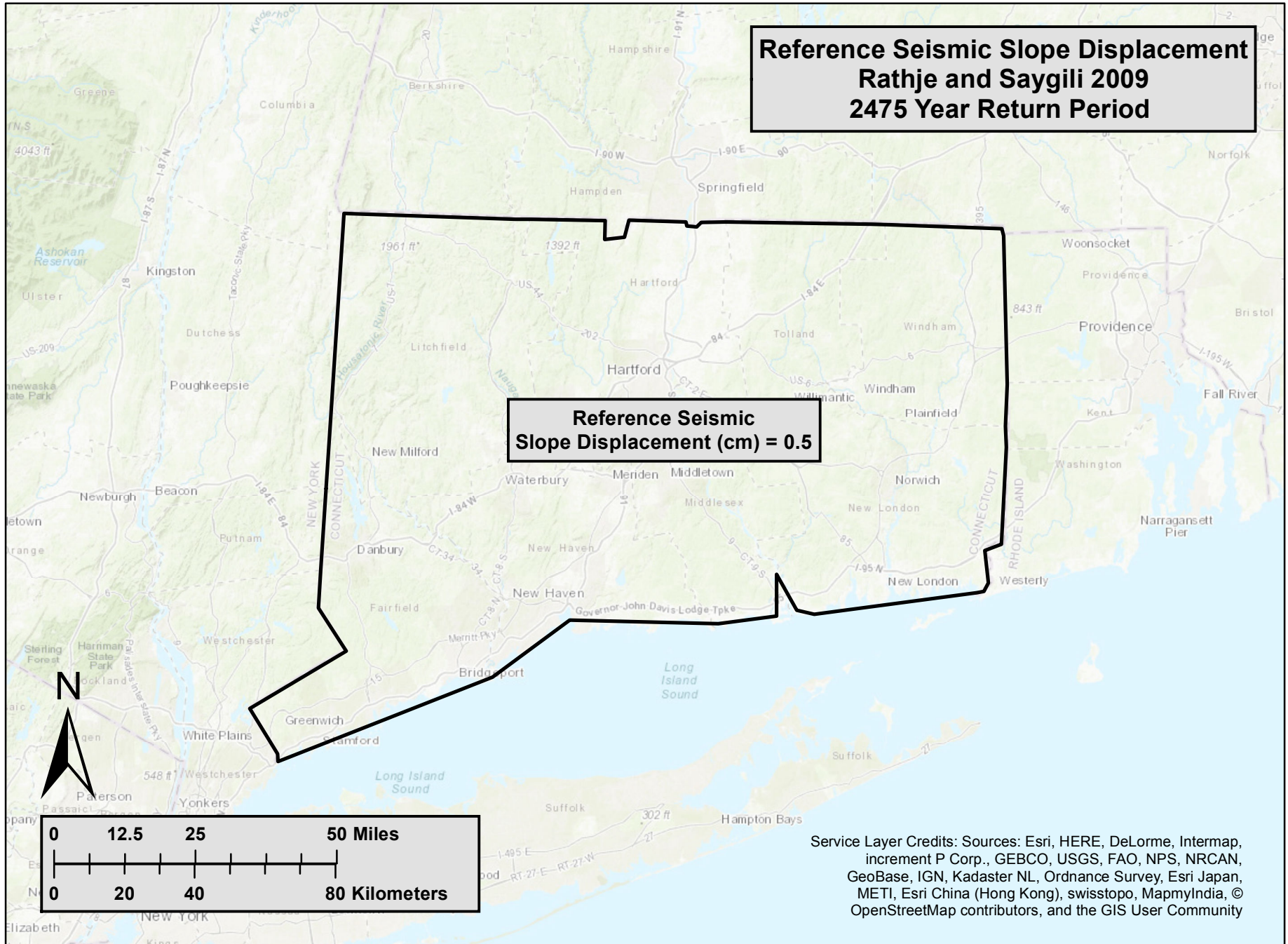






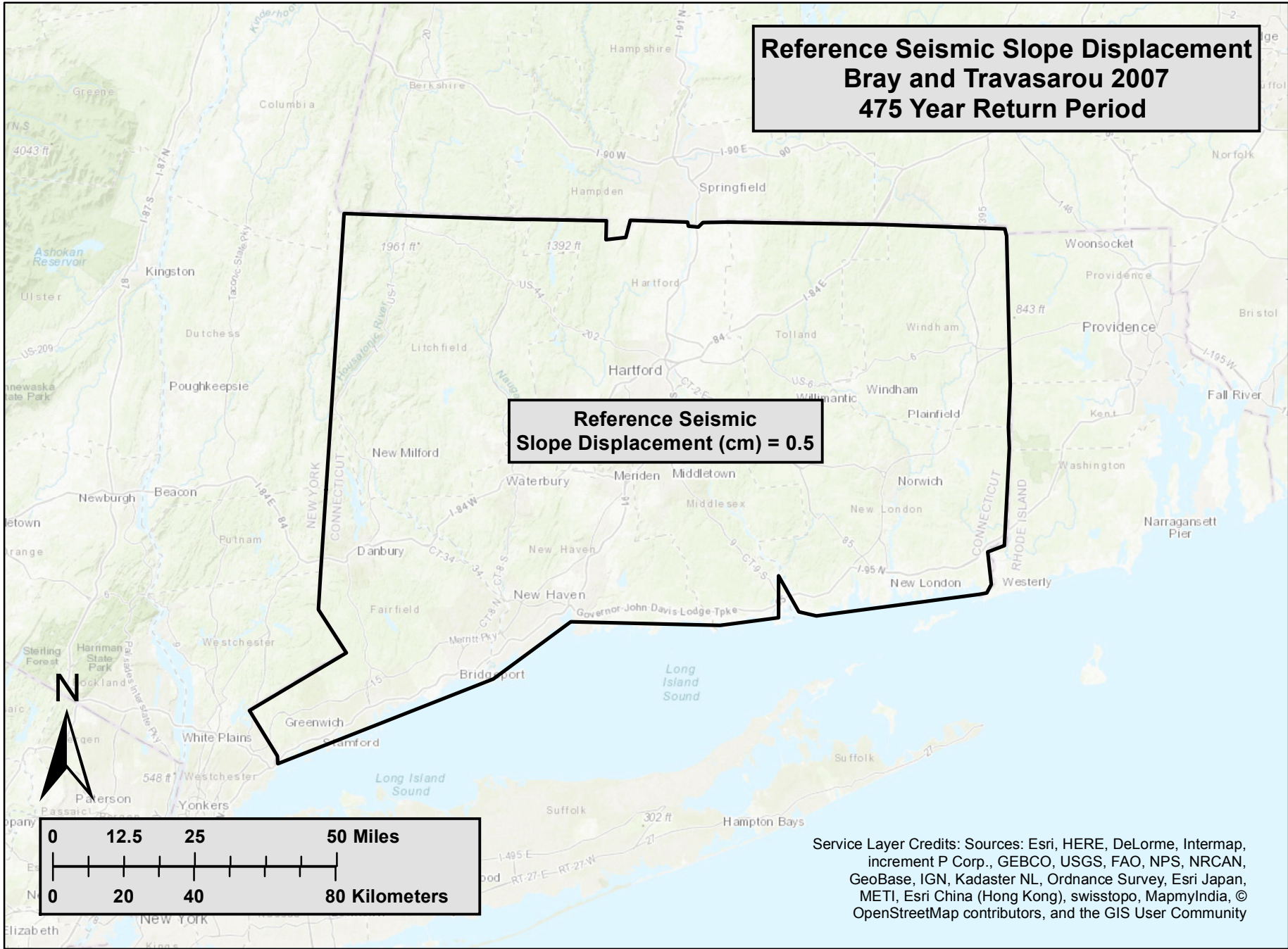




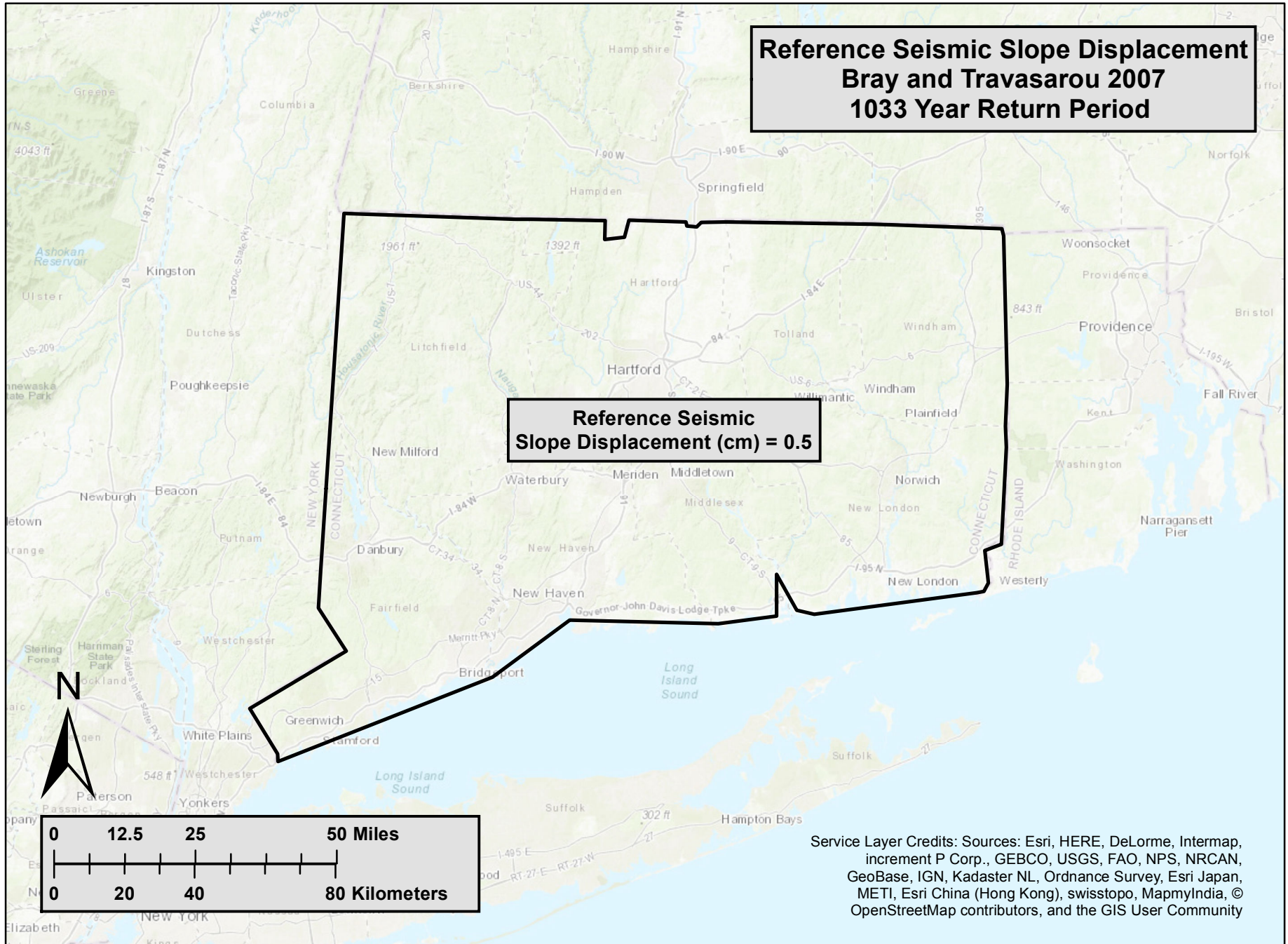


**Reference Seismic Slope Displacement
Bray and Travararou 2007
475 Year Return Period**

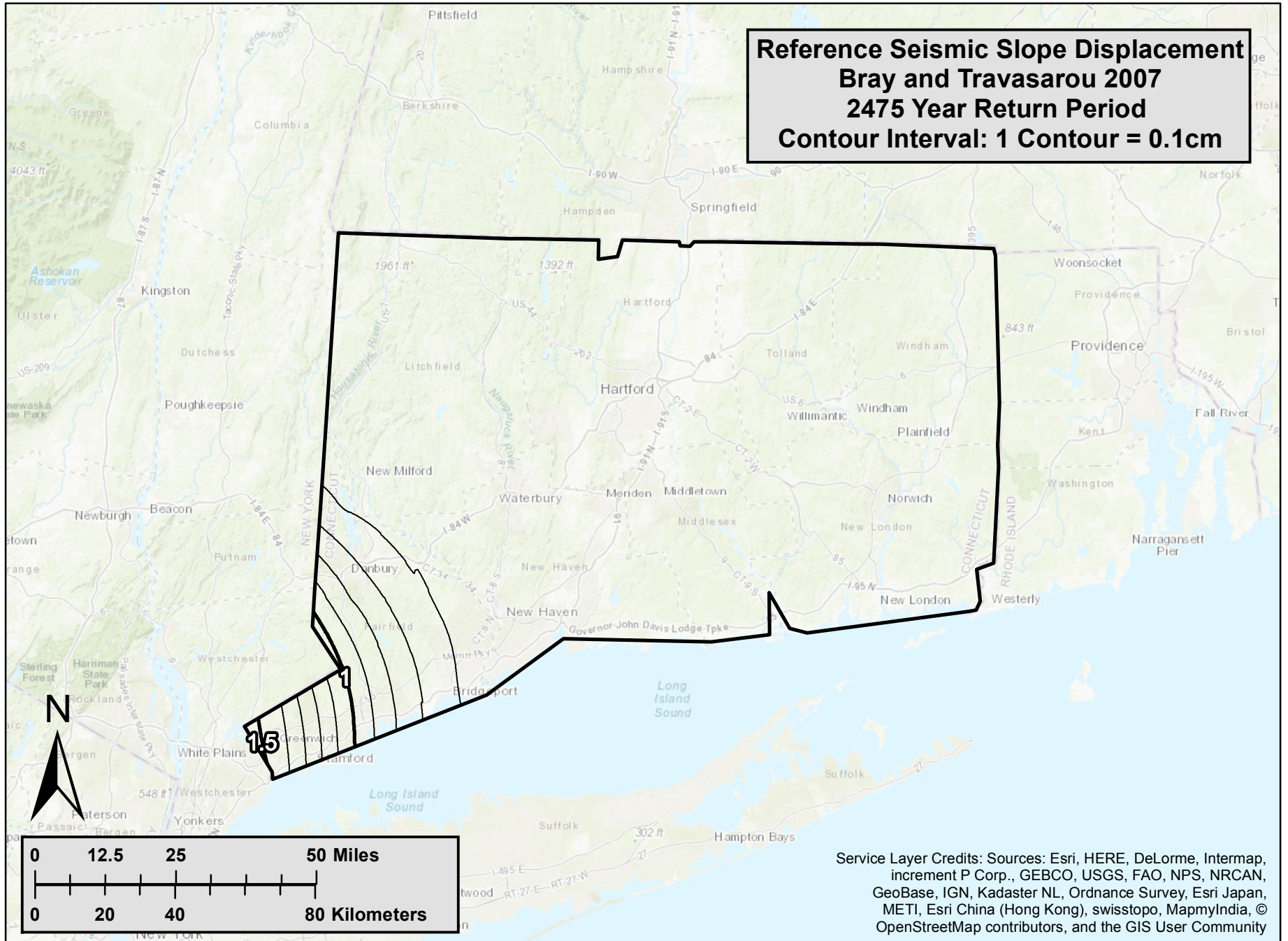
**Reference Seismic
Slope Displacement (cm) = 0.5**



Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

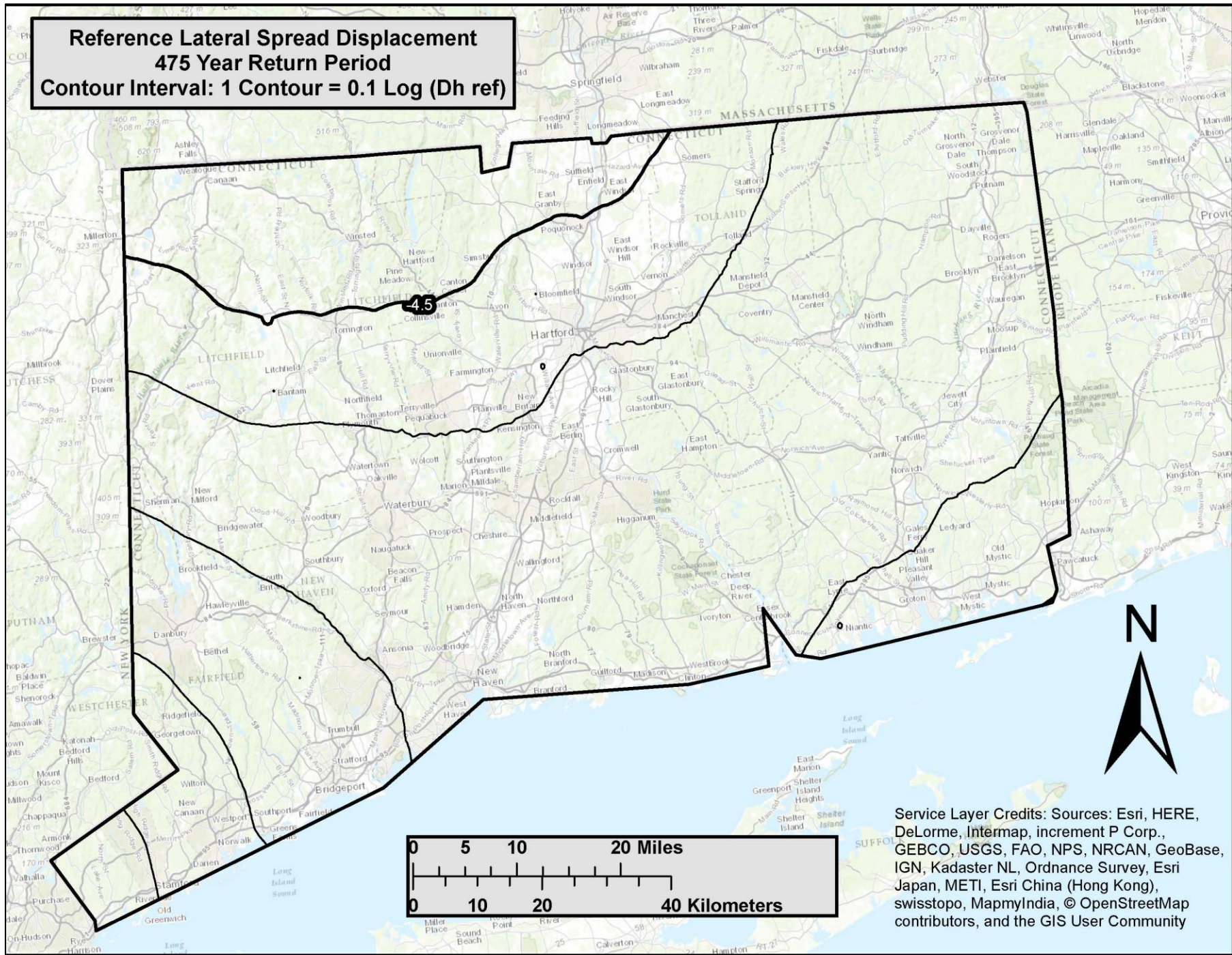


**Reference Seismic Slope Displacement
Bray and Travasarou 2007
2475 Year Return Period
Contour Interval: 1 Contour = 0.1cm**



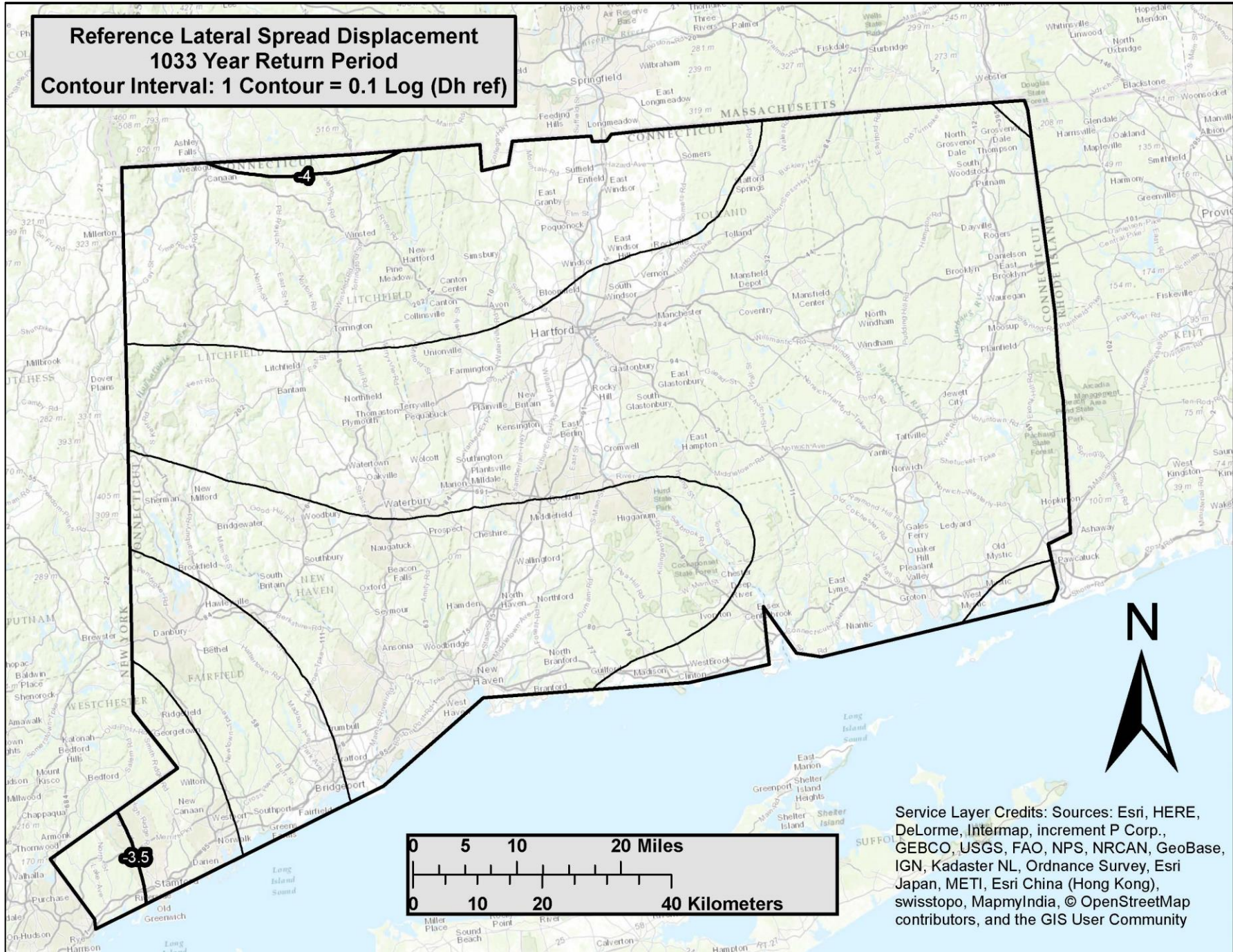
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**Reference Lateral Spread Displacement
475 Year Return Period
Contour Interval: 1 Contour = 0.1 Log (Dh ref)**



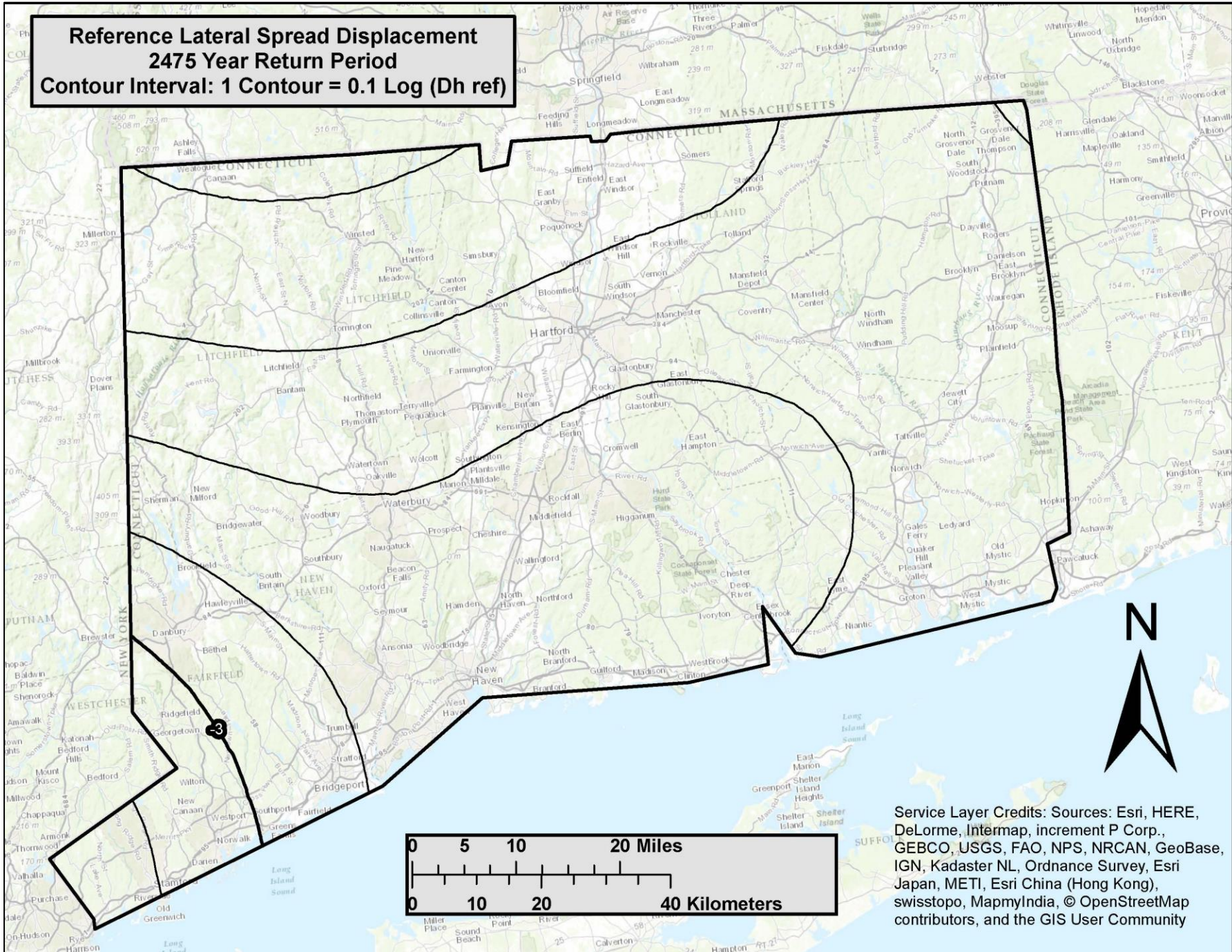
Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

**Reference Lateral Spread Displacement
1033 Year Return Period
Contour Interval: 1 Contour = 0.1 Log (Dh ref)**



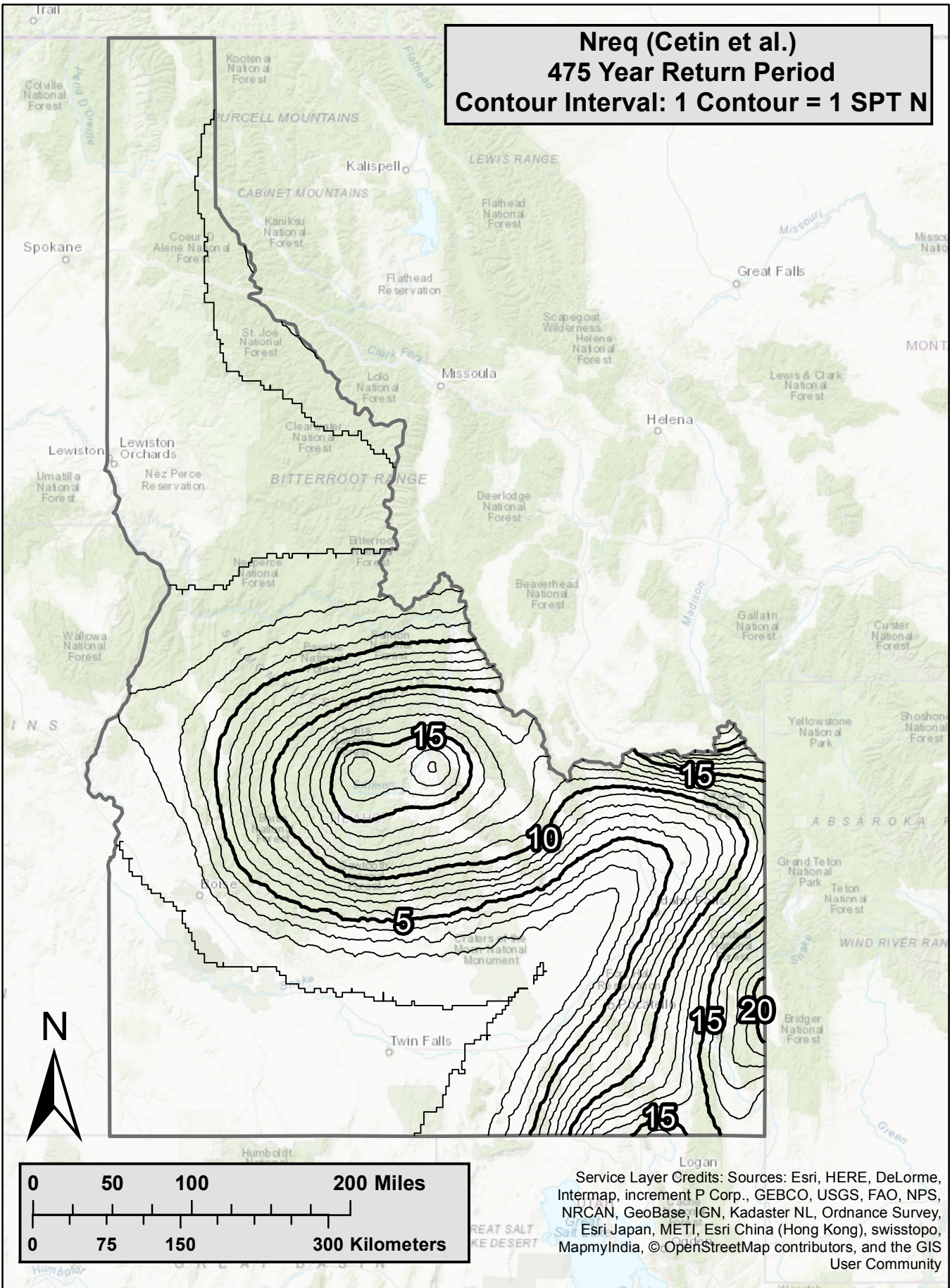
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**Reference Lateral Spread Displacement
2475 Year Return Period
Contour Interval: 1 Contour = 0.1 Log (Dh ref)**

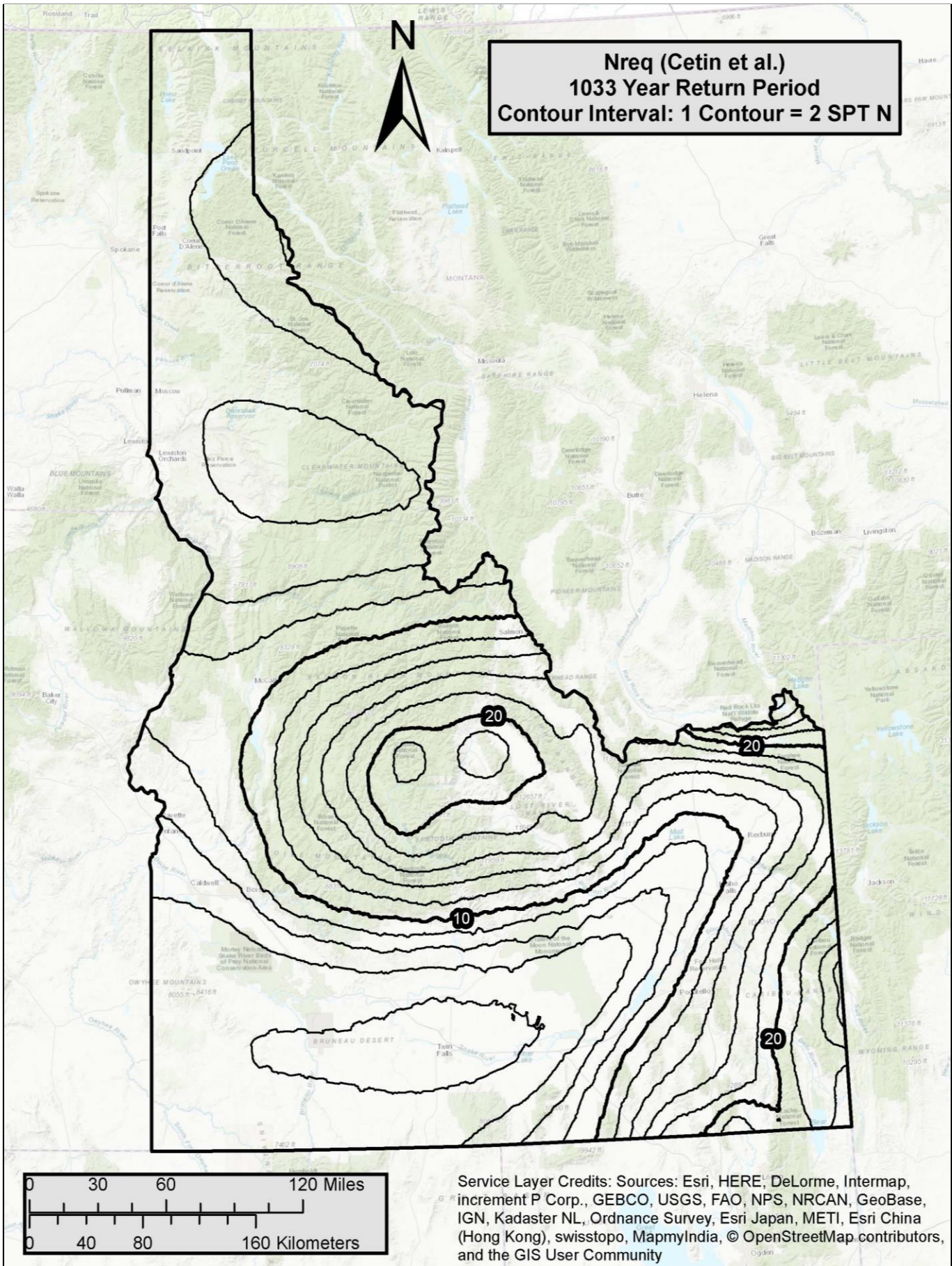


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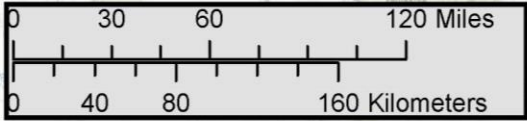
**Nreq (Cetin et al.)
475 Year Return Period
Contour Interval: 1 Contour = 1 SPT N**



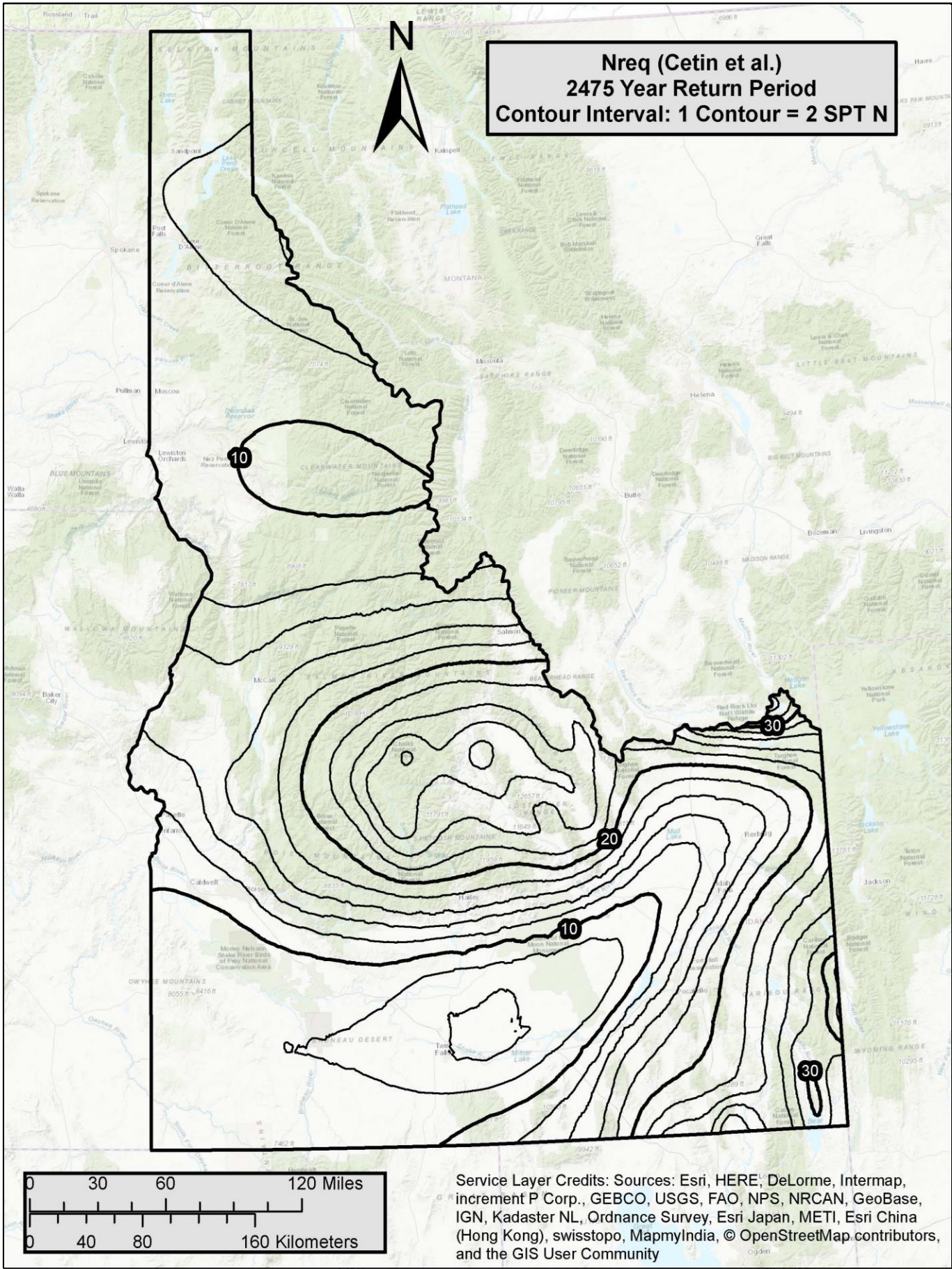
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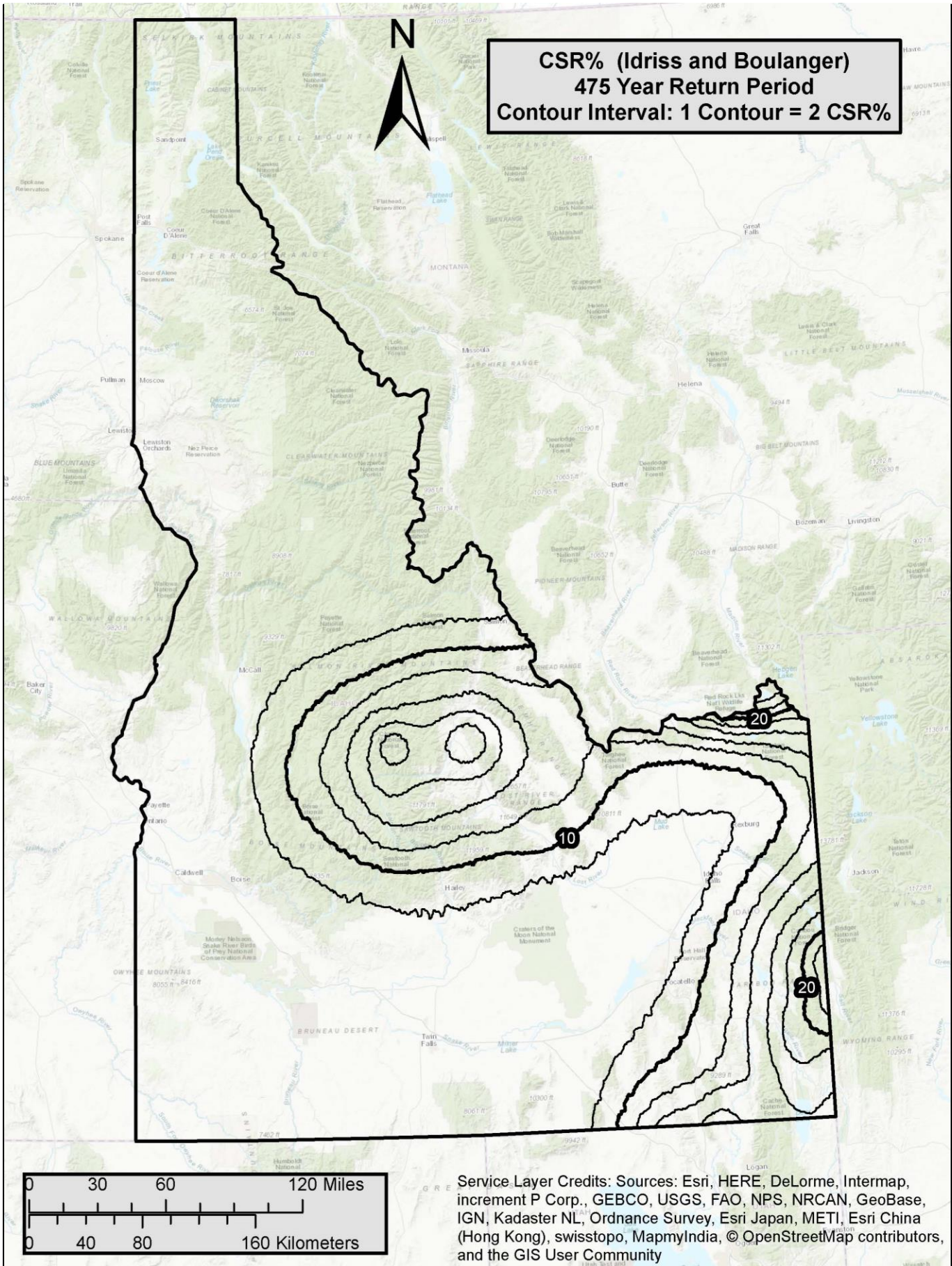


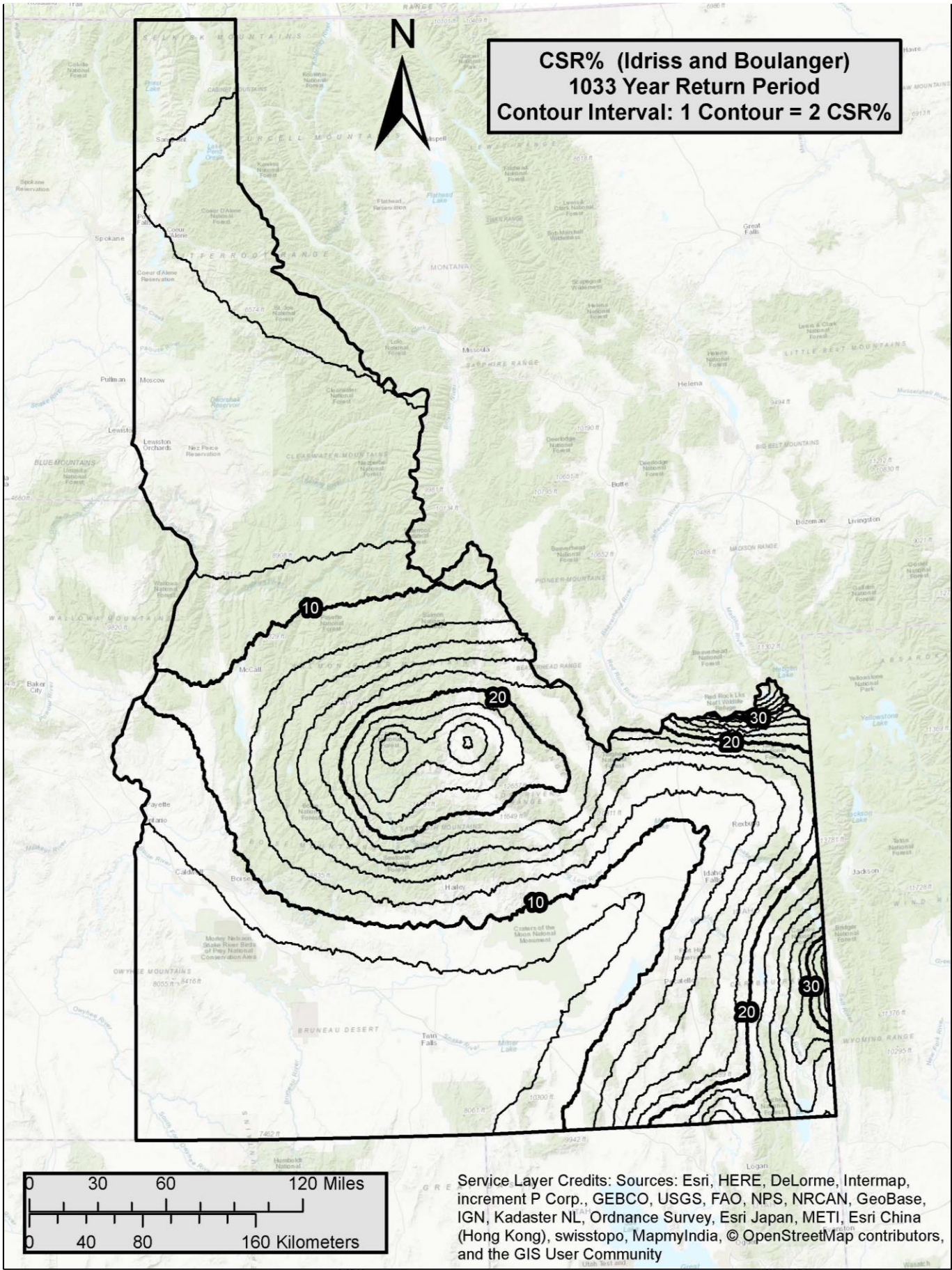
**Nreq (Cetin et al.)
1033 Year Return Period
Contour Interval: 1 Contour = 2 SPT N**

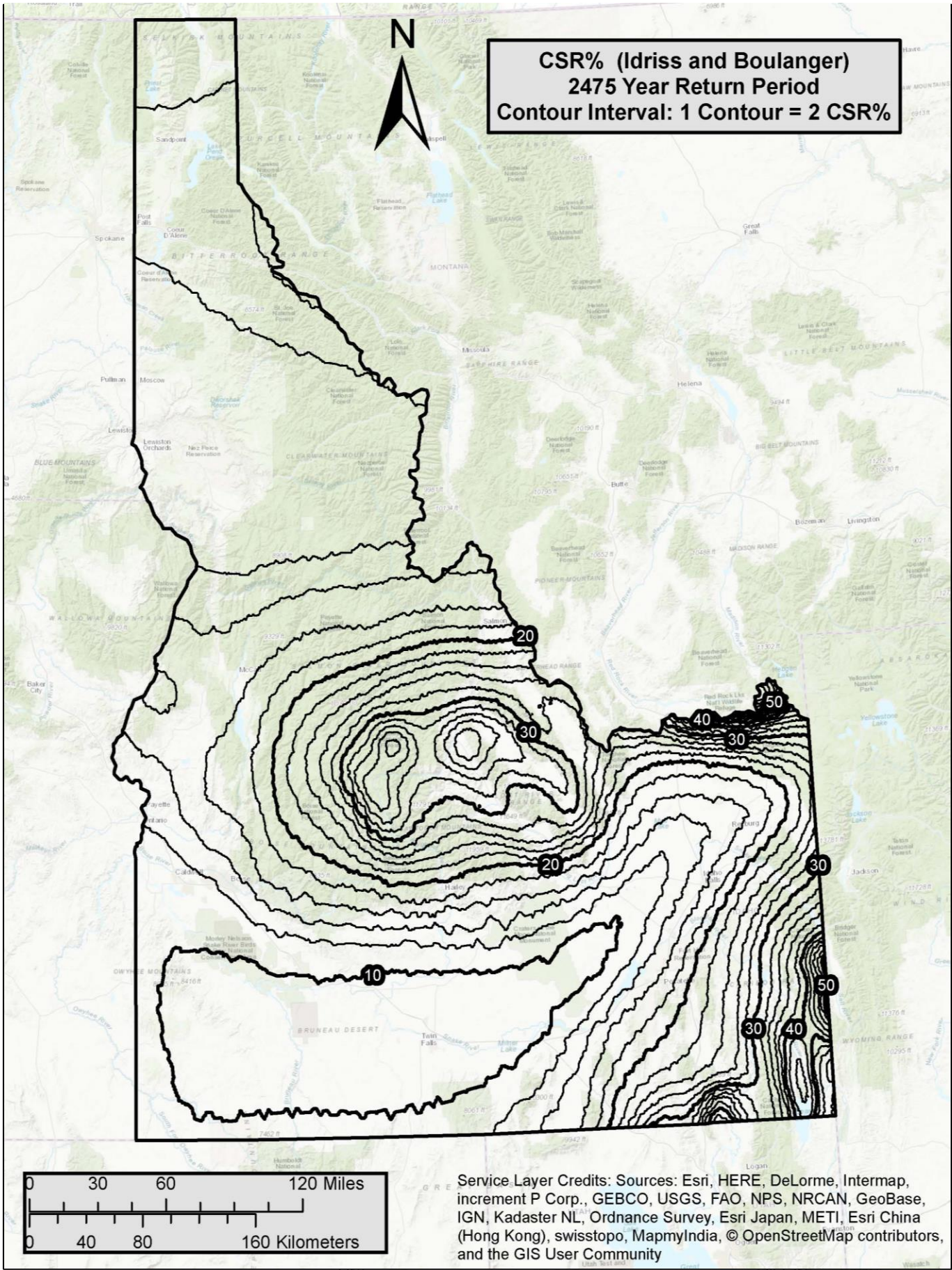


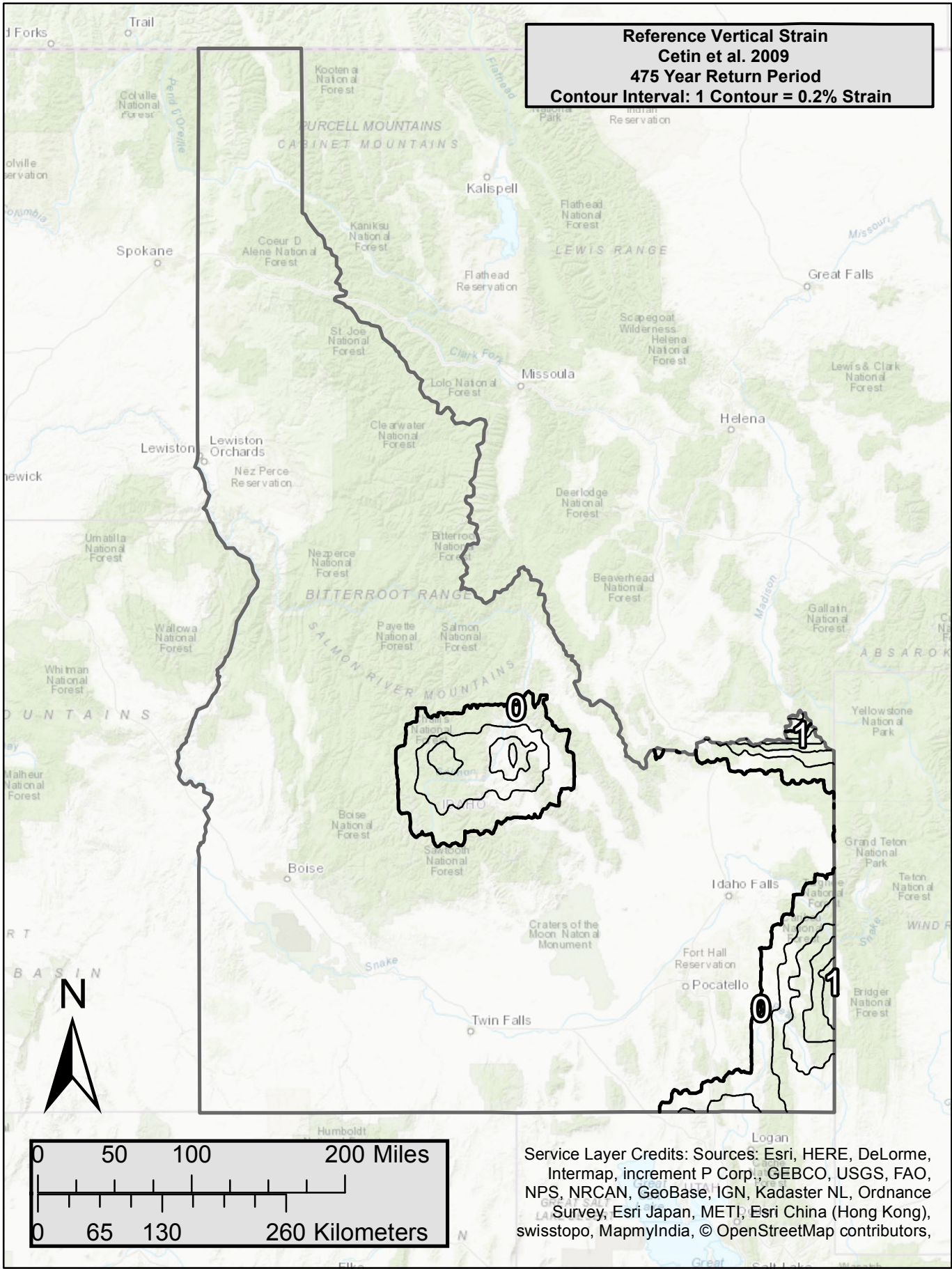
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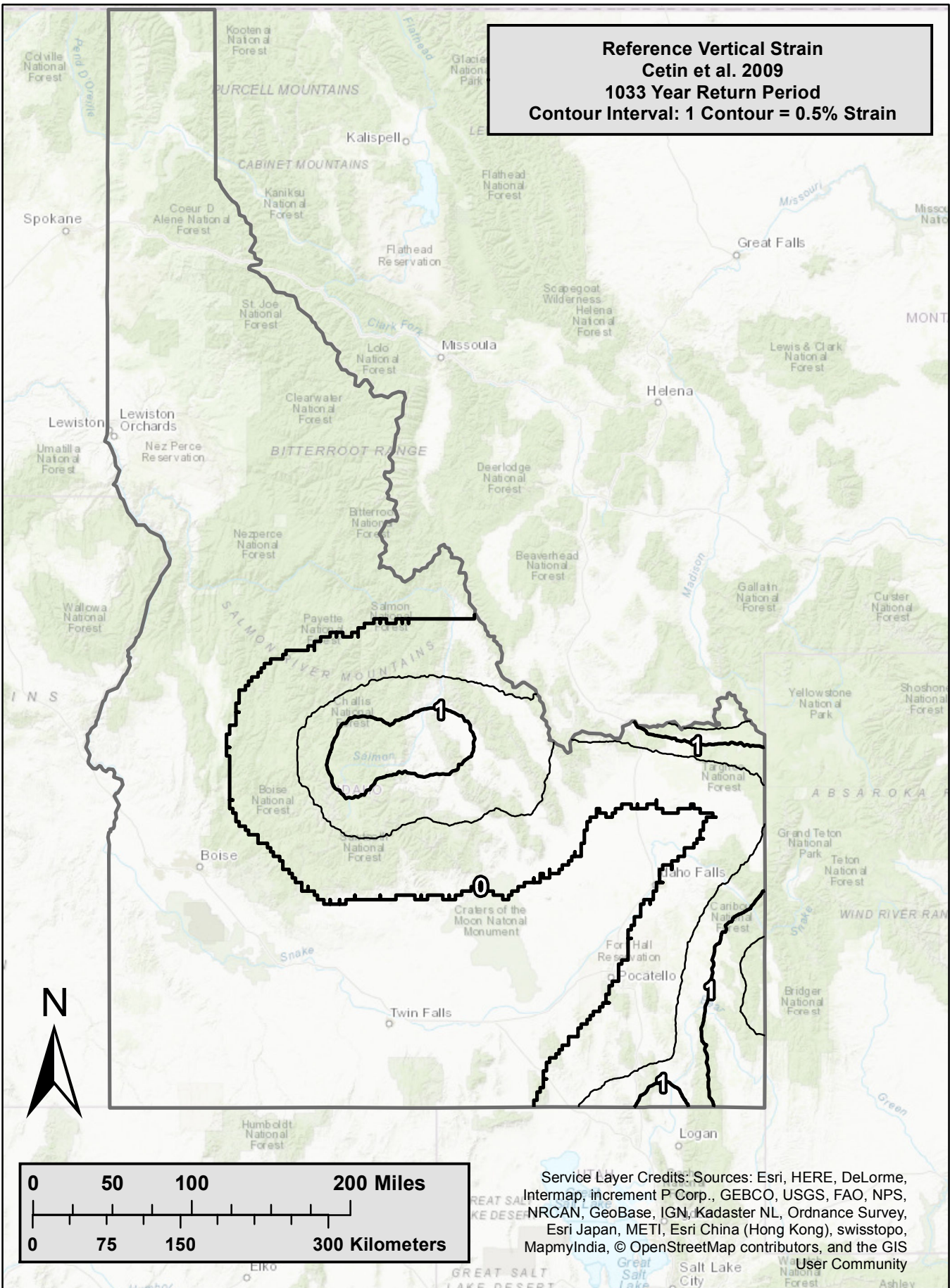






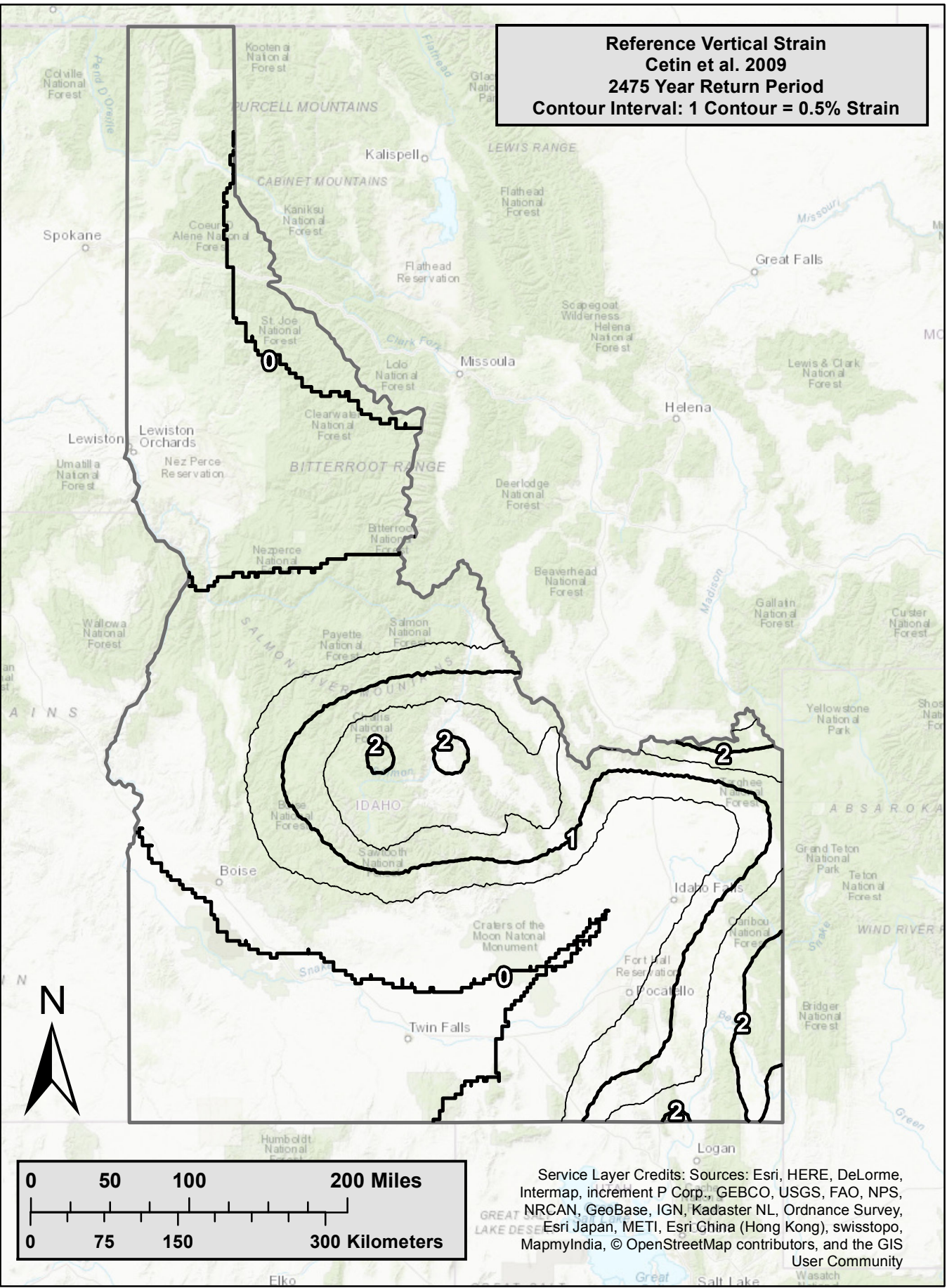


Reference Vertical Strain
Cetin et al. 2009
1033 Year Return Period
Contour Interval: 1 Contour = 0.5% Strain



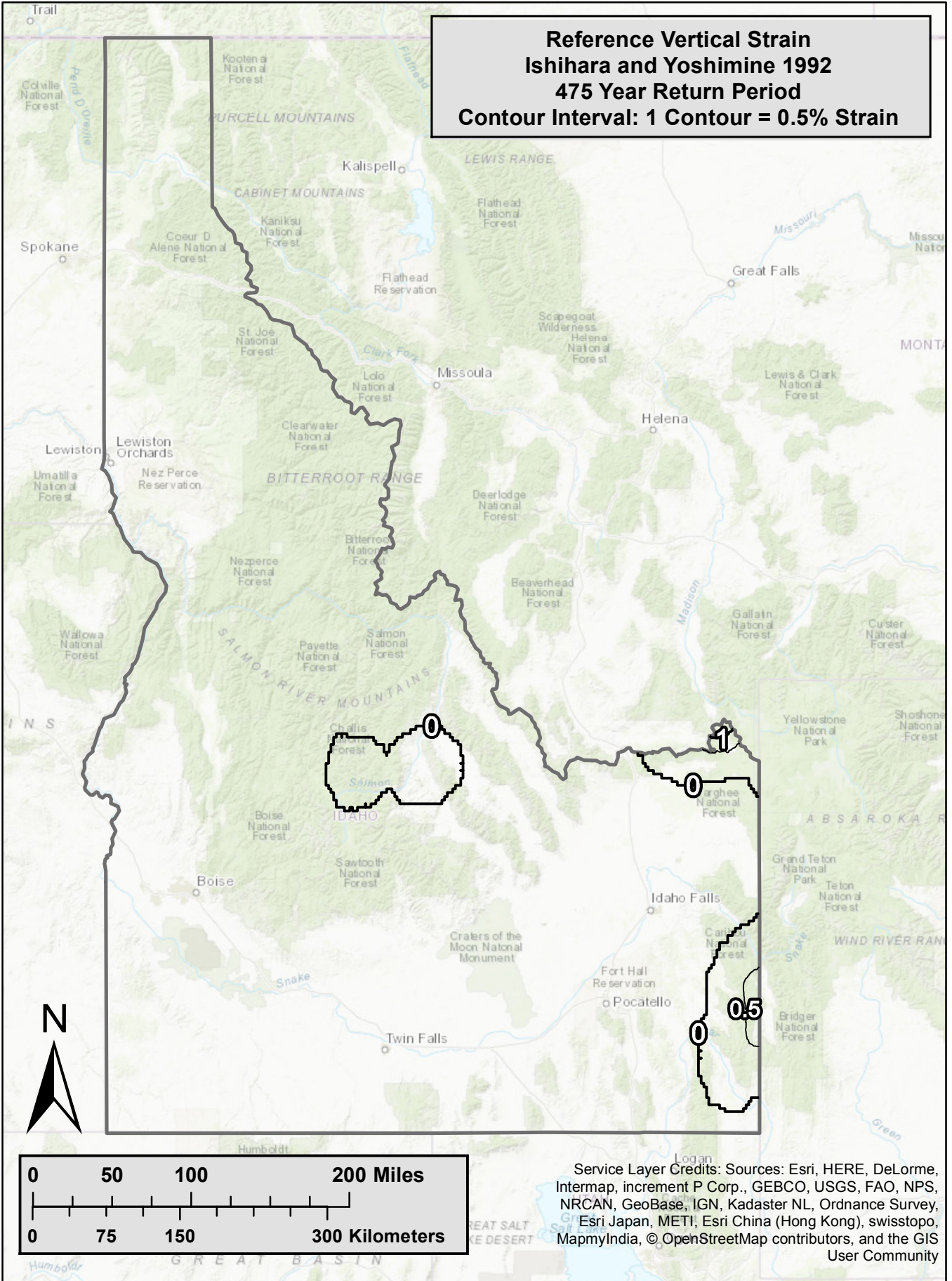
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**Reference Vertical Strain
Cetin et al. 2009
2475 Year Return Period
Contour Interval: 1 Contour = 0.5% Strain**



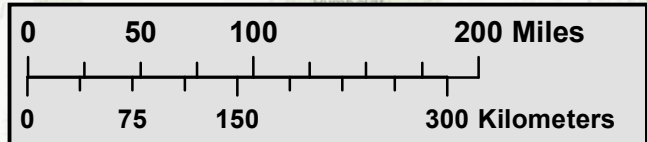
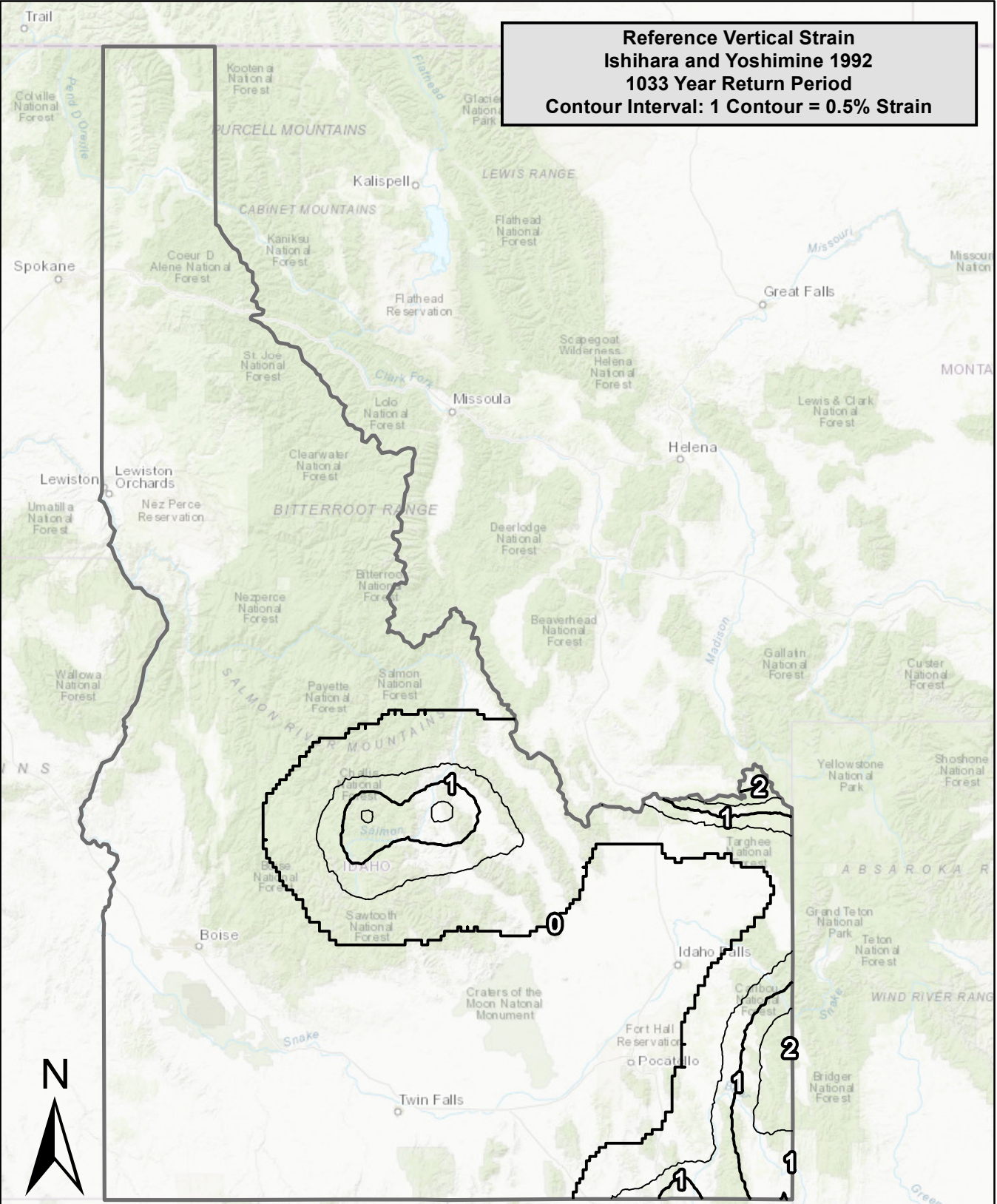
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**Reference Vertical Strain
Ishihara and Yoshimine 1992
475 Year Return Period
Contour Interval: 1 Contour = 0.5% Strain**



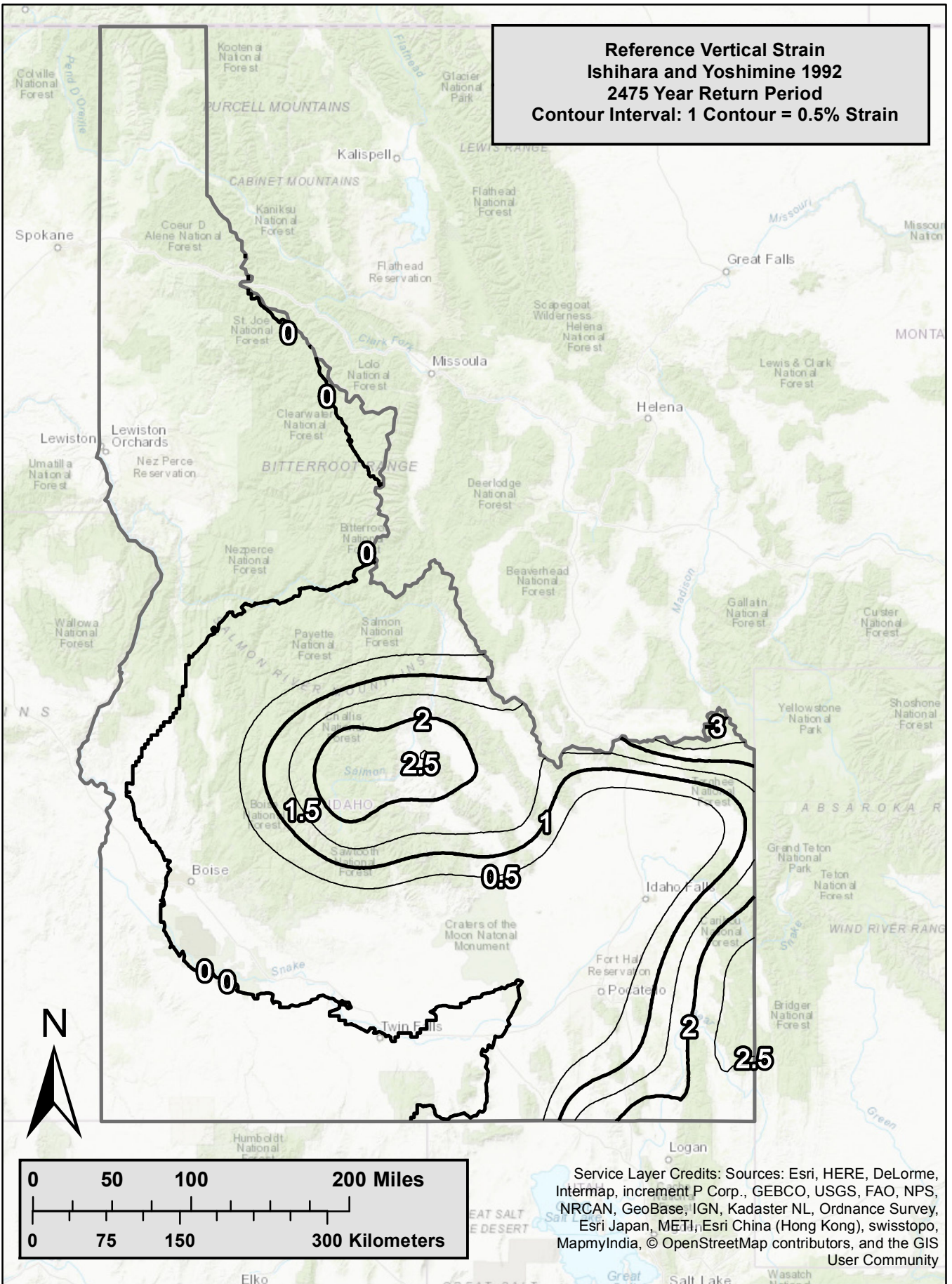
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**Reference Vertical Strain
Ishihara and Yoshimine 1992
1033 Year Return Period
Contour Interval: 1 Contour = 0.5% Strain**



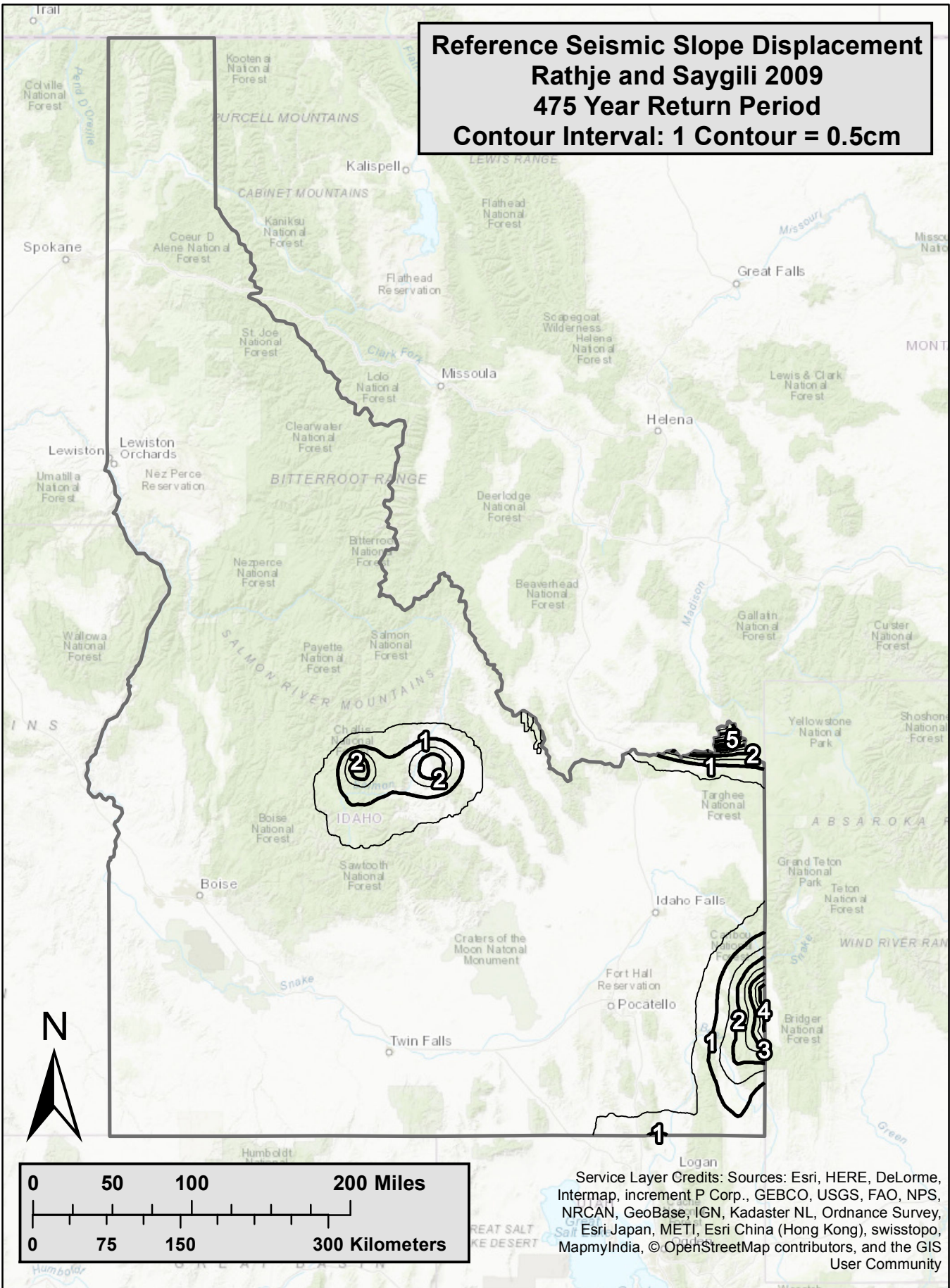
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**Reference Vertical Strain
Ishihara and Yoshimine 1992
2475 Year Return Period
Contour Interval: 1 Contour = 0.5% Strain**



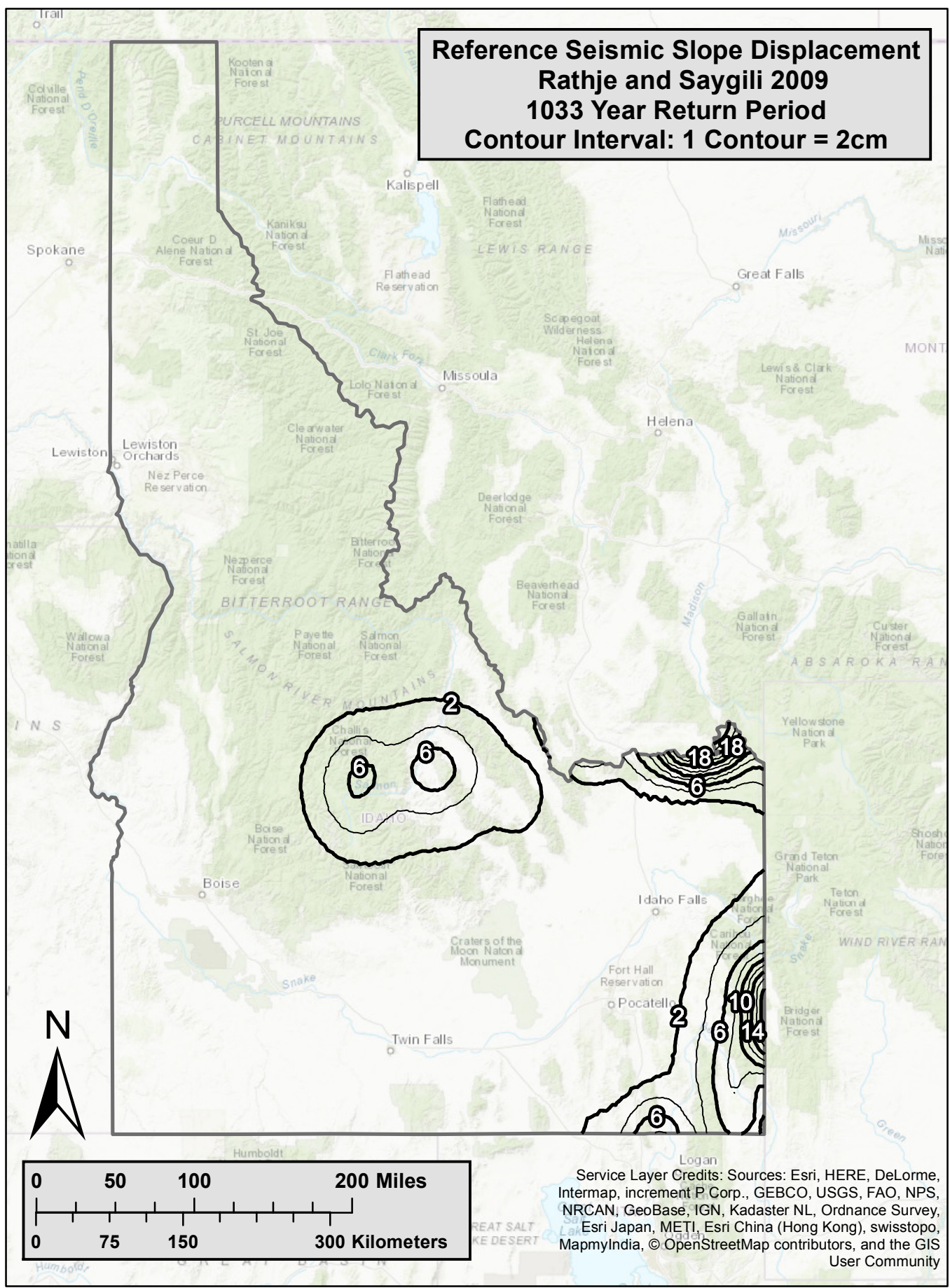
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**Reference Seismic Slope Displacement
Rathje and Saygili 2009
475 Year Return Period
Contour Interval: 1 Contour = 0.5cm**



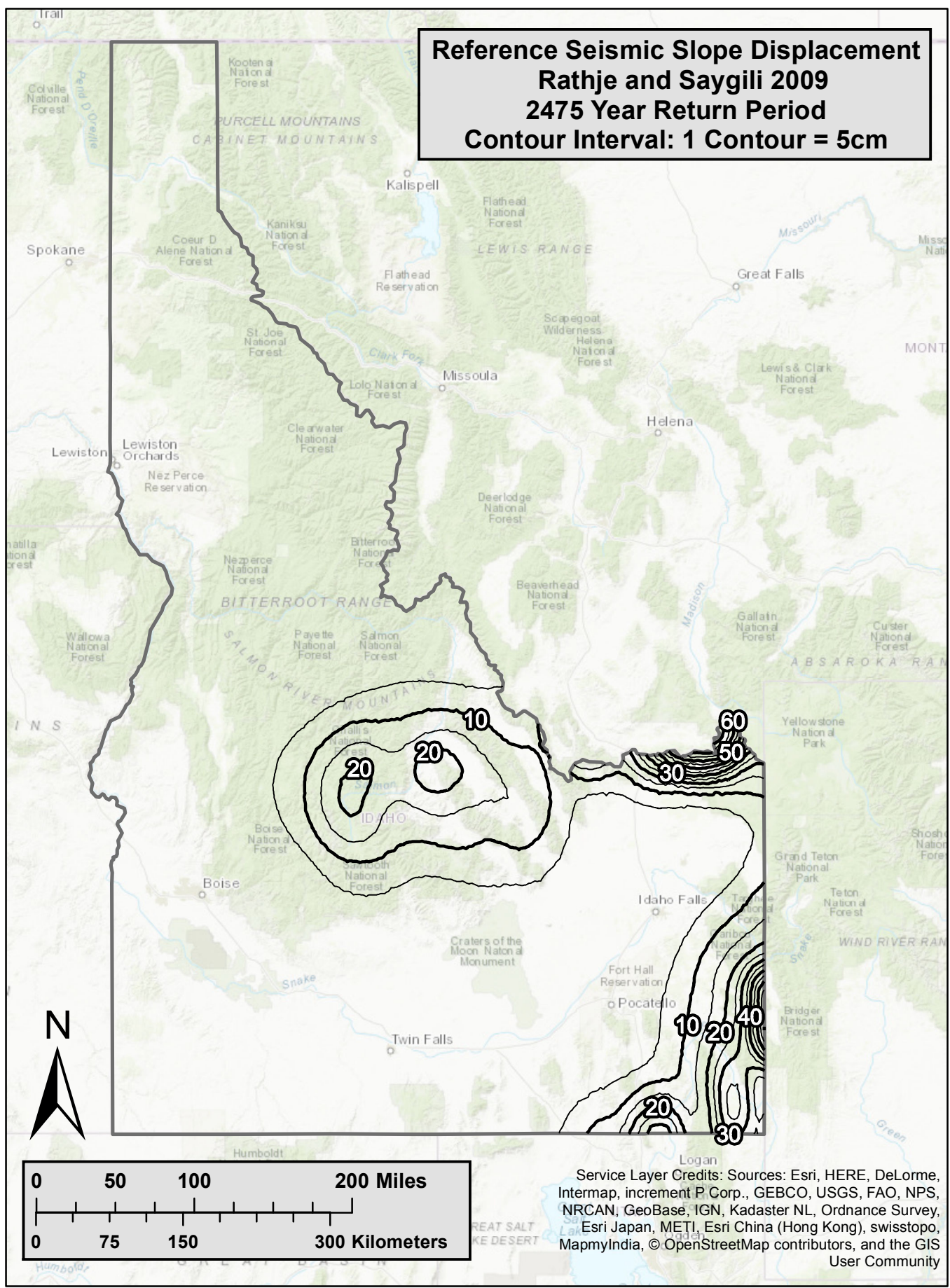
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**Reference Seismic Slope Displacement
Rathje and Saygili 2009
1033 Year Return Period
Contour Interval: 1 Contour = 2cm**



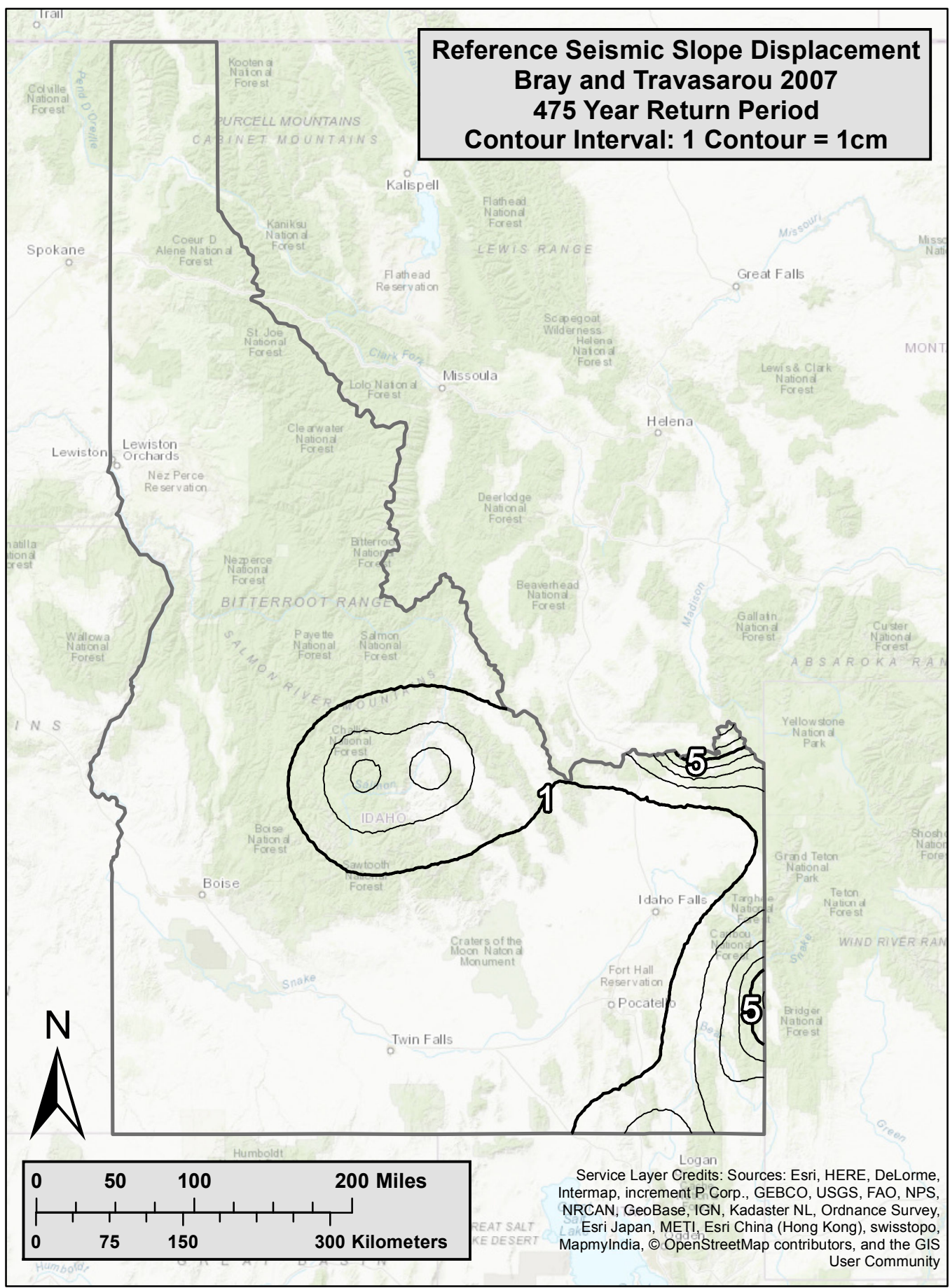
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**Reference Seismic Slope Displacement
Rathje and Saygili 2009
2475 Year Return Period
Contour Interval: 1 Contour = 5cm**



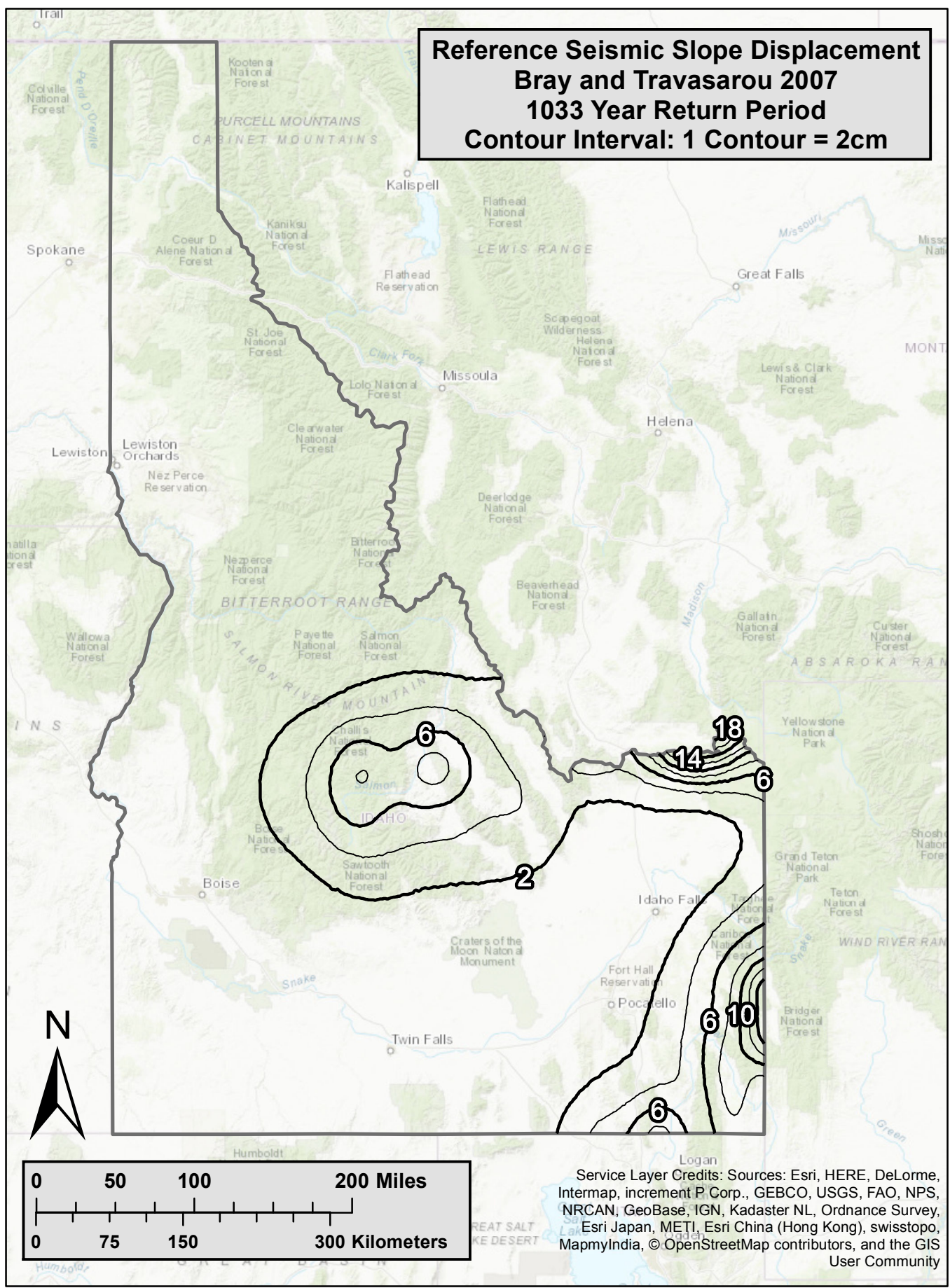
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**Reference Seismic Slope Displacement
 Bray and Travasarou 2007
 475 Year Return Period
 Contour Interval: 1 Contour = 1cm**



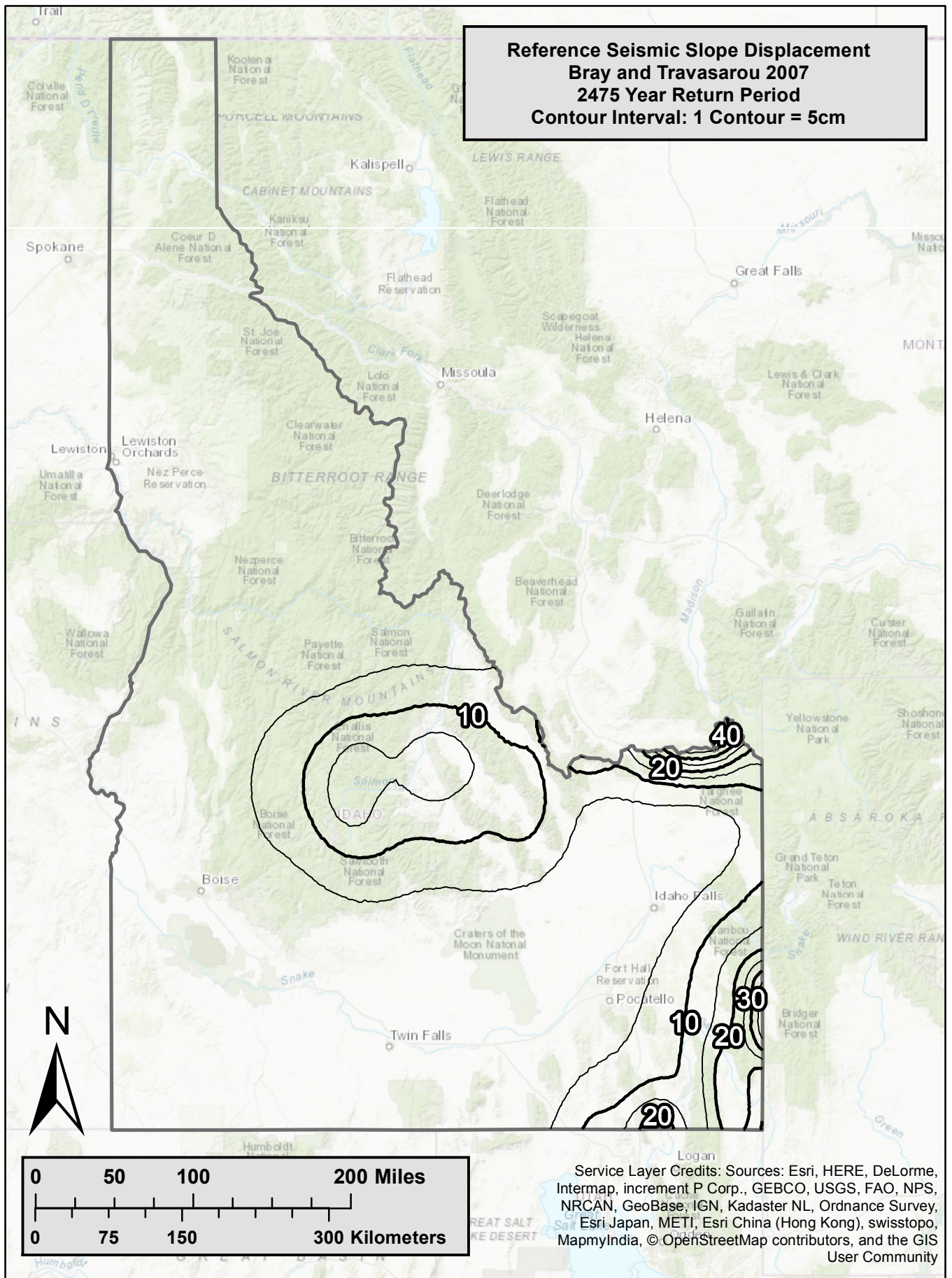
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**Reference Seismic Slope Displacement
 Bray and Travasarou 2007
 1033 Year Return Period
 Contour Interval: 1 Contour = 2cm**

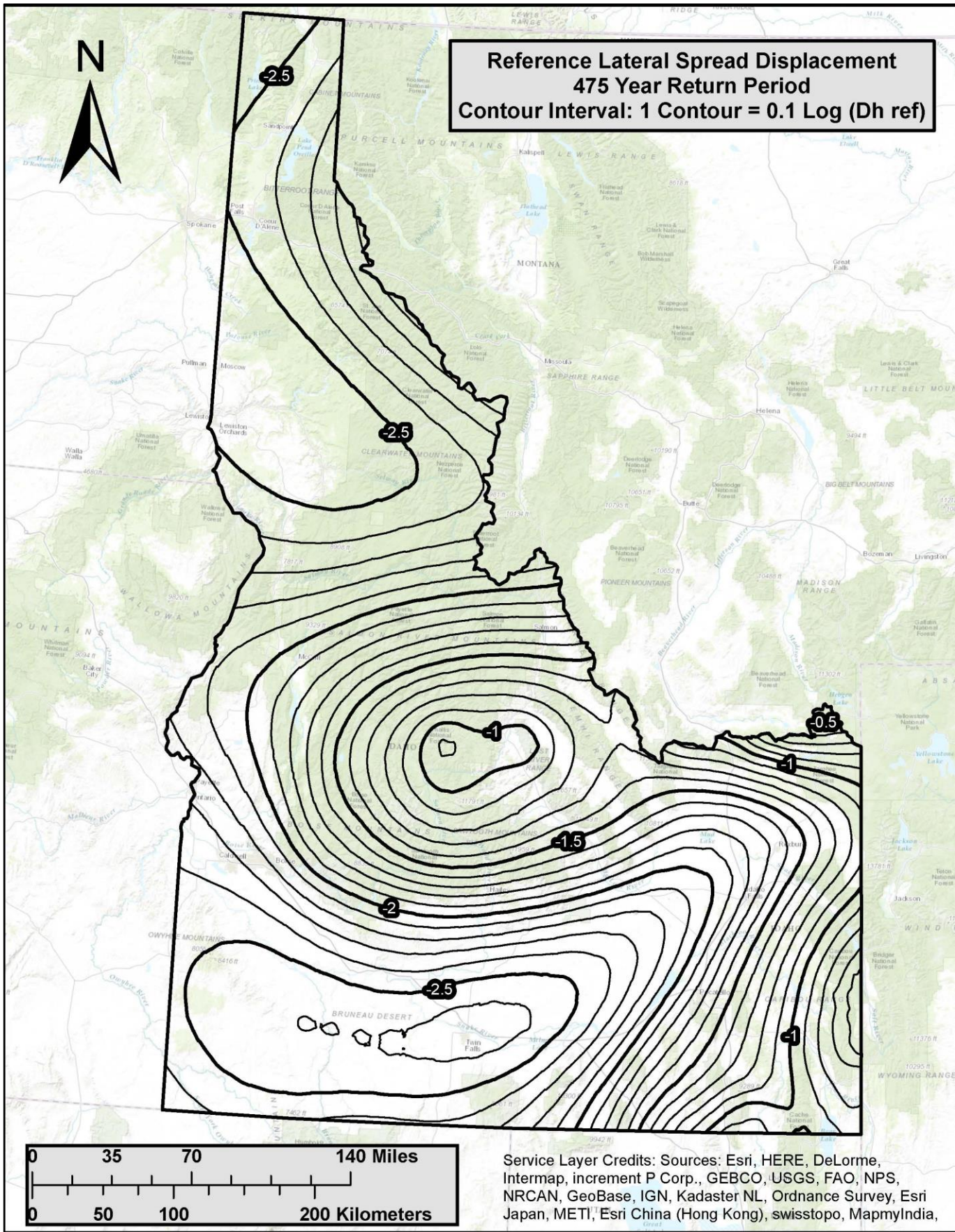


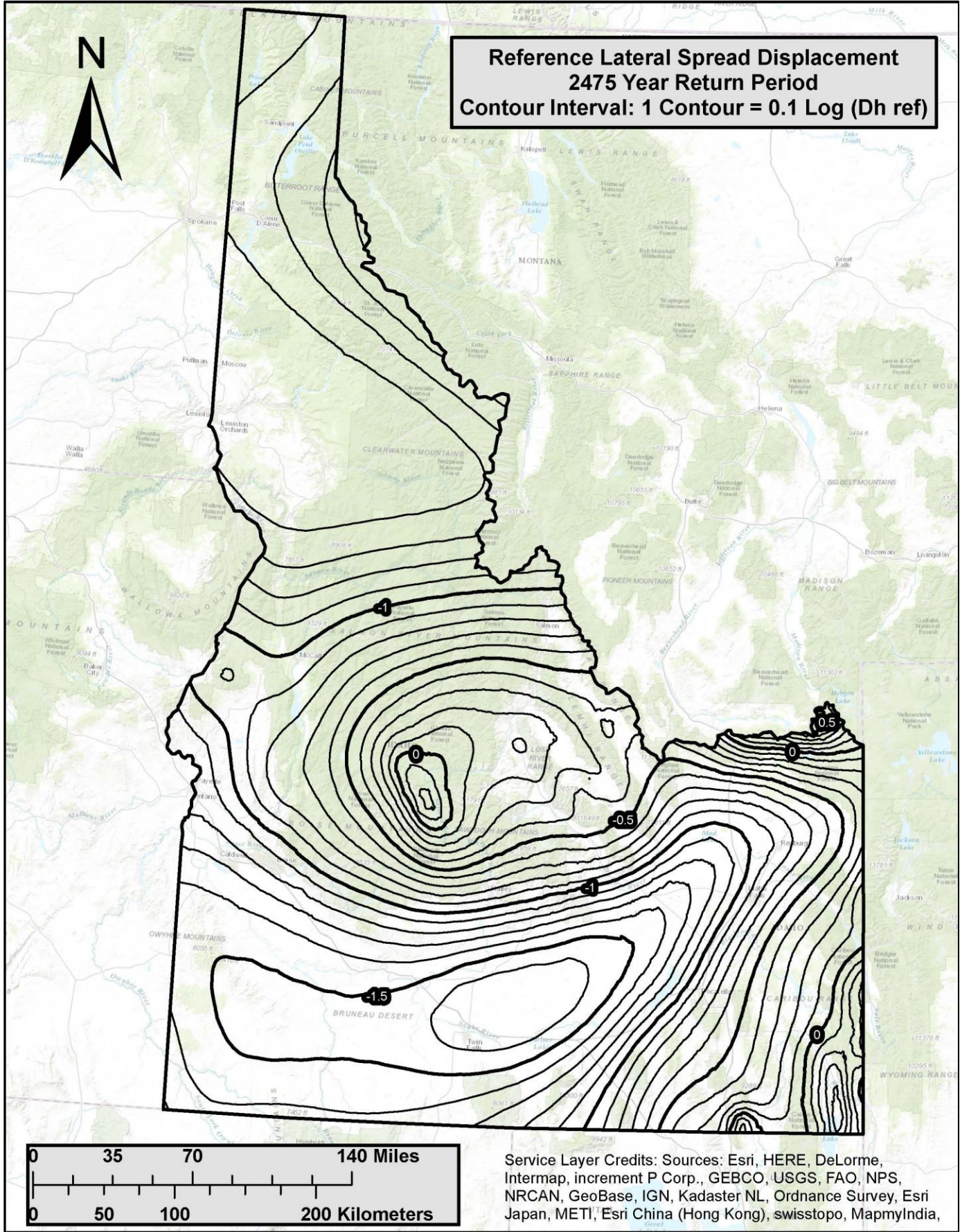
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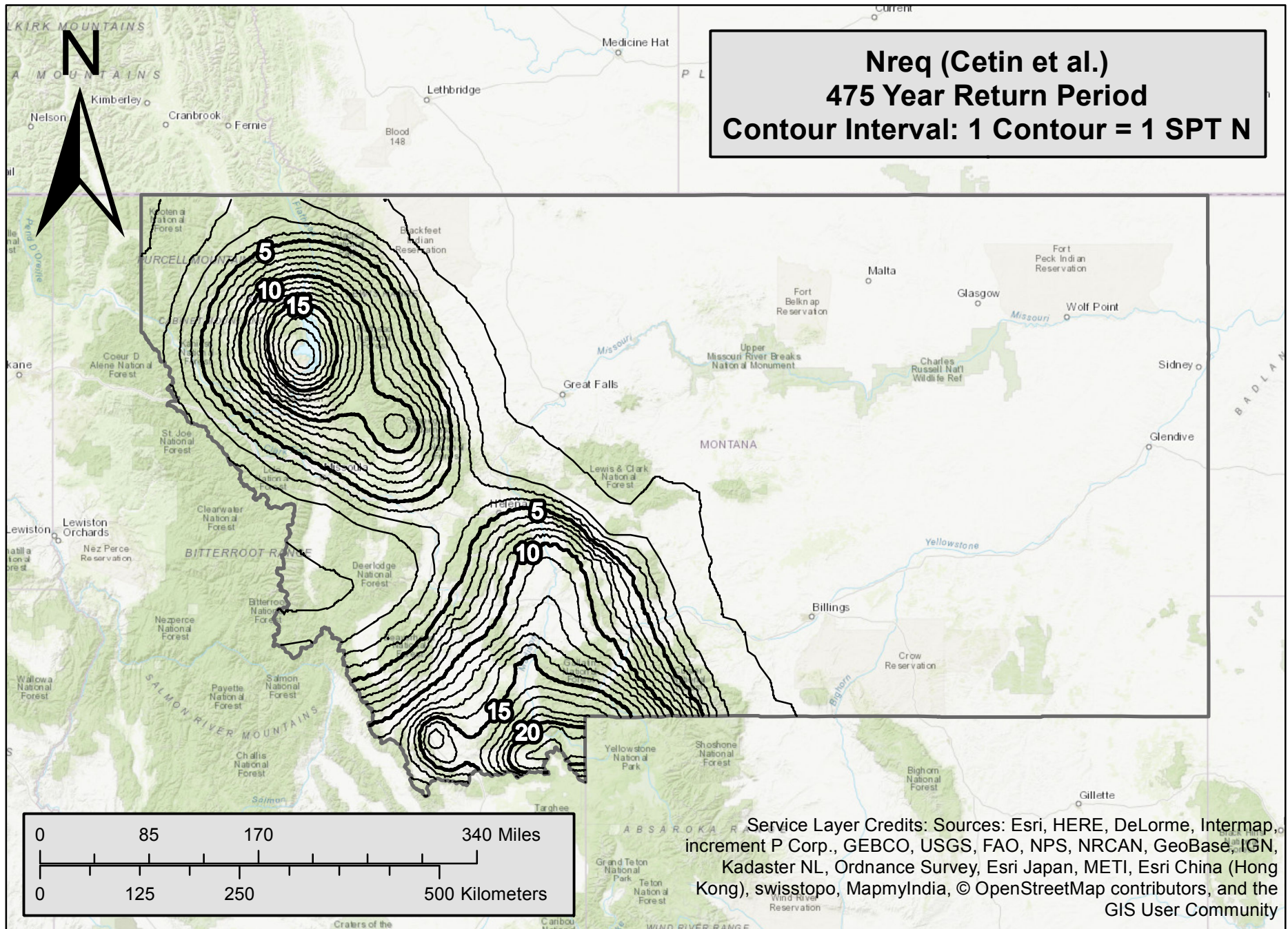
**Reference Seismic Slope Displacement
Bray and Travararou 2007
2475 Year Return Period
Contour Interval: 1 Contour = 5cm**

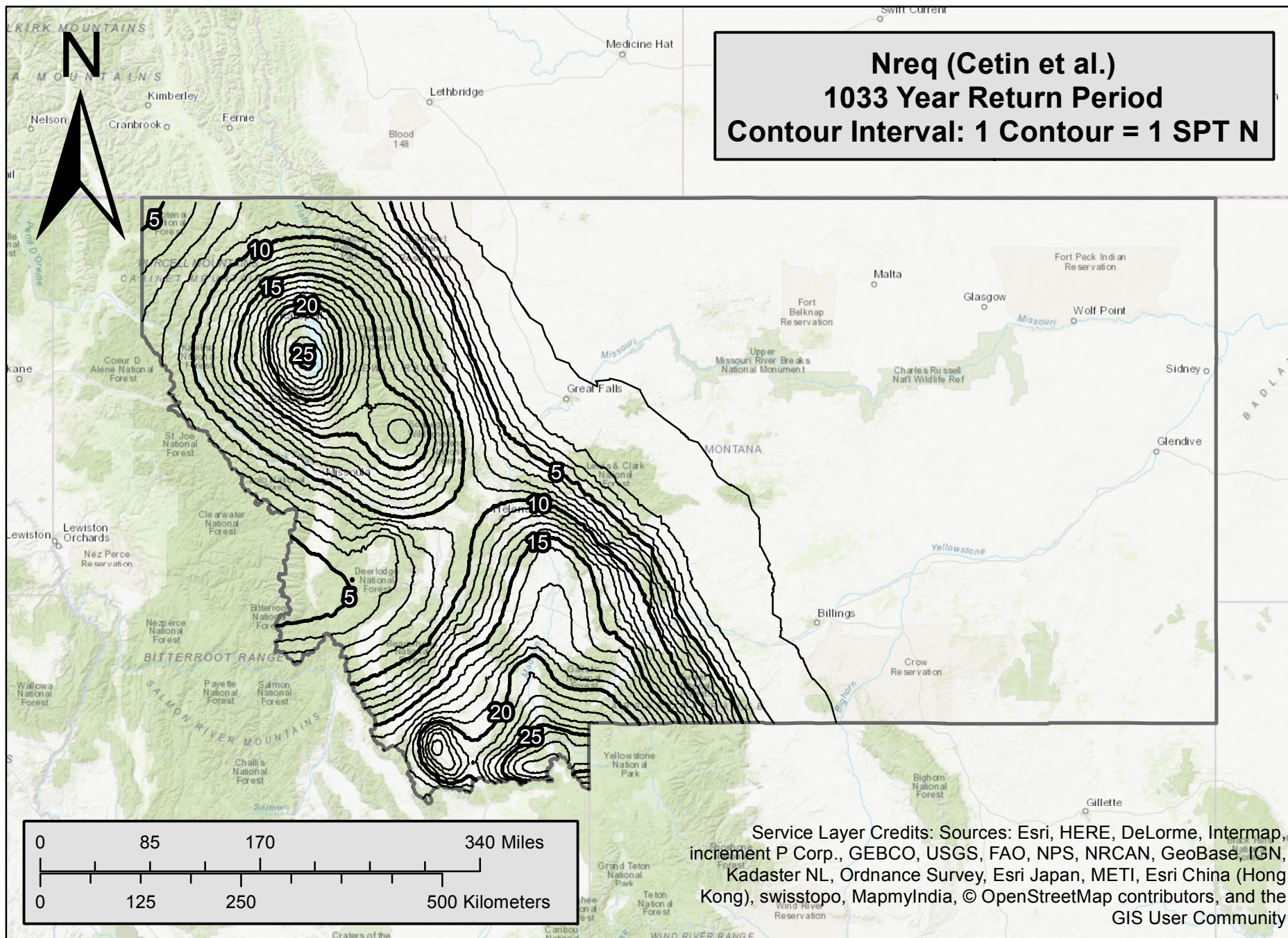


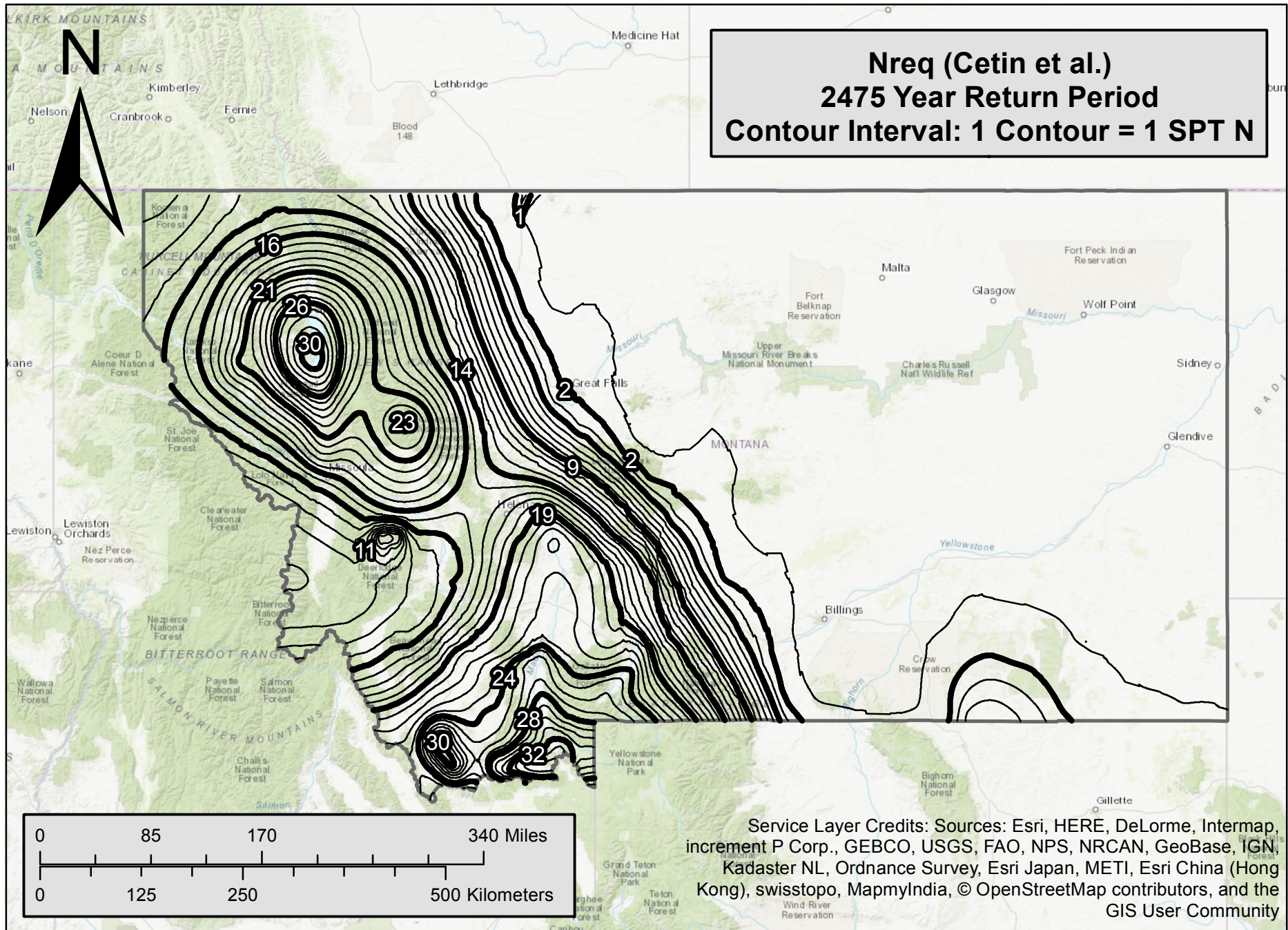
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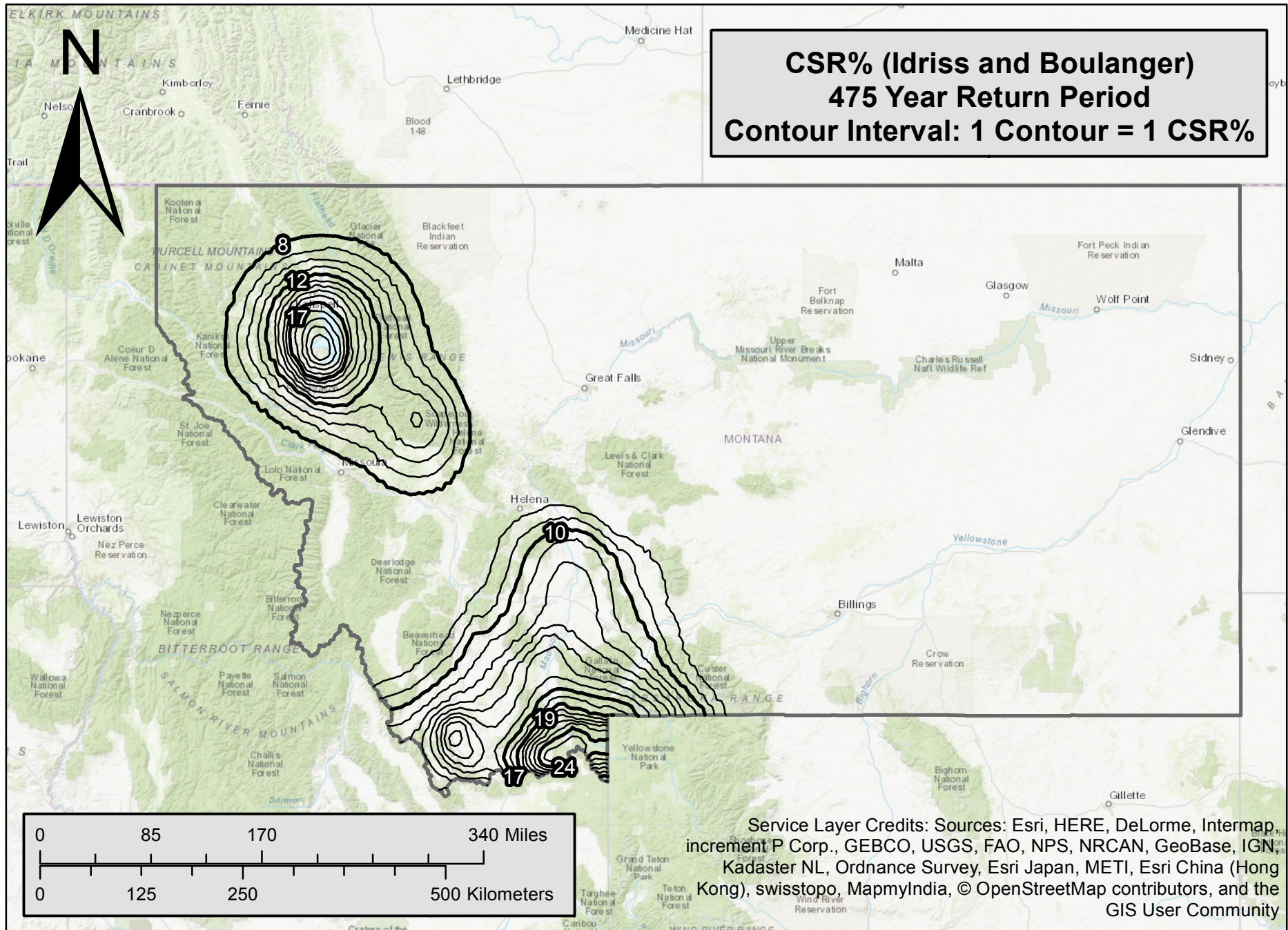


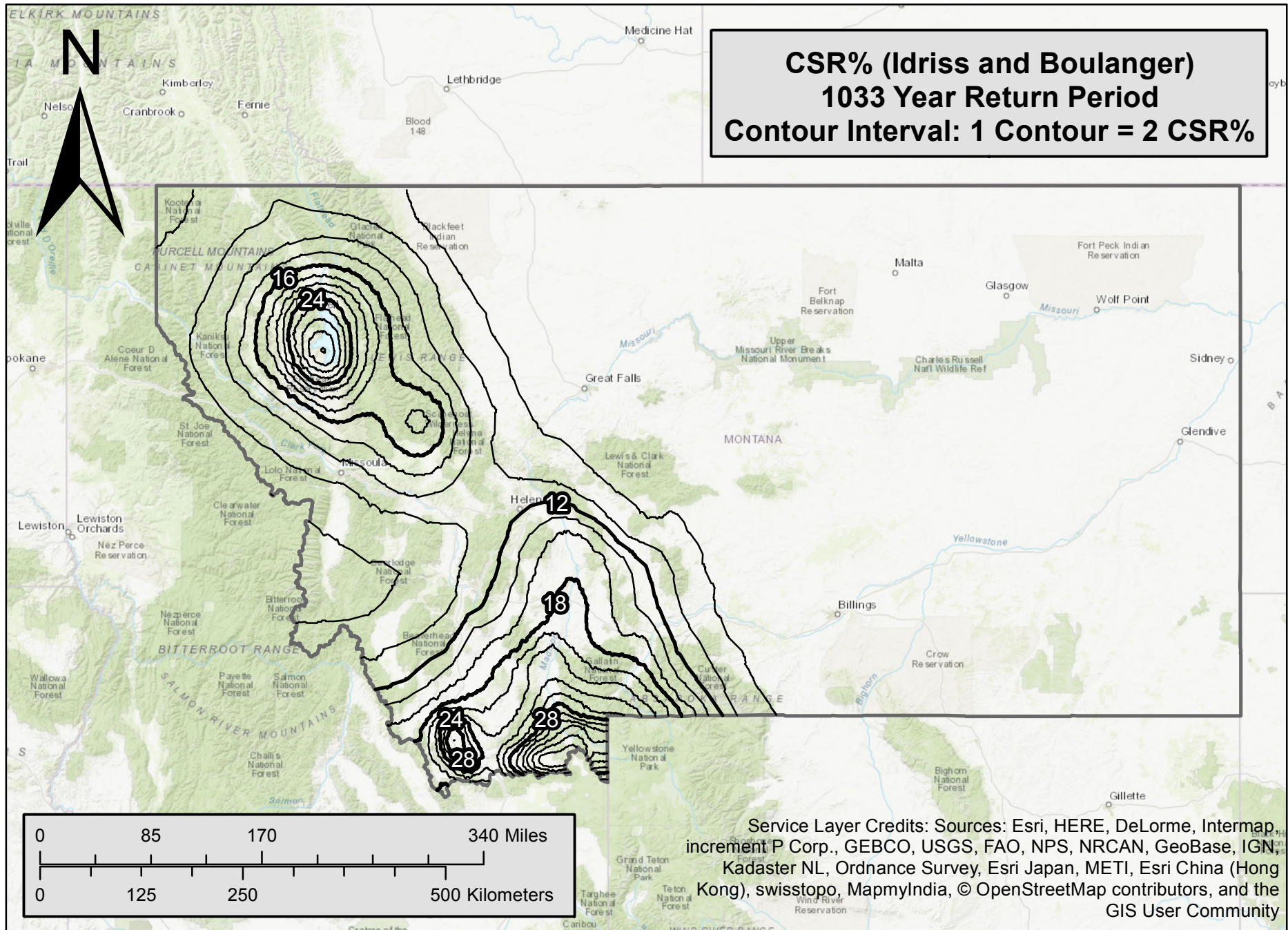


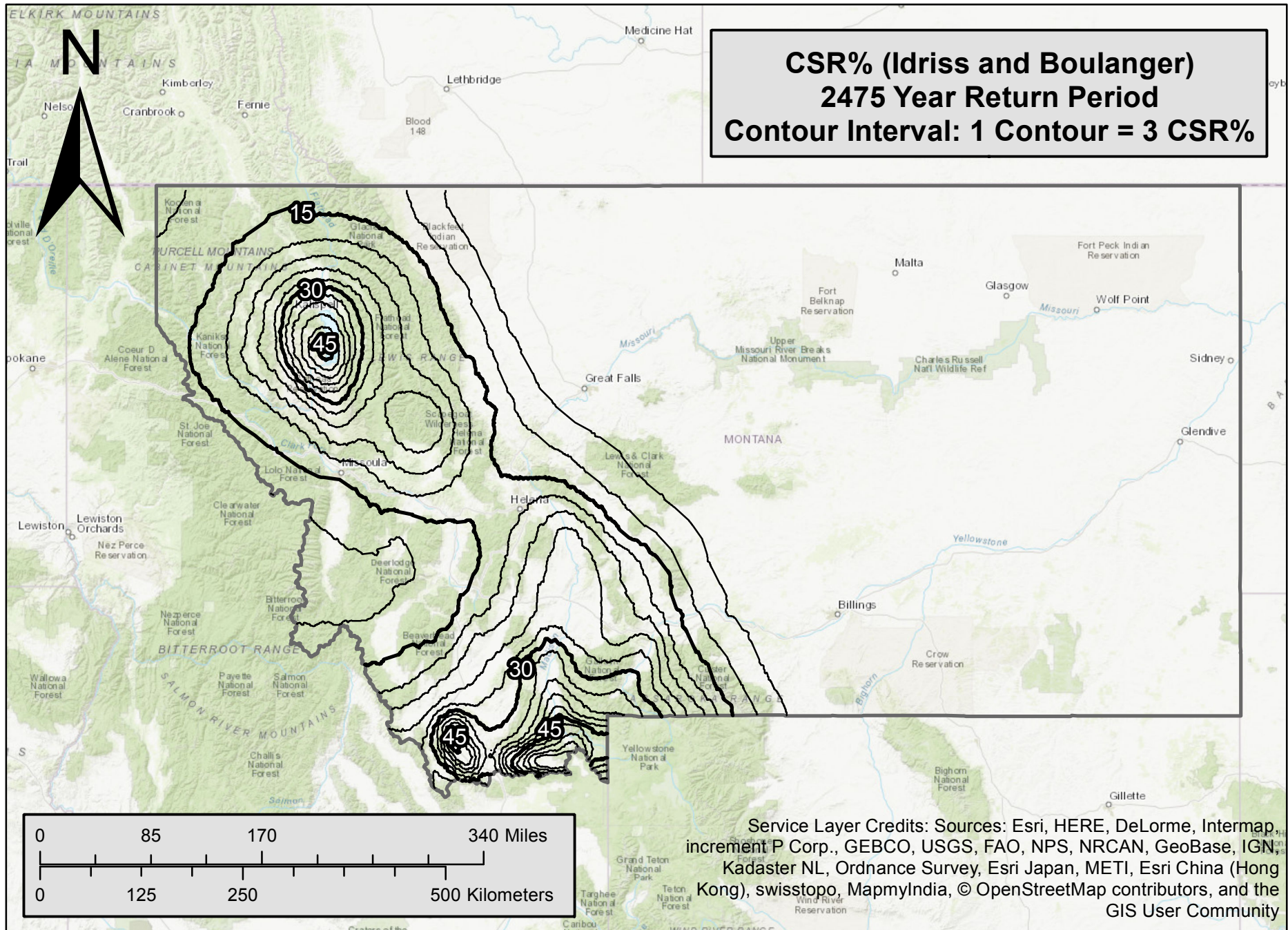


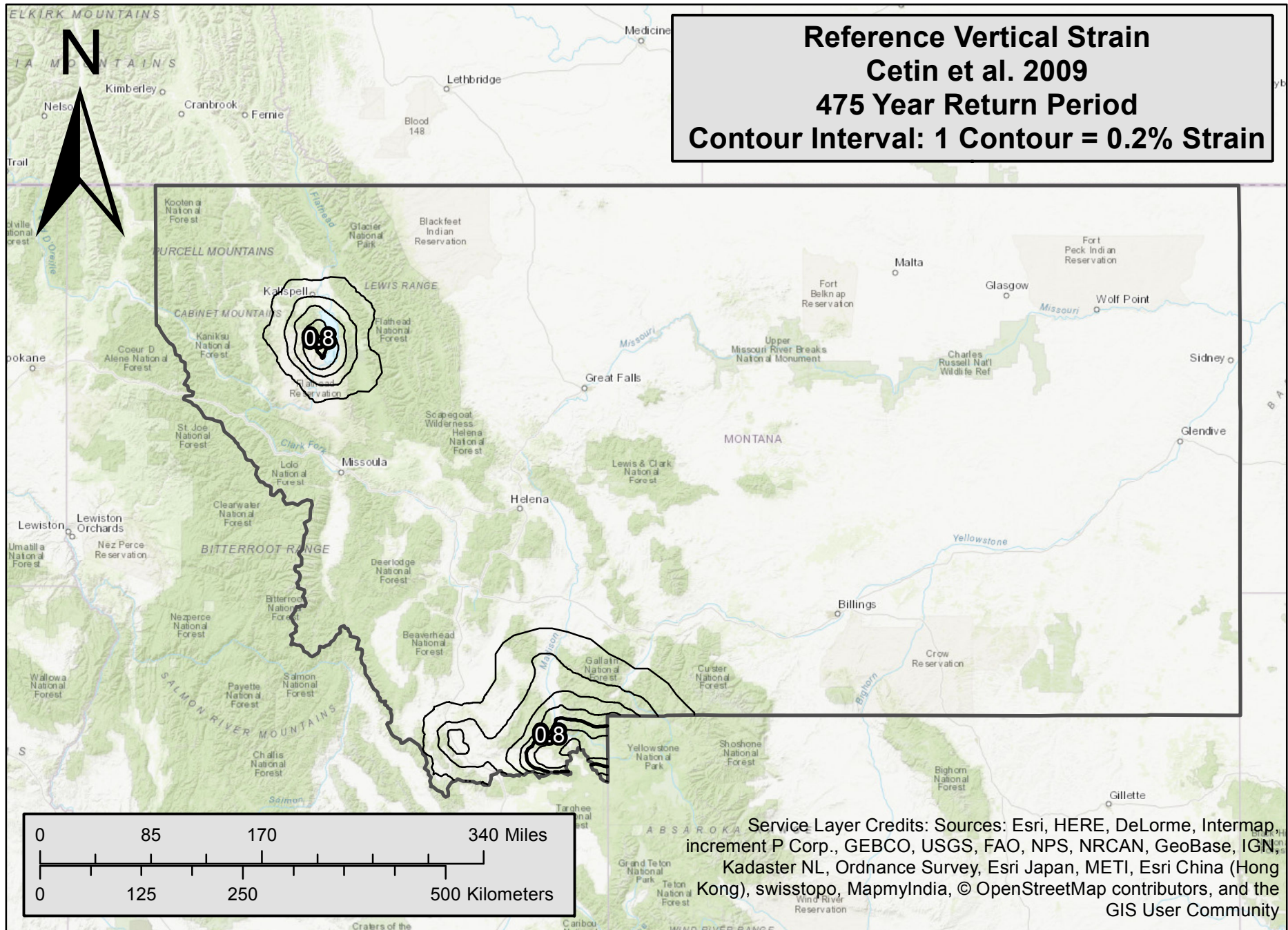


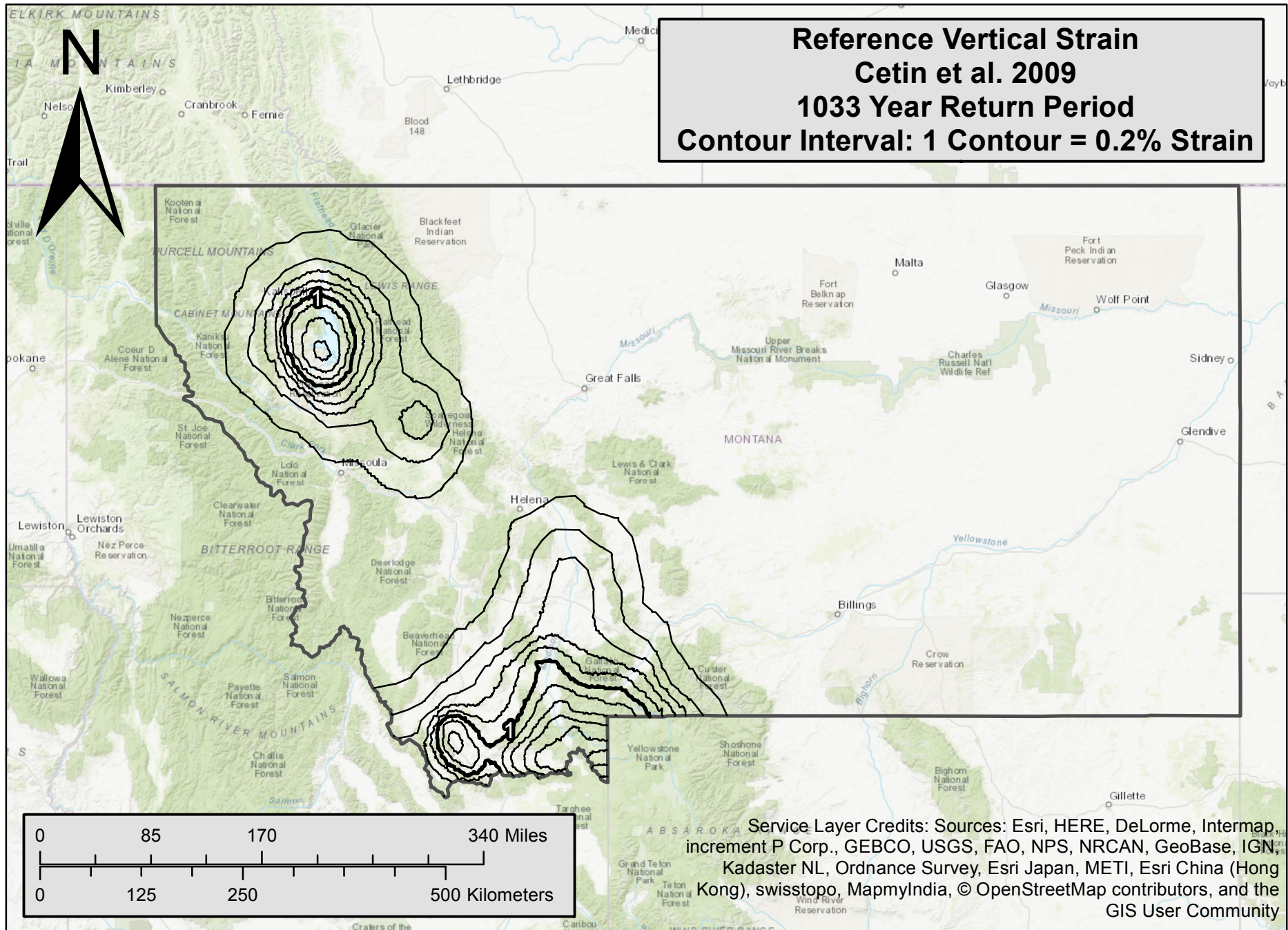


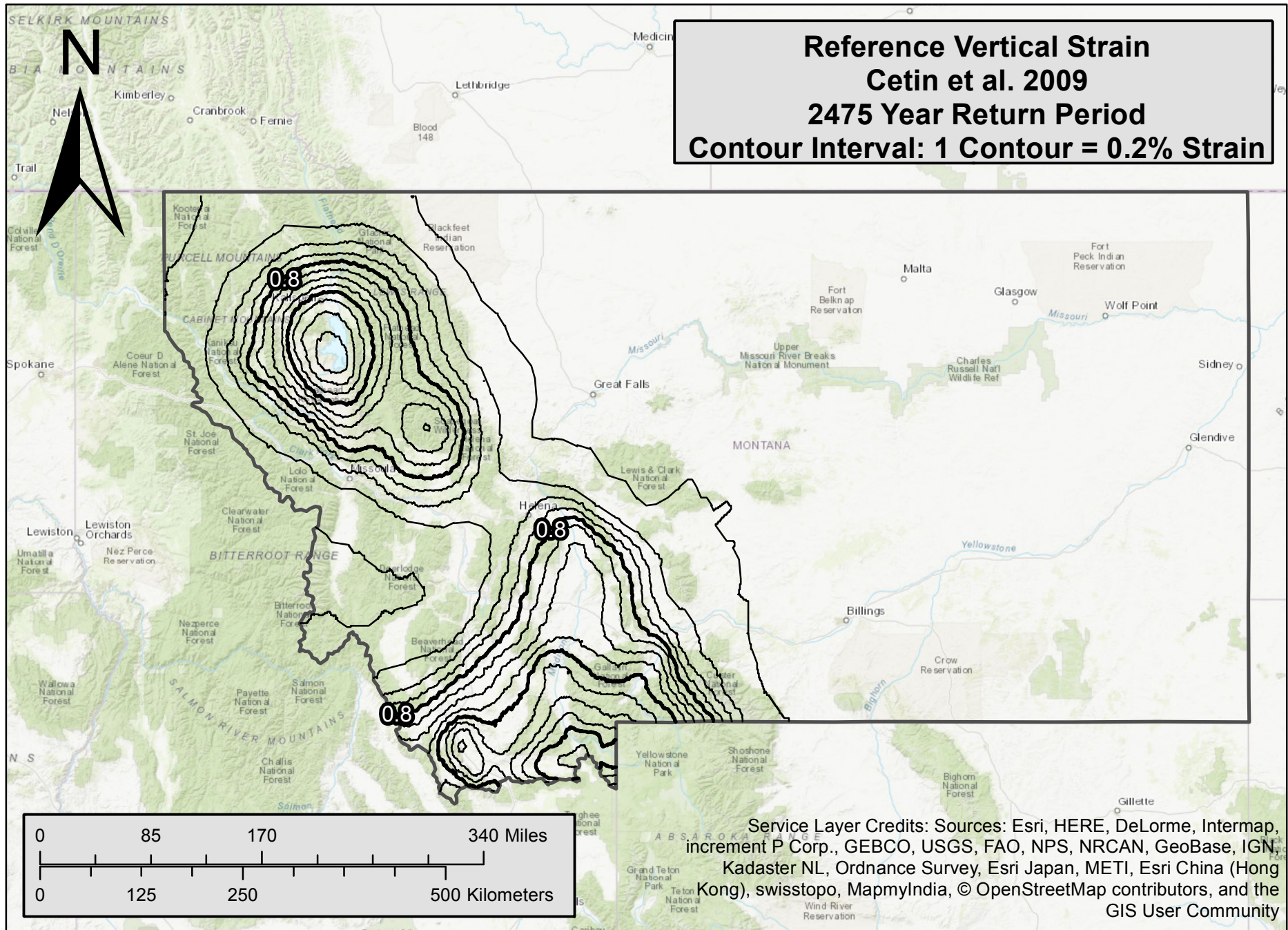


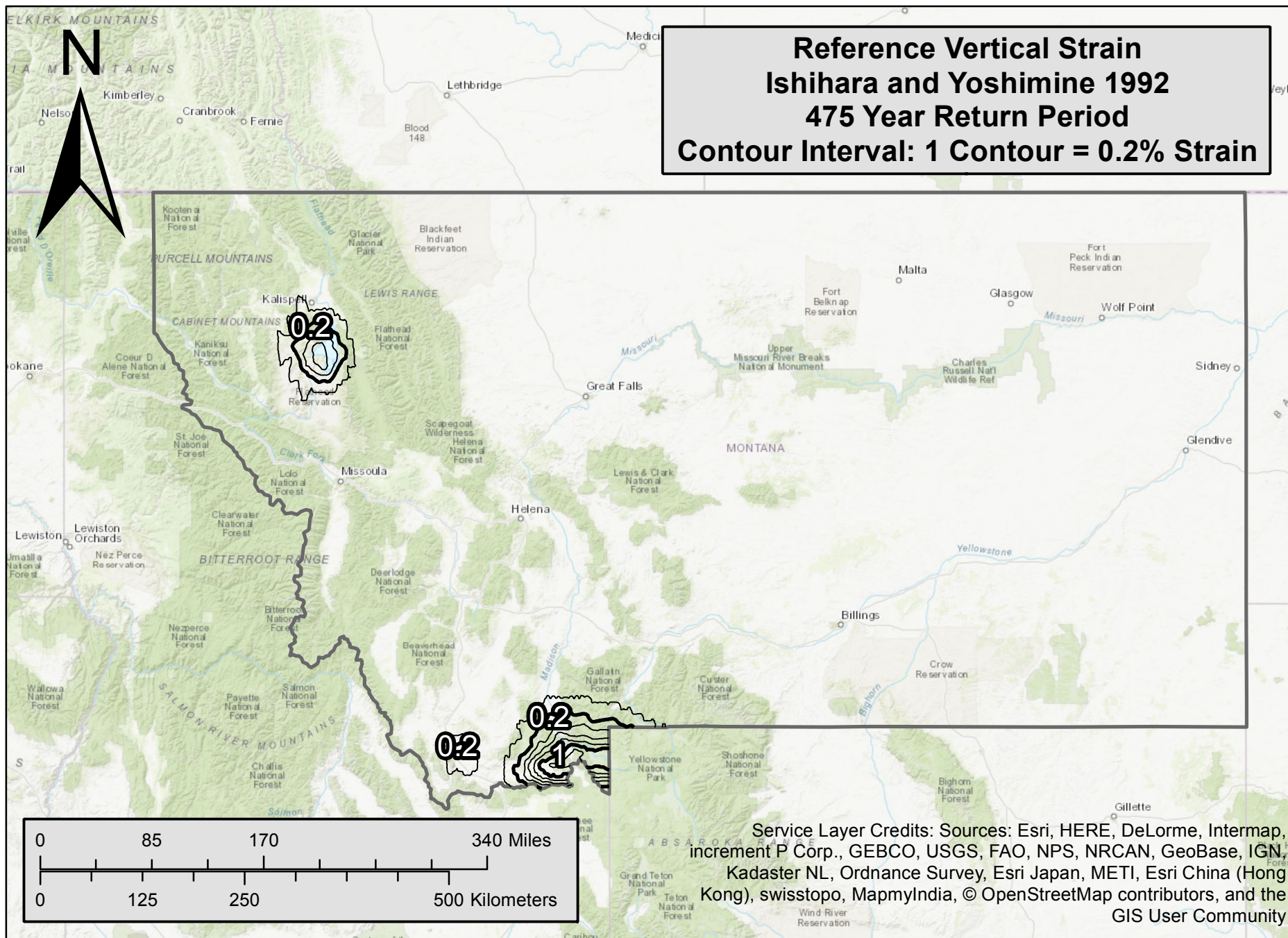




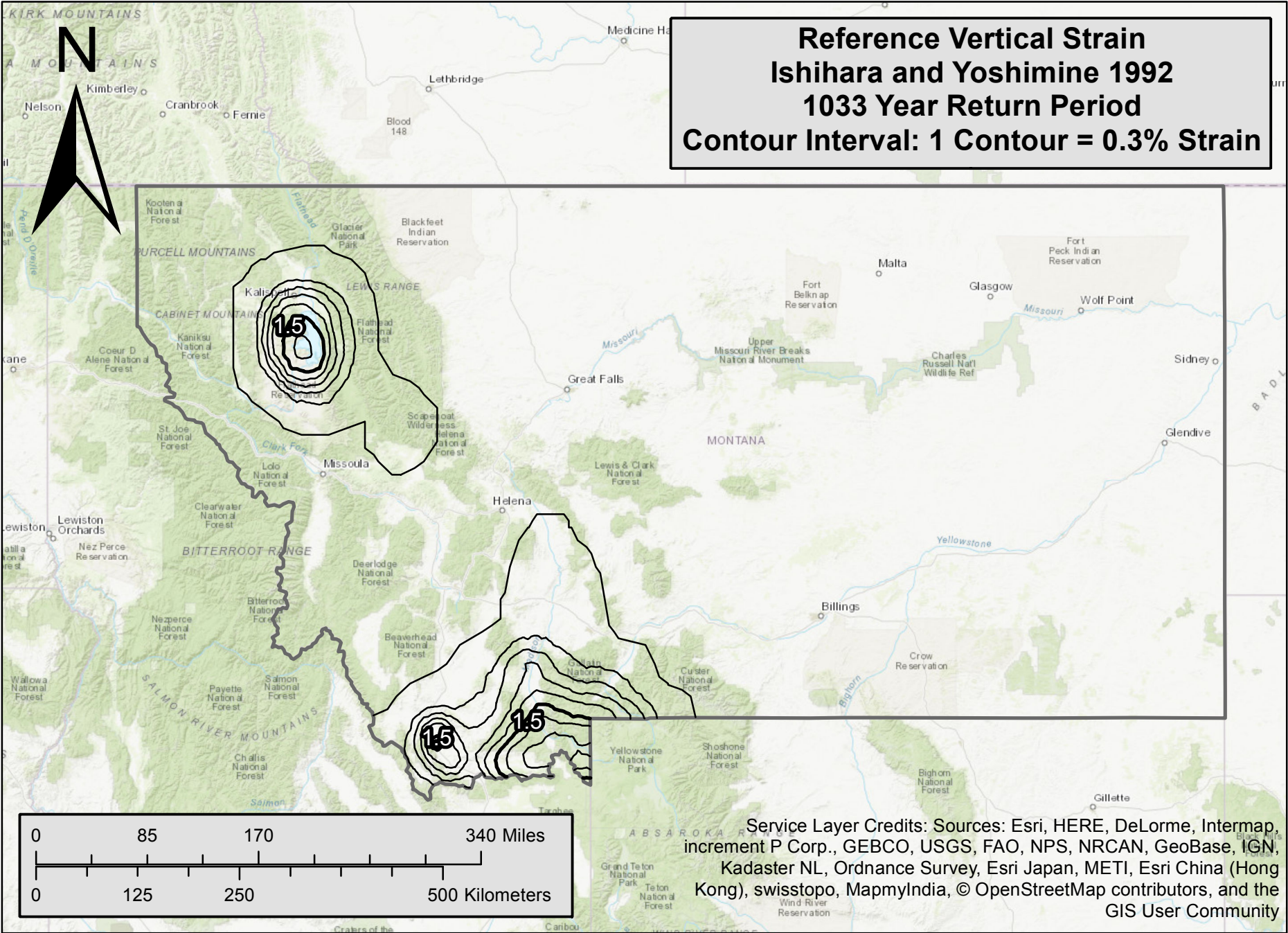




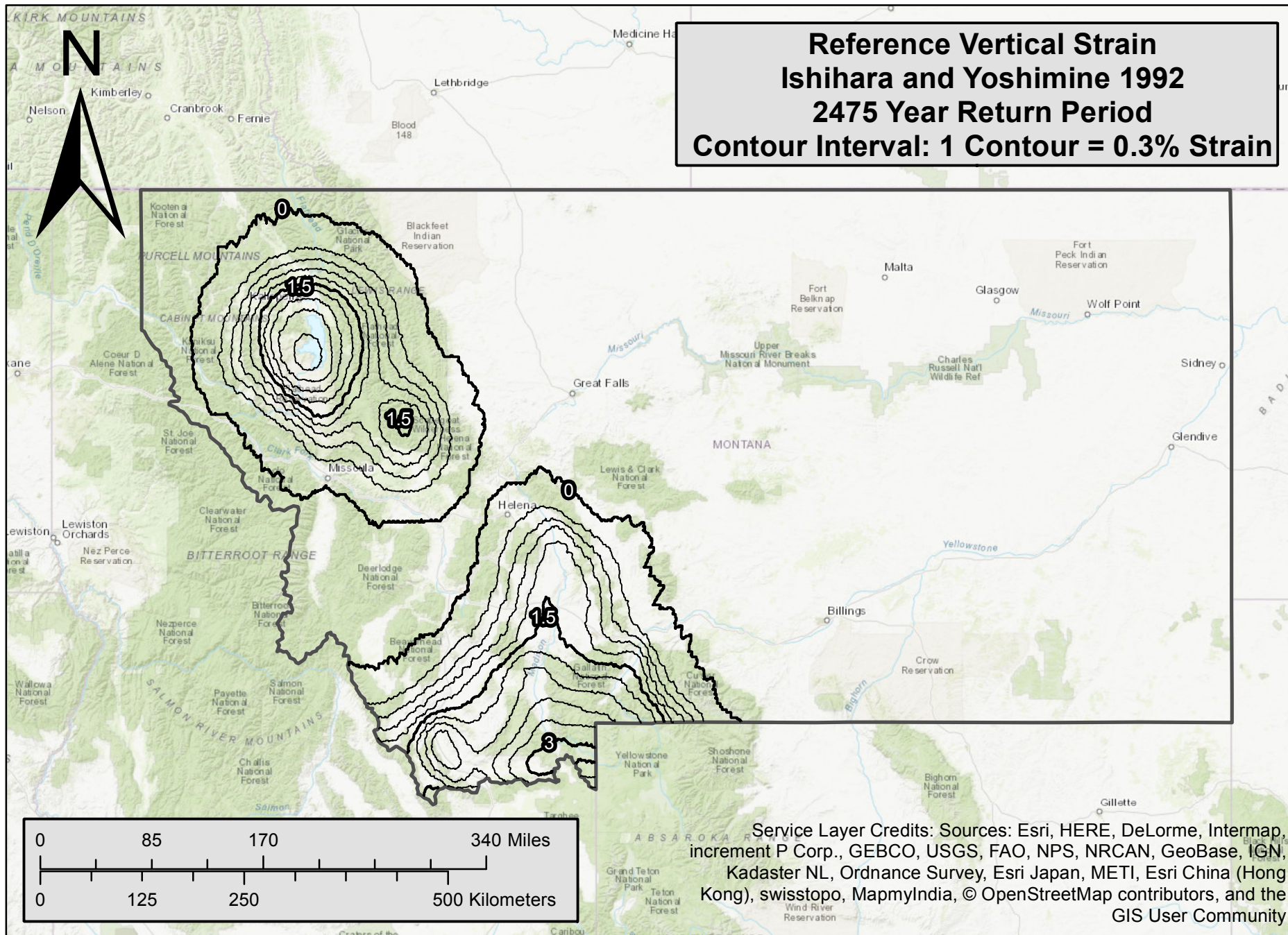


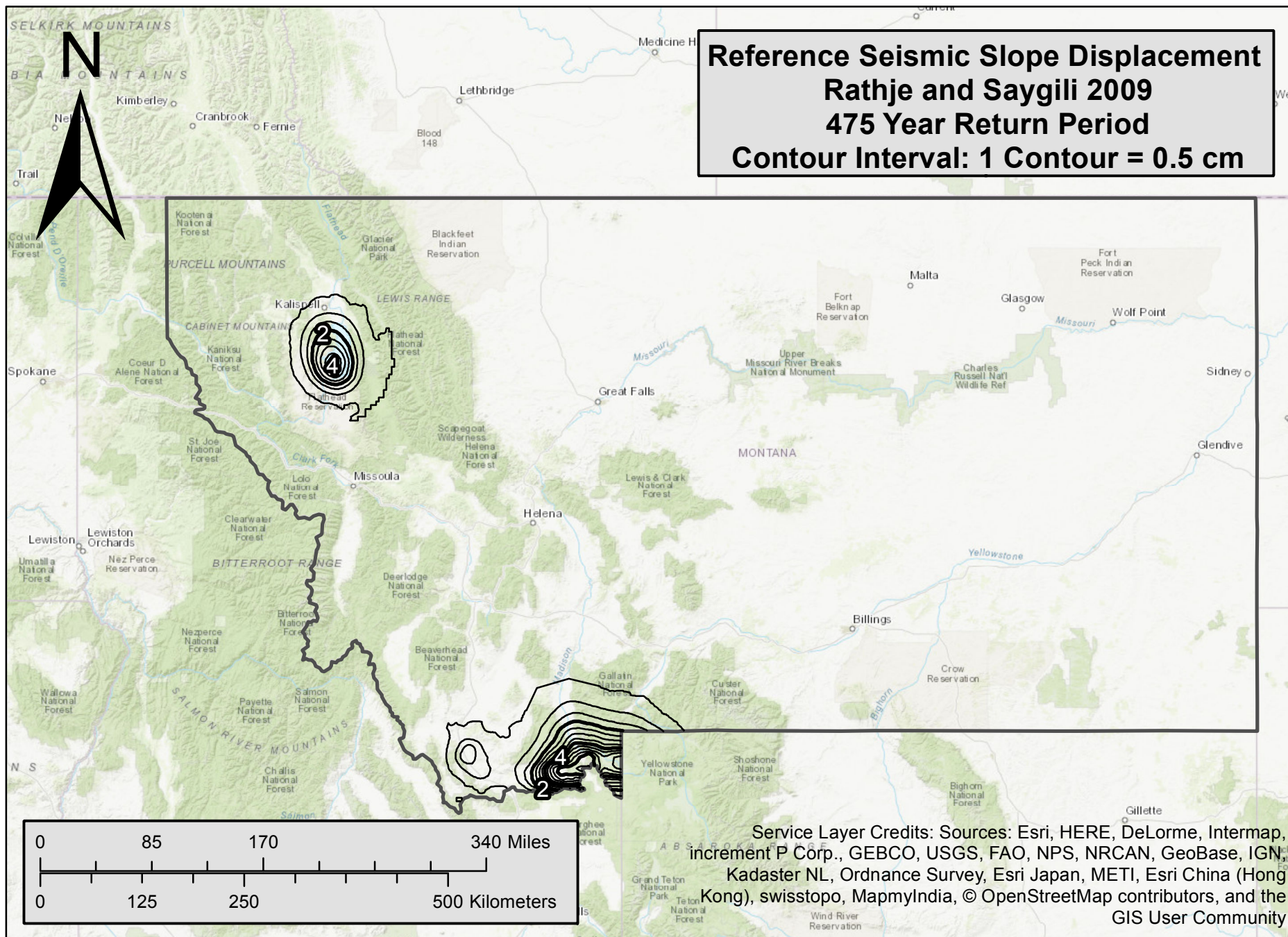


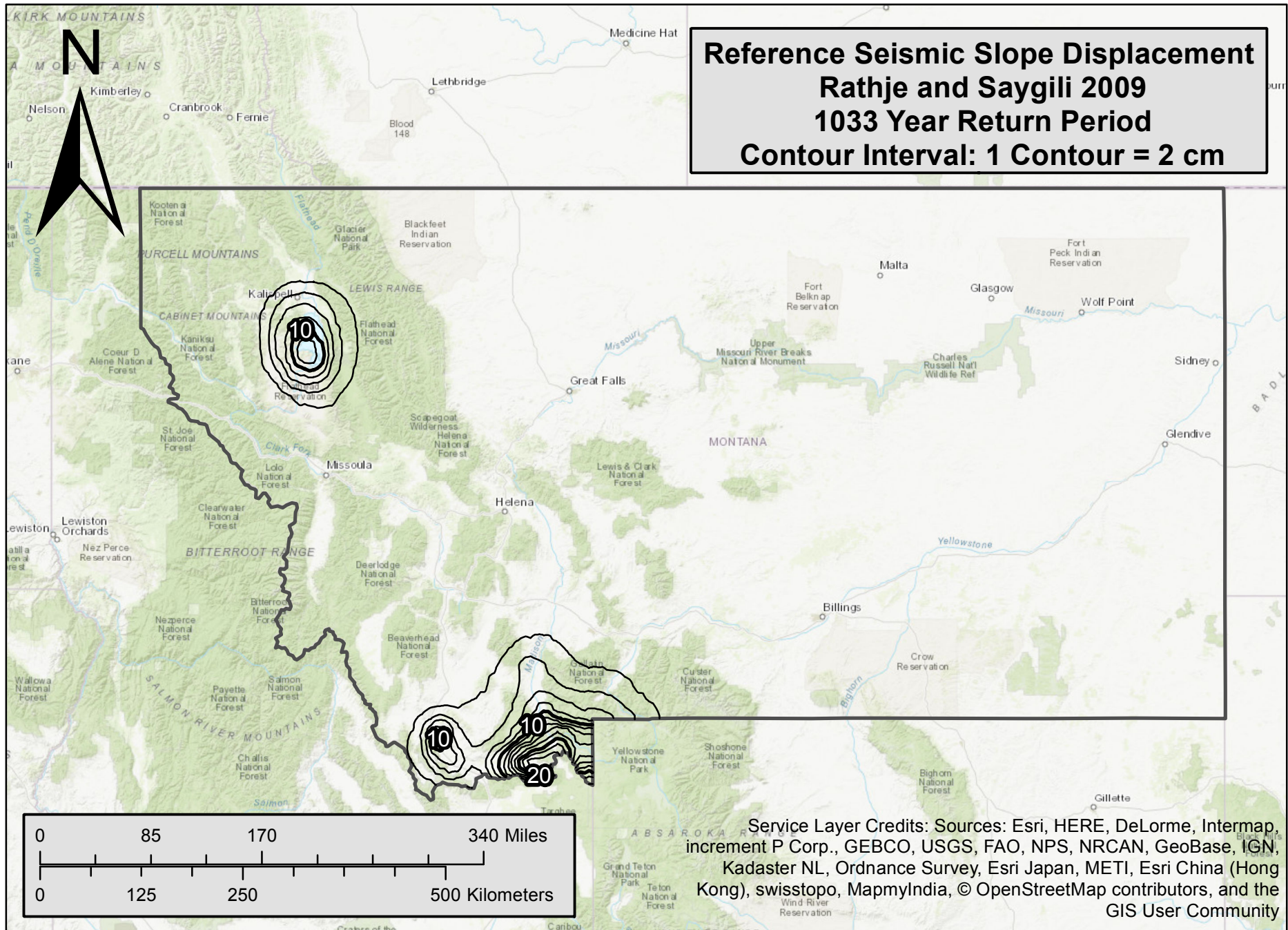
**Reference Vertical Strain
Ishihara and Yoshimine 1992
1033 Year Return Period
Contour Interval: 1 Contour = 0.3% Strain**



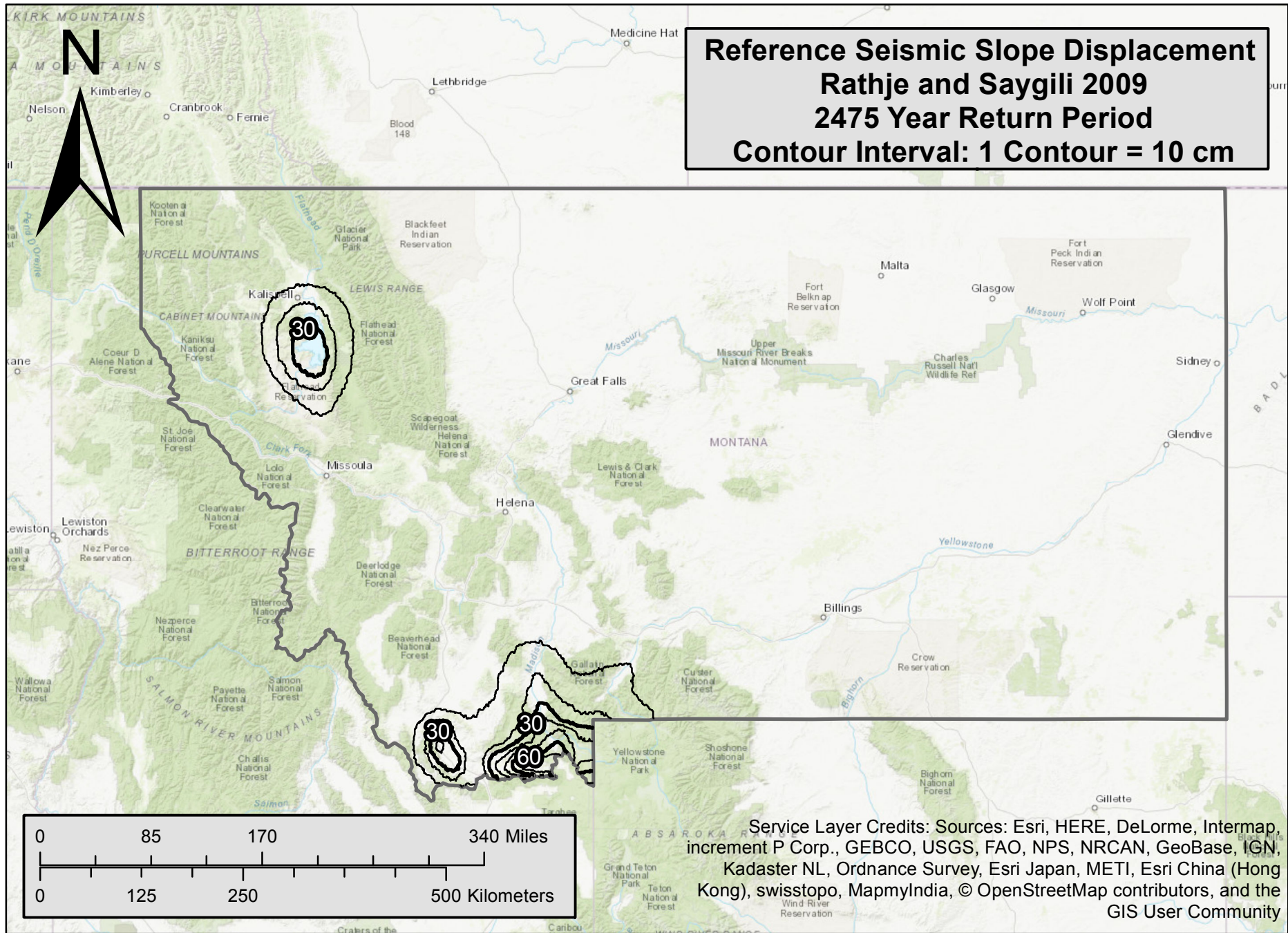
Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community



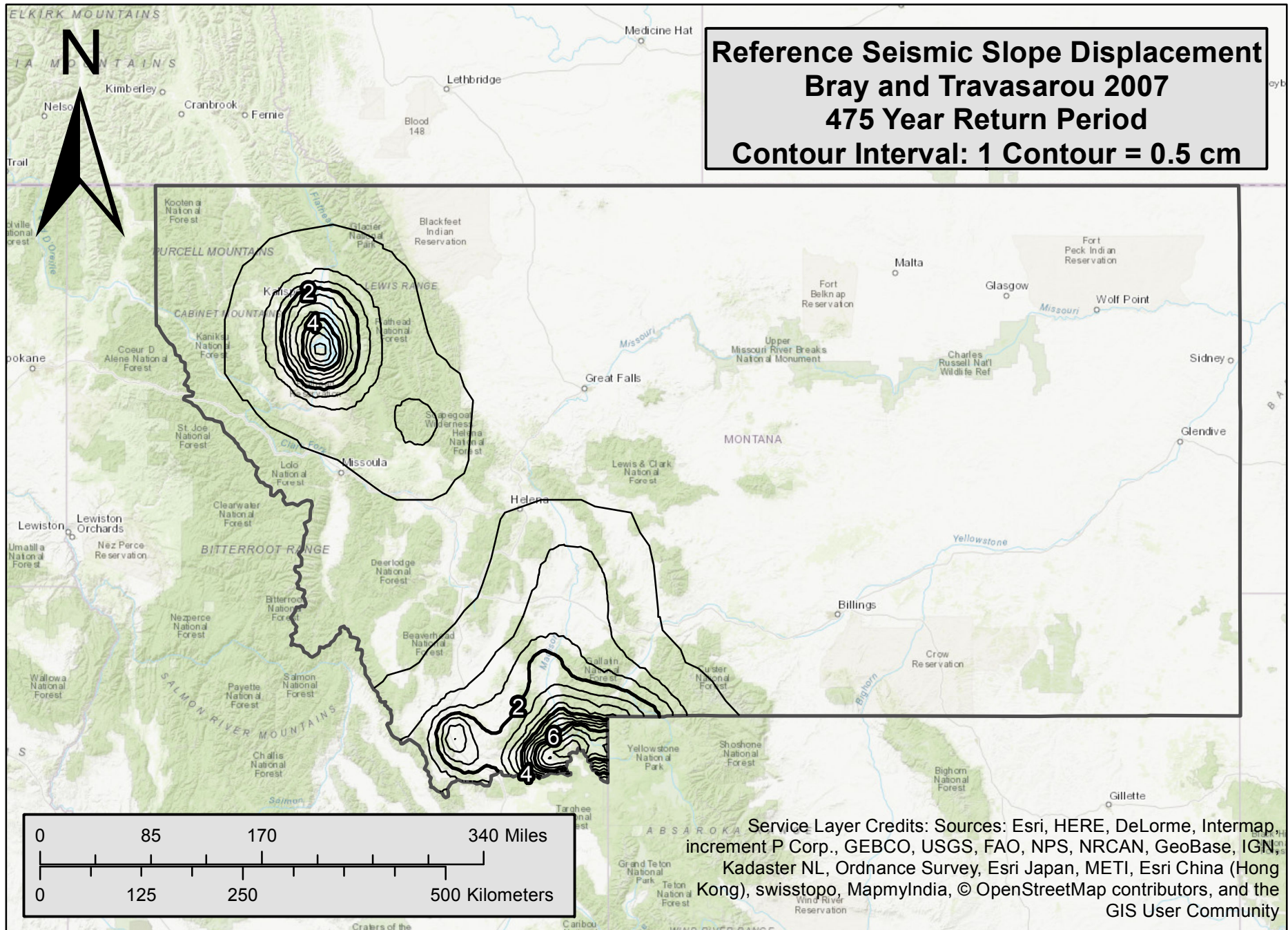


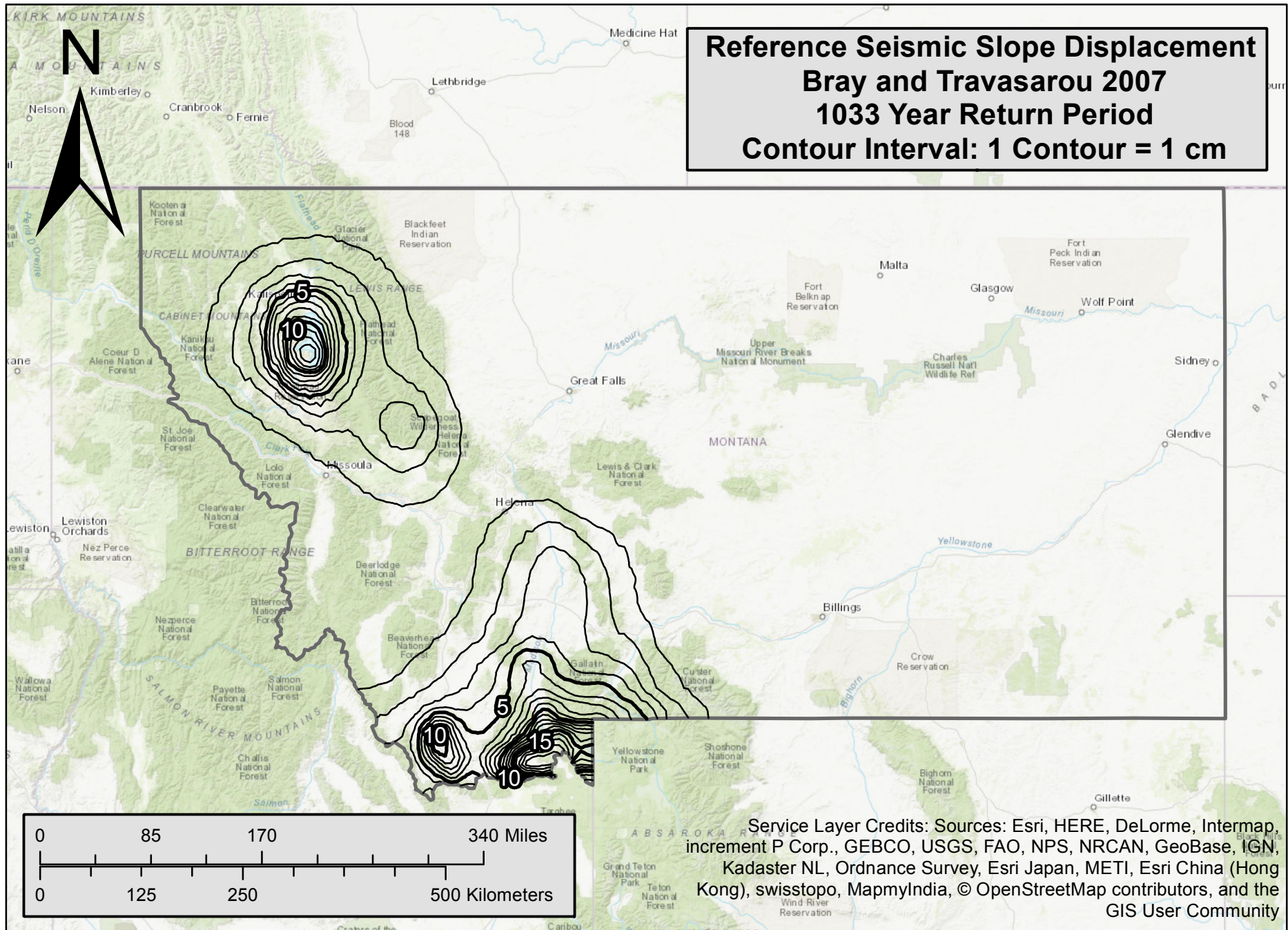


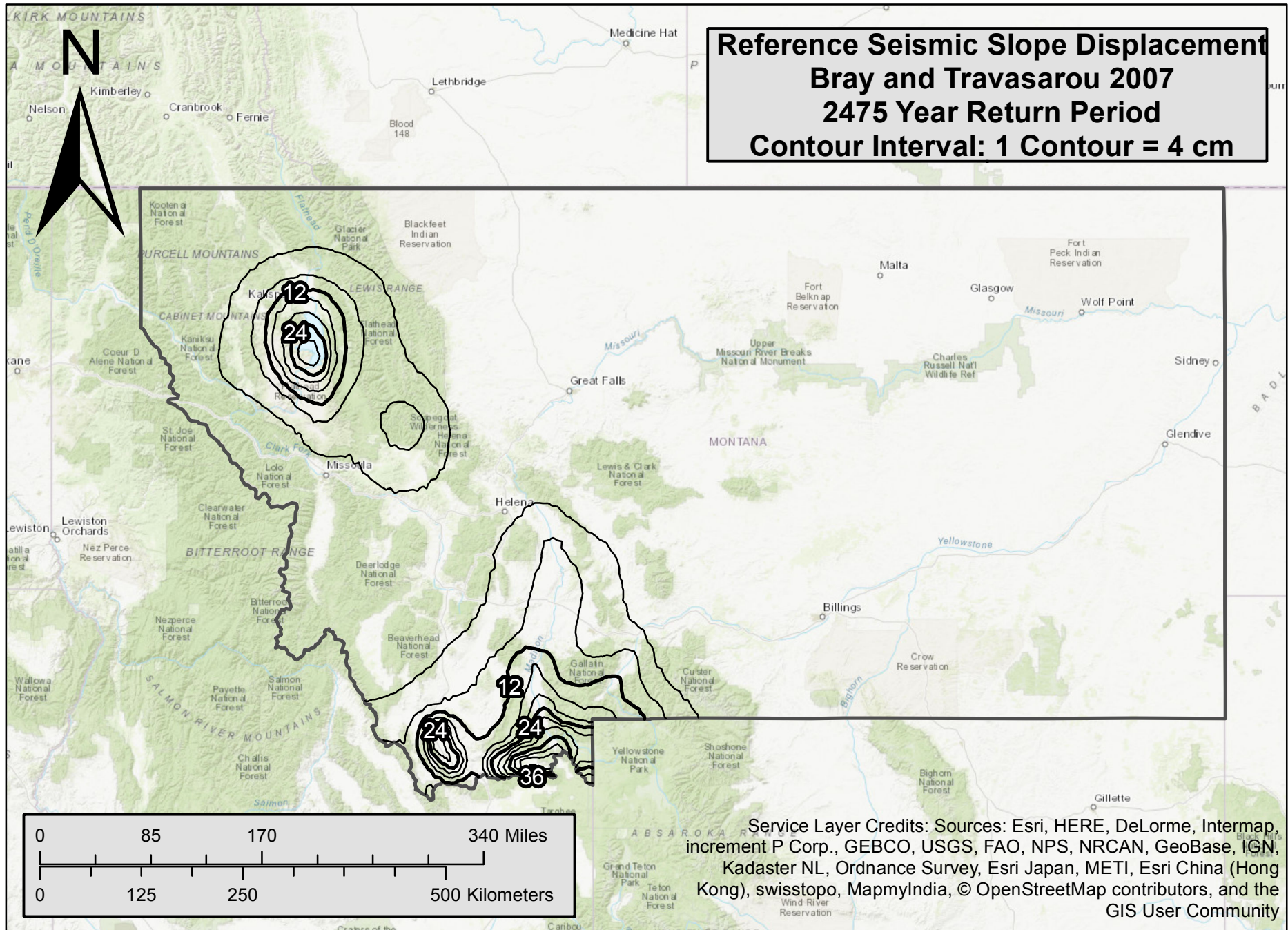
**Reference Seismic Slope Displacement
Rathje and Saygili 2009
2475 Year Return Period
Contour Interval: 1 Contour = 10 cm**



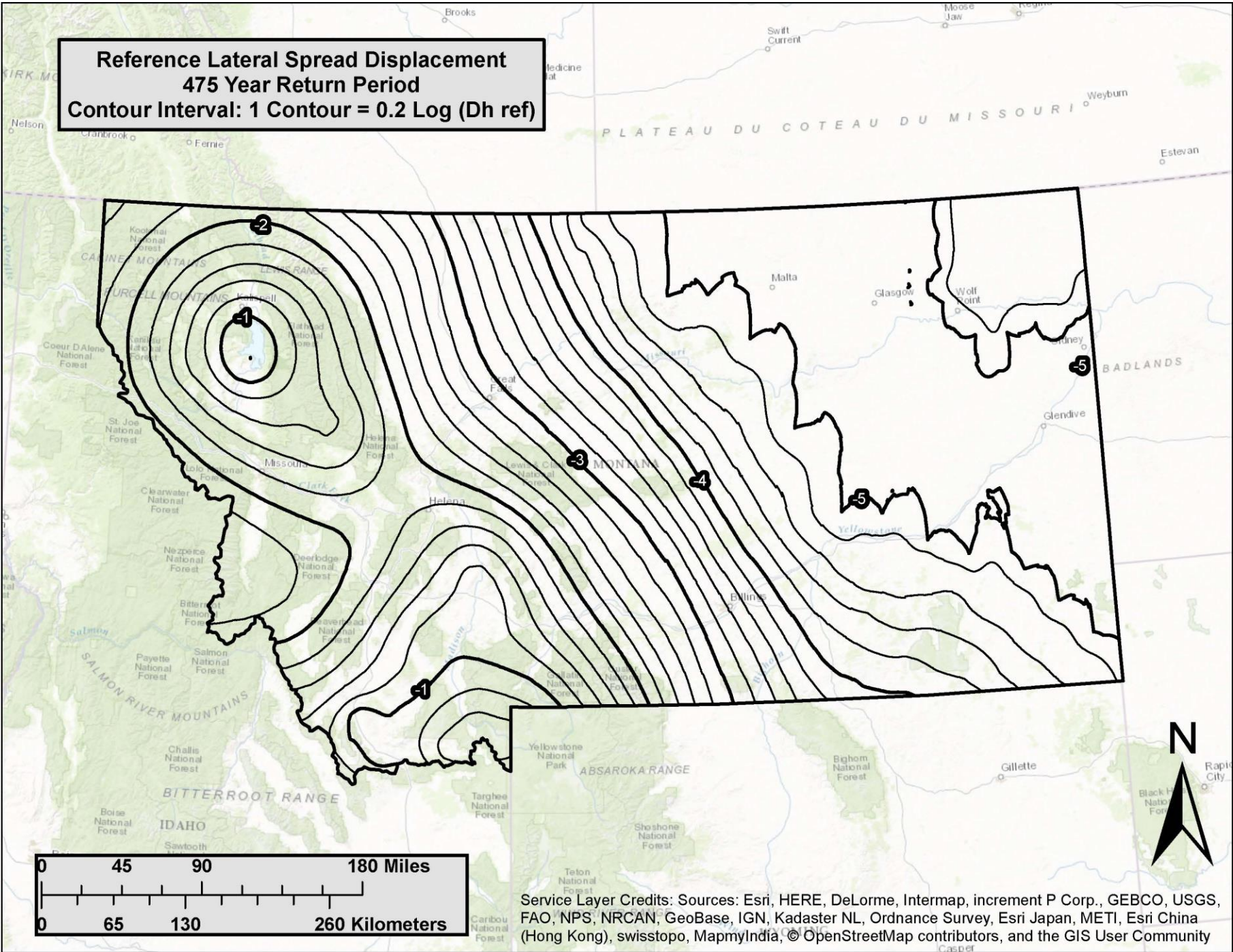
Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community



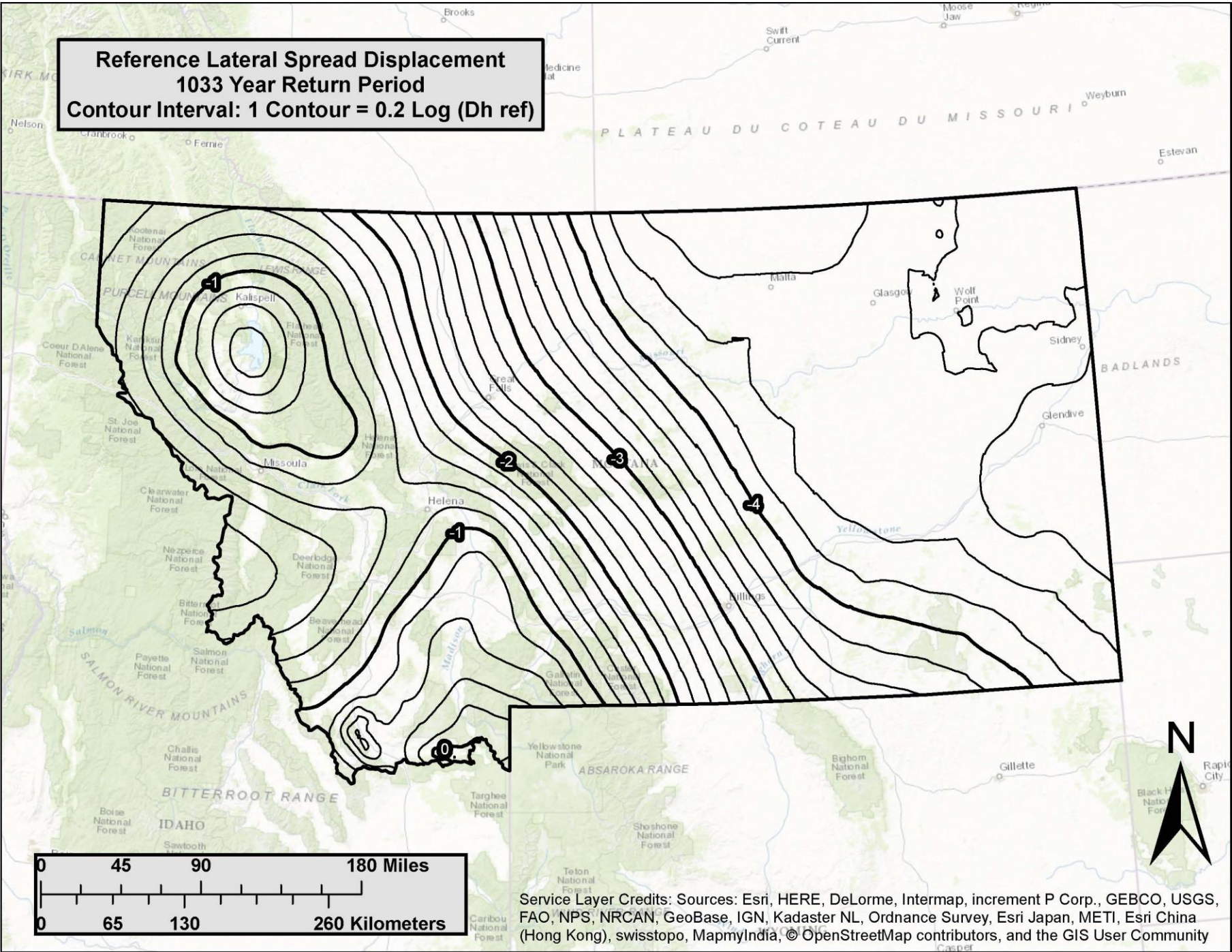




**Reference Lateral Spread Displacement
475 Year Return Period
Contour Interval: 1 Contour = 0.2 Log (Dh ref)**

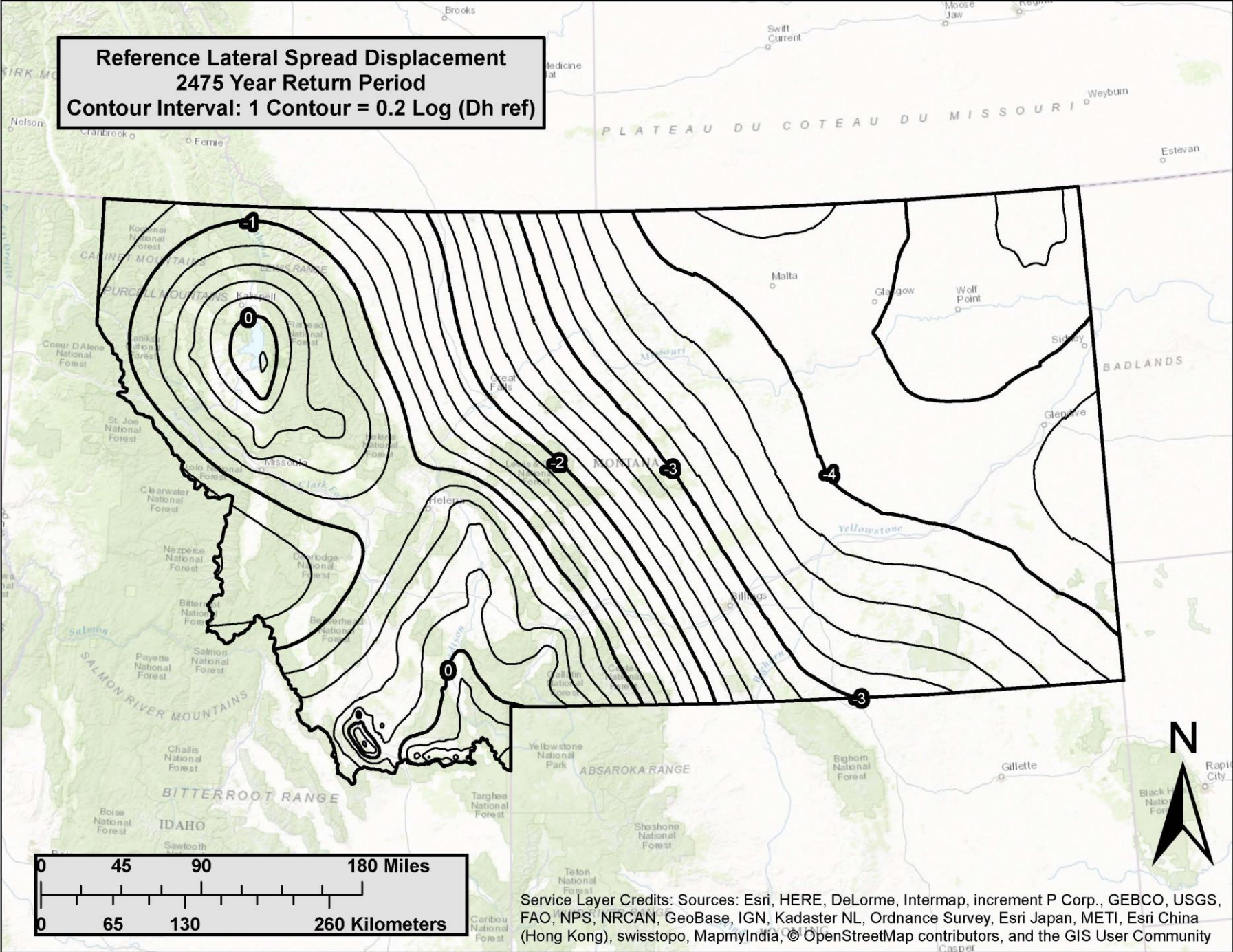


**Reference Lateral Spread Displacement
1033 Year Return Period
Contour Interval: 1 Contour = 0.2 Log (Dh ref)**

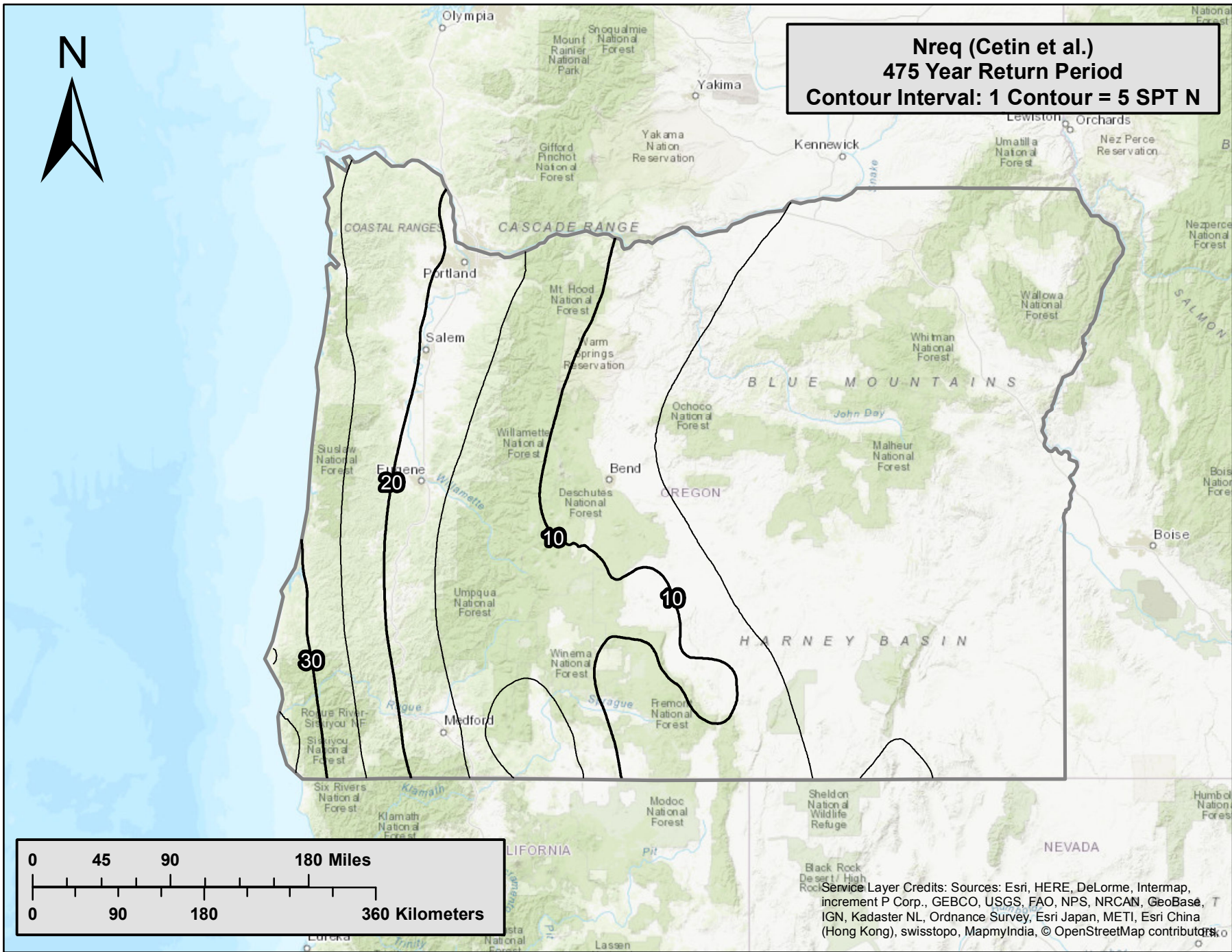


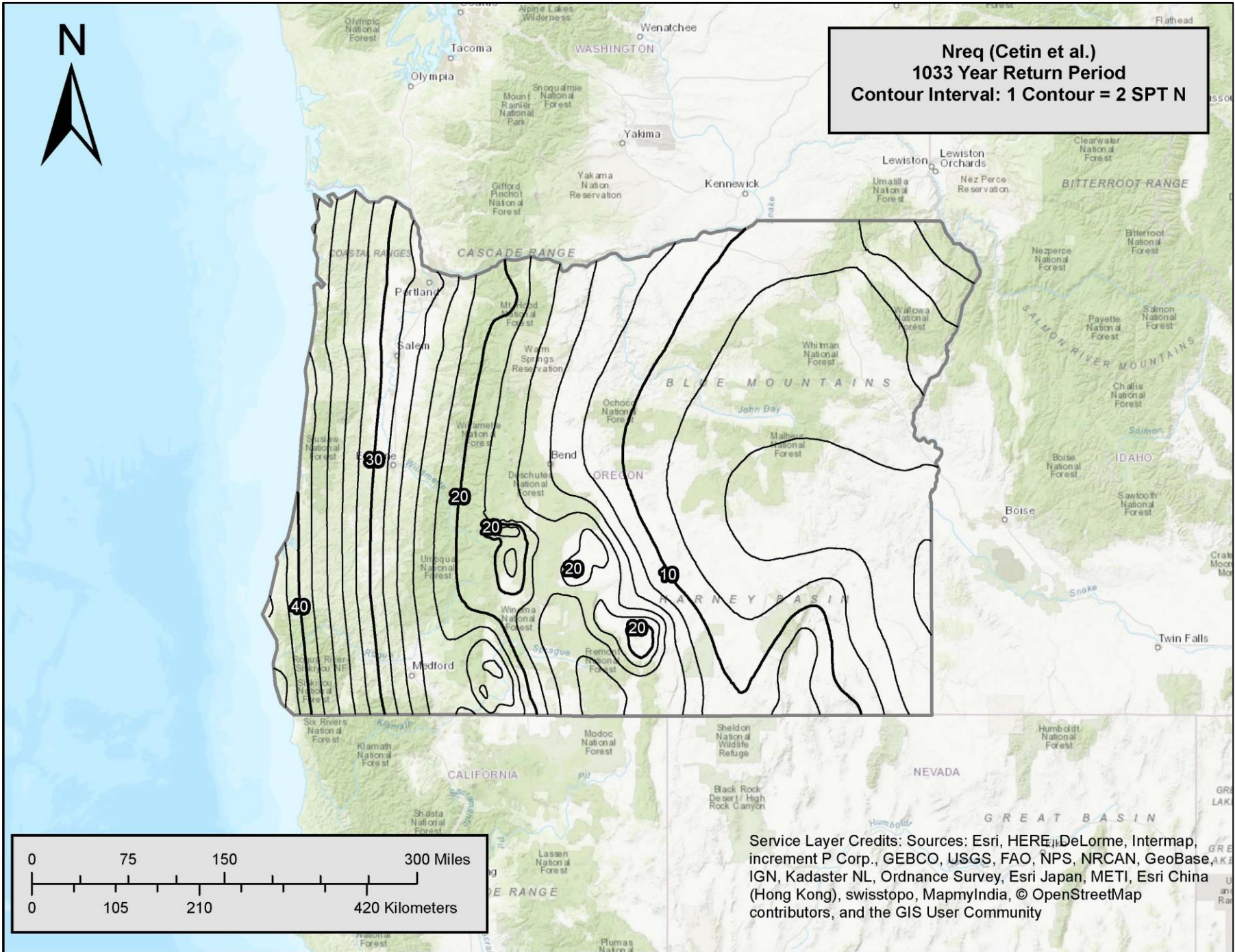
Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

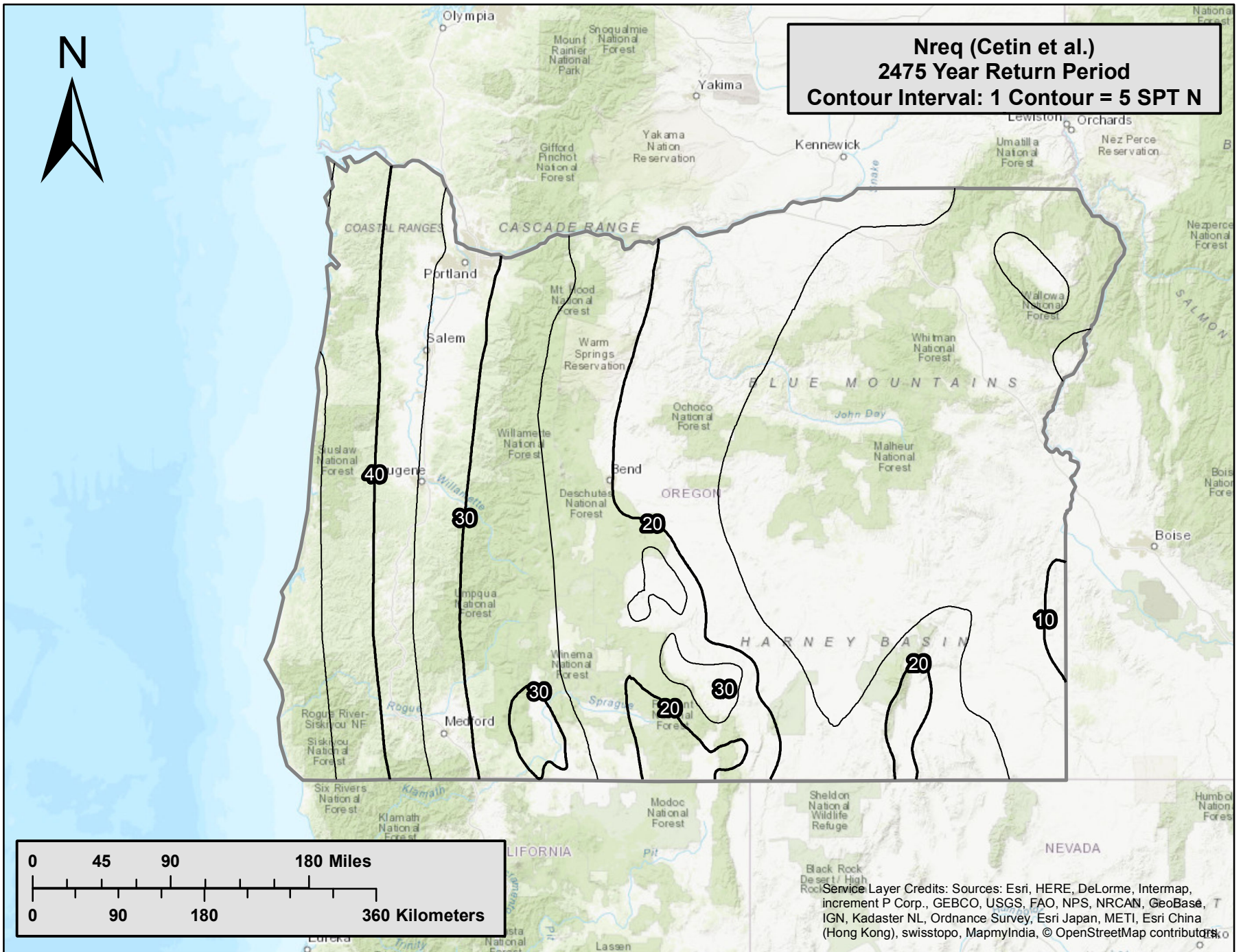
**Reference Lateral Spread Displacement
2475 Year Return Period
Contour Interval: 1 Contour = 0.2 Log (Dh ref)**



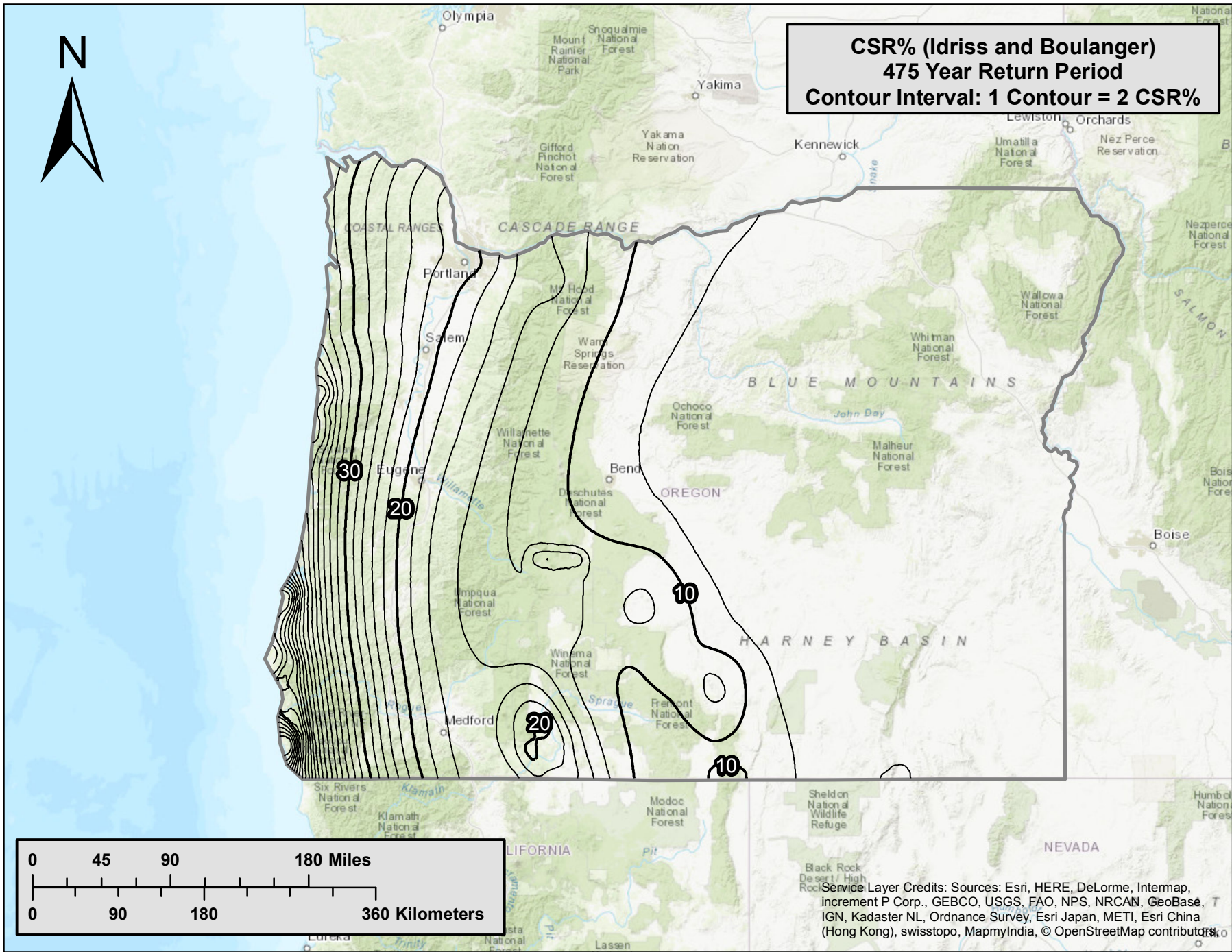
Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

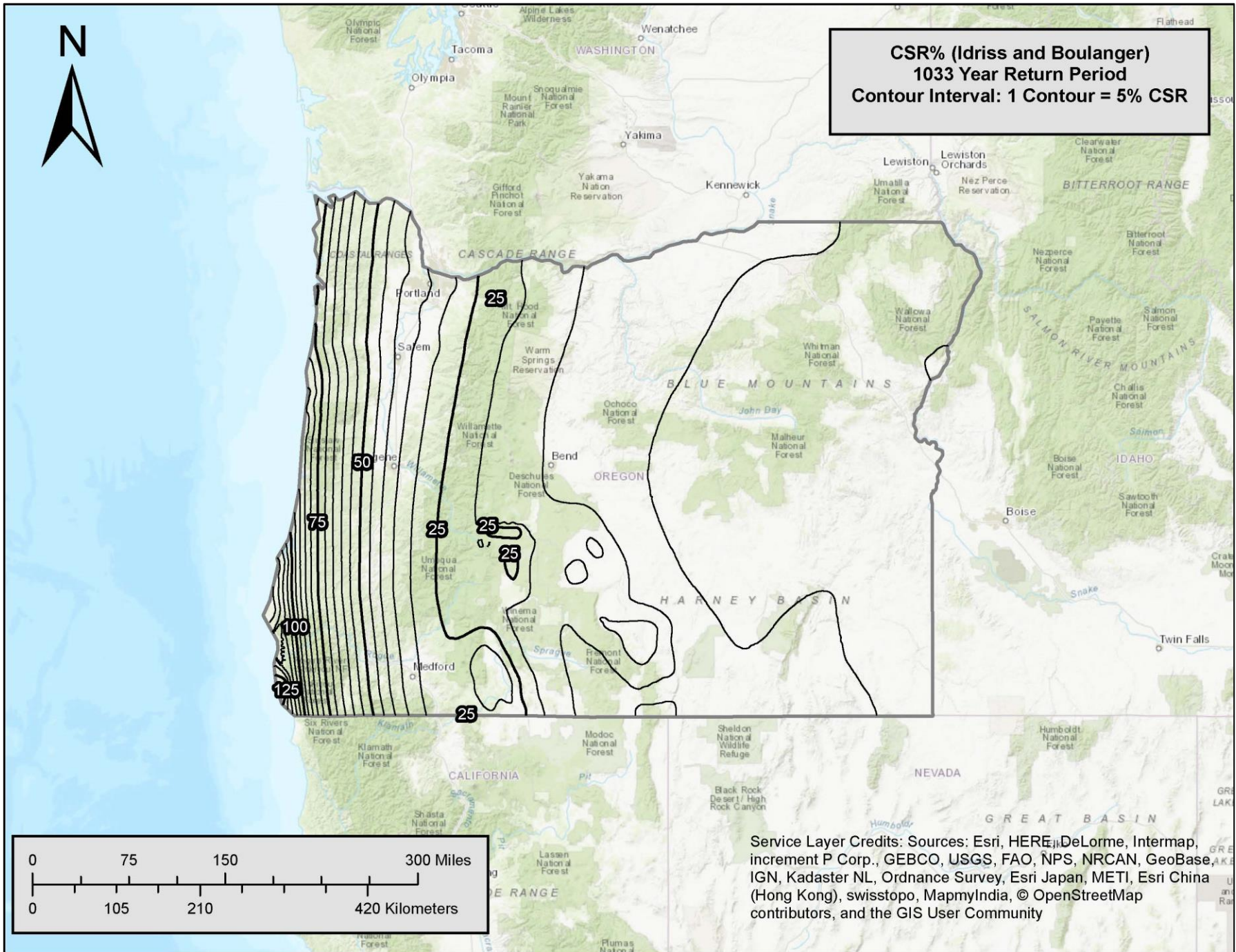


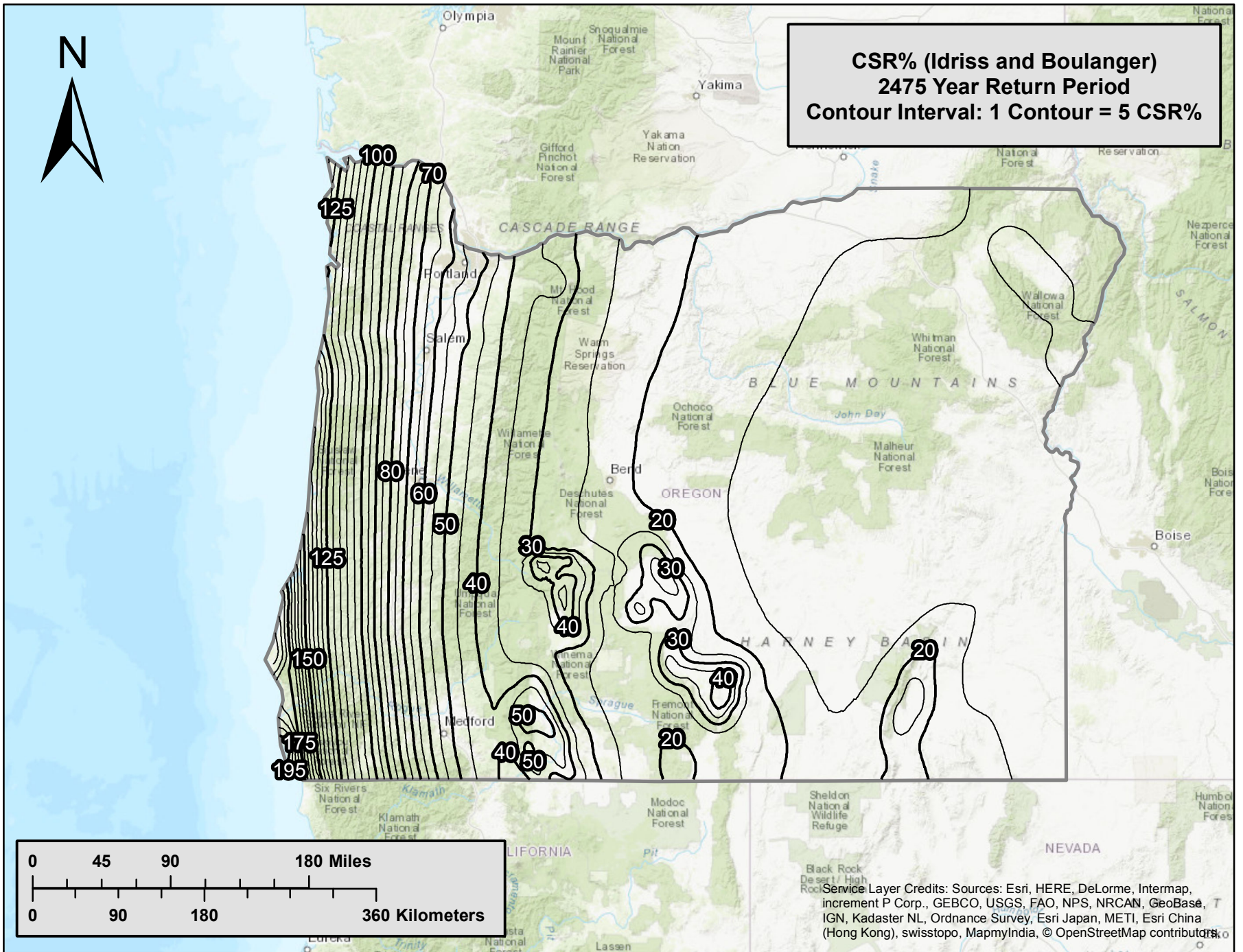


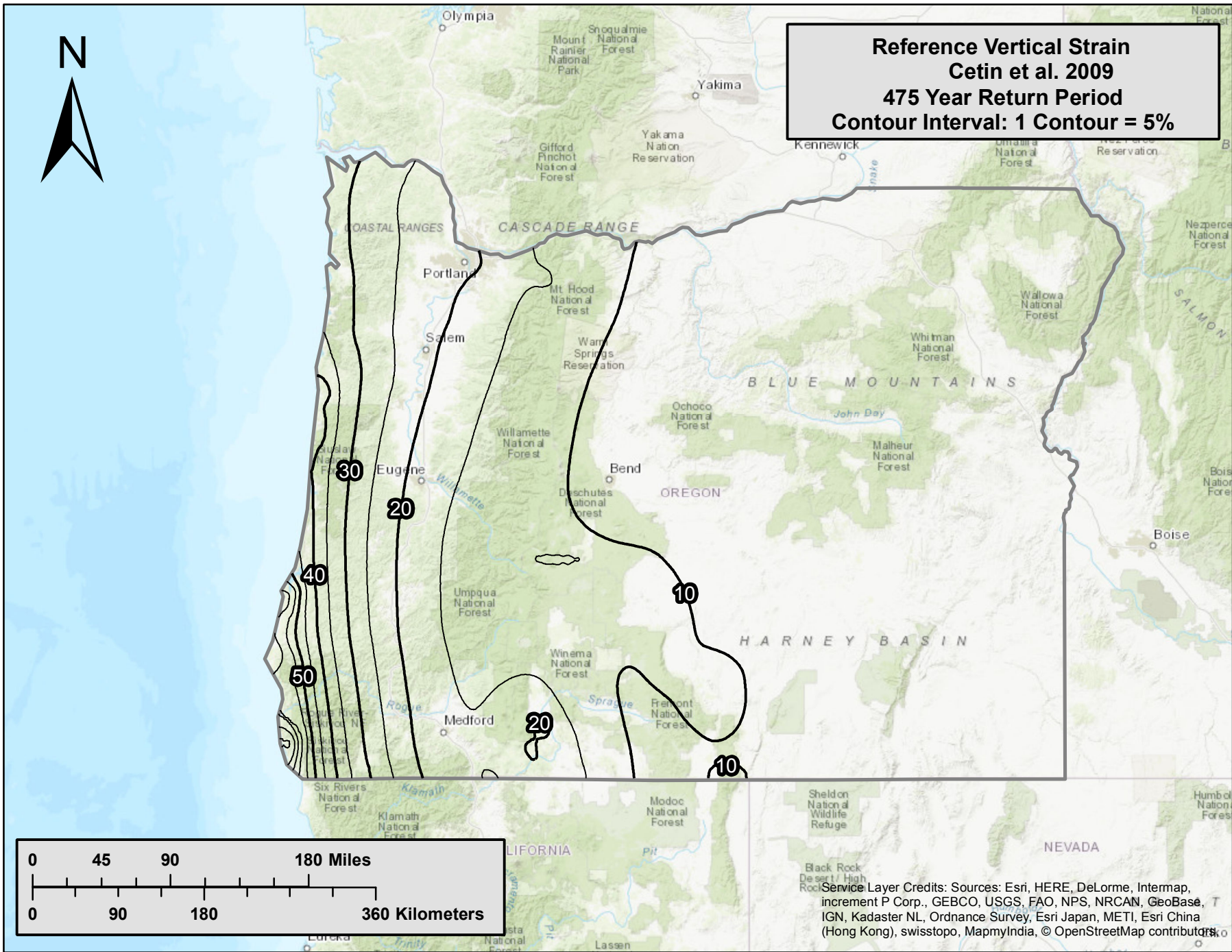


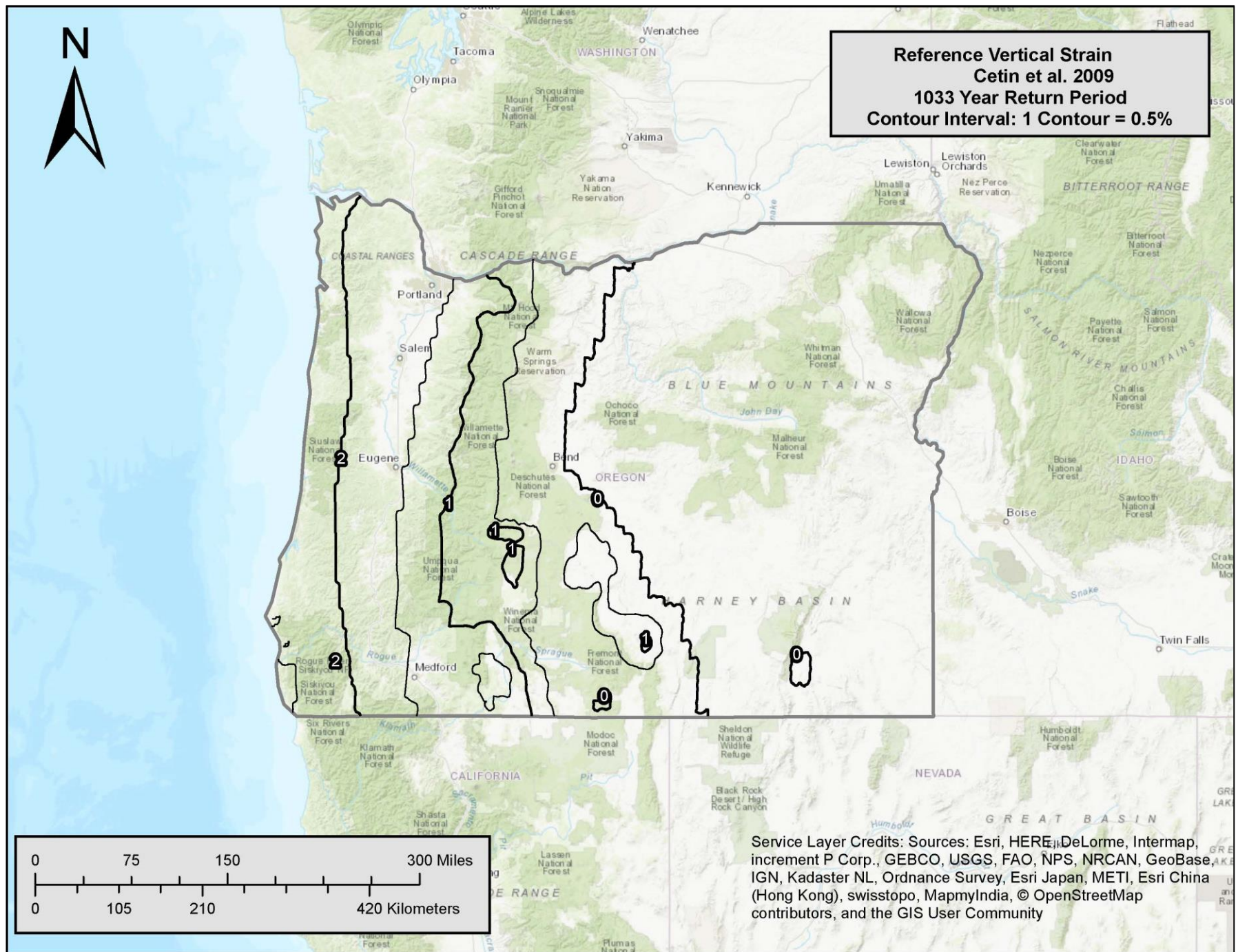
Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors,

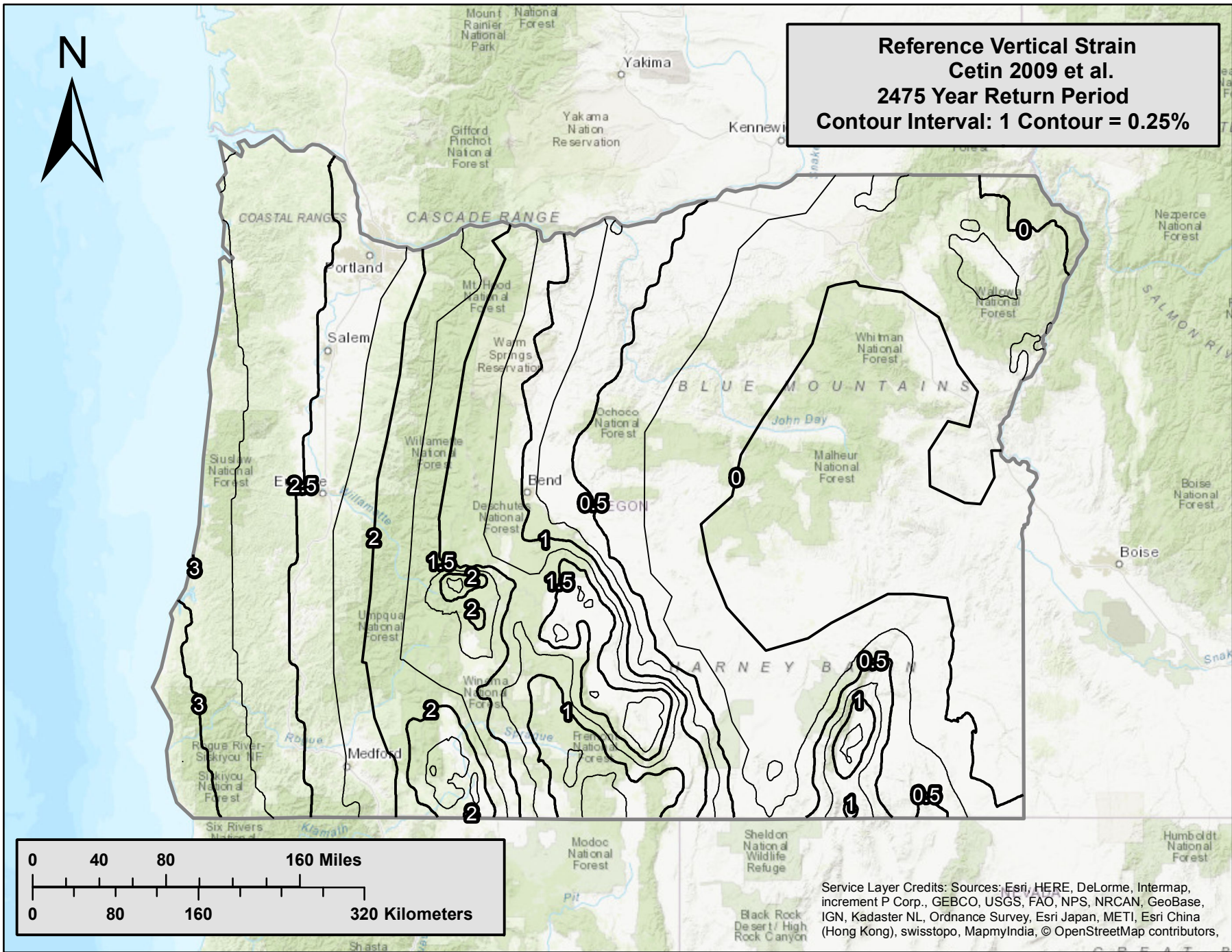


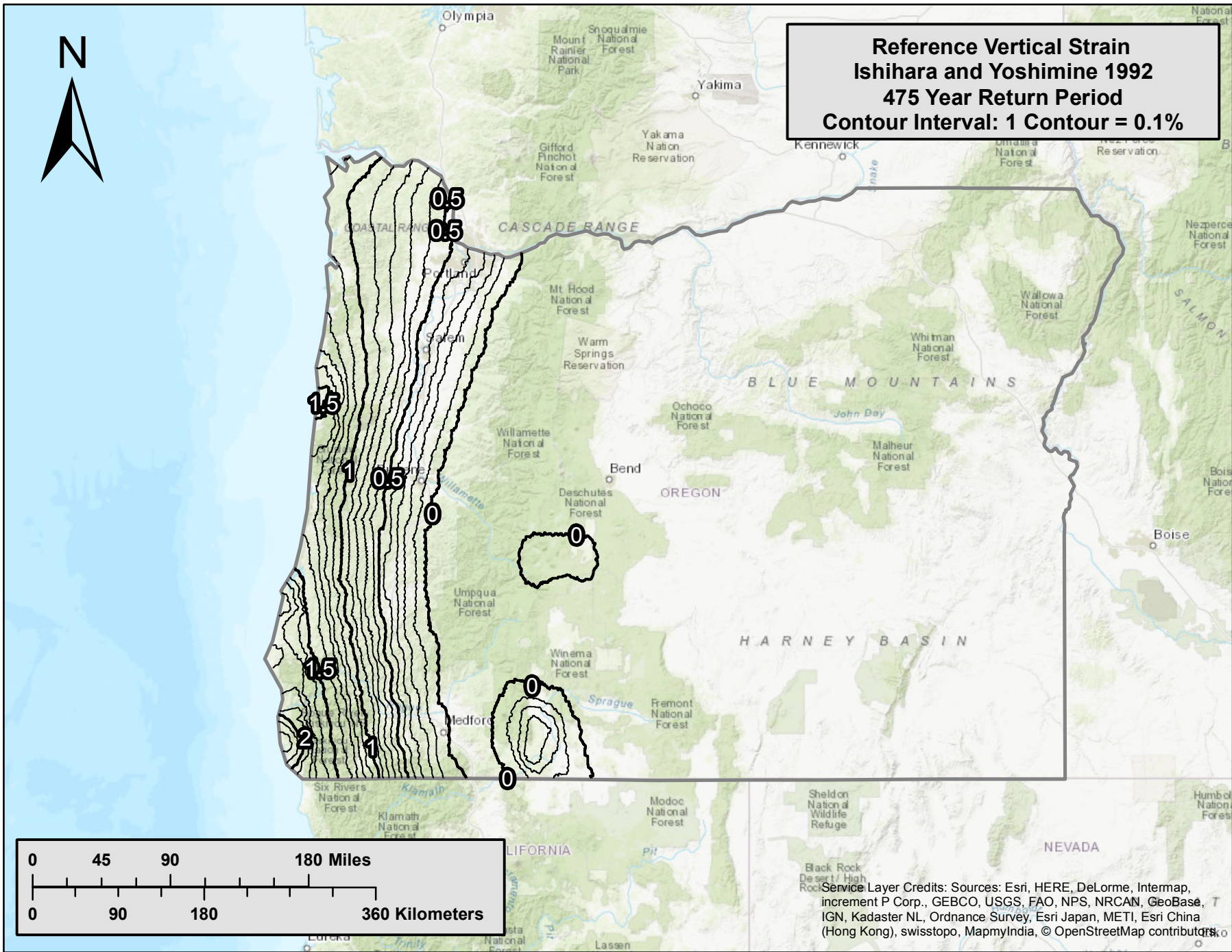


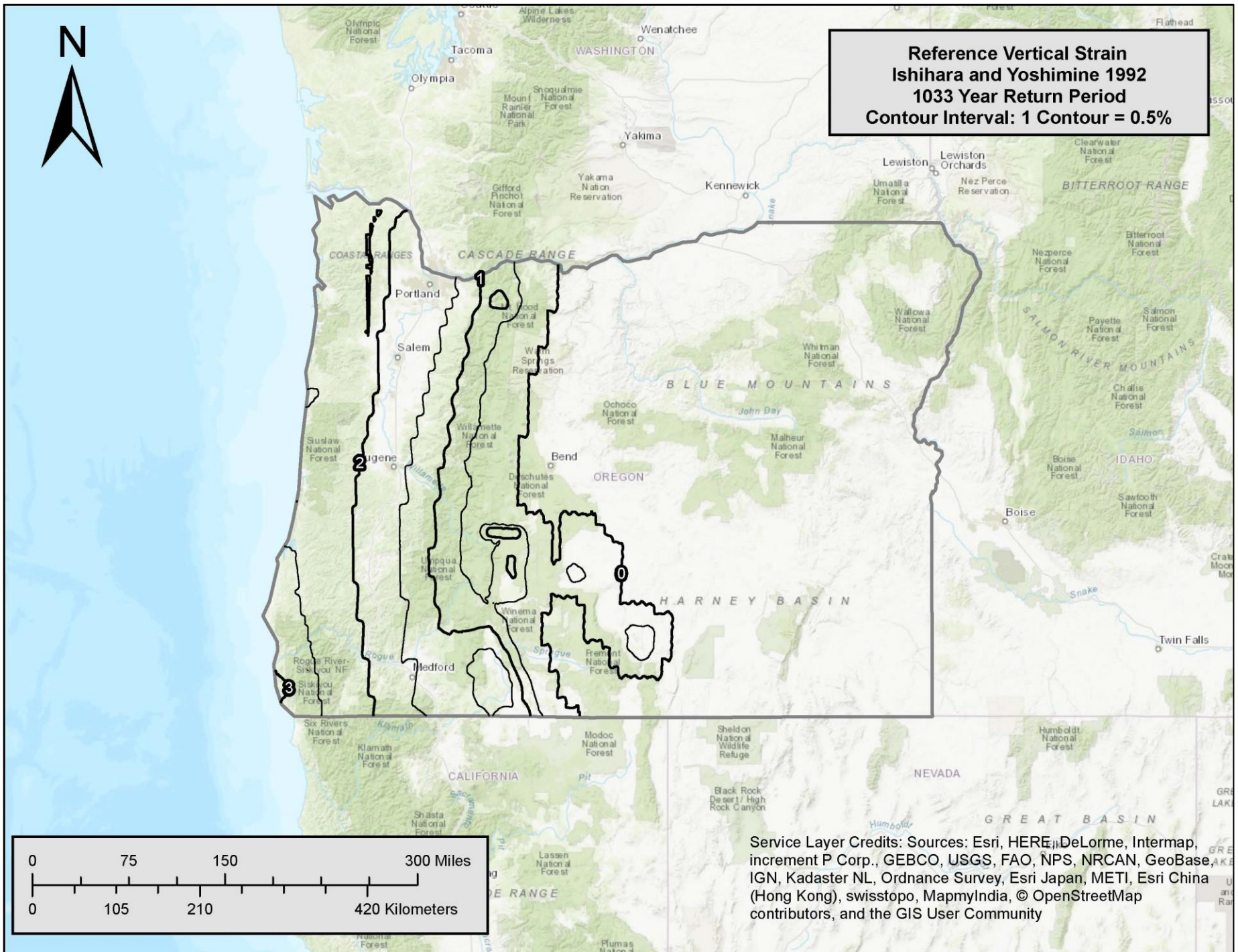


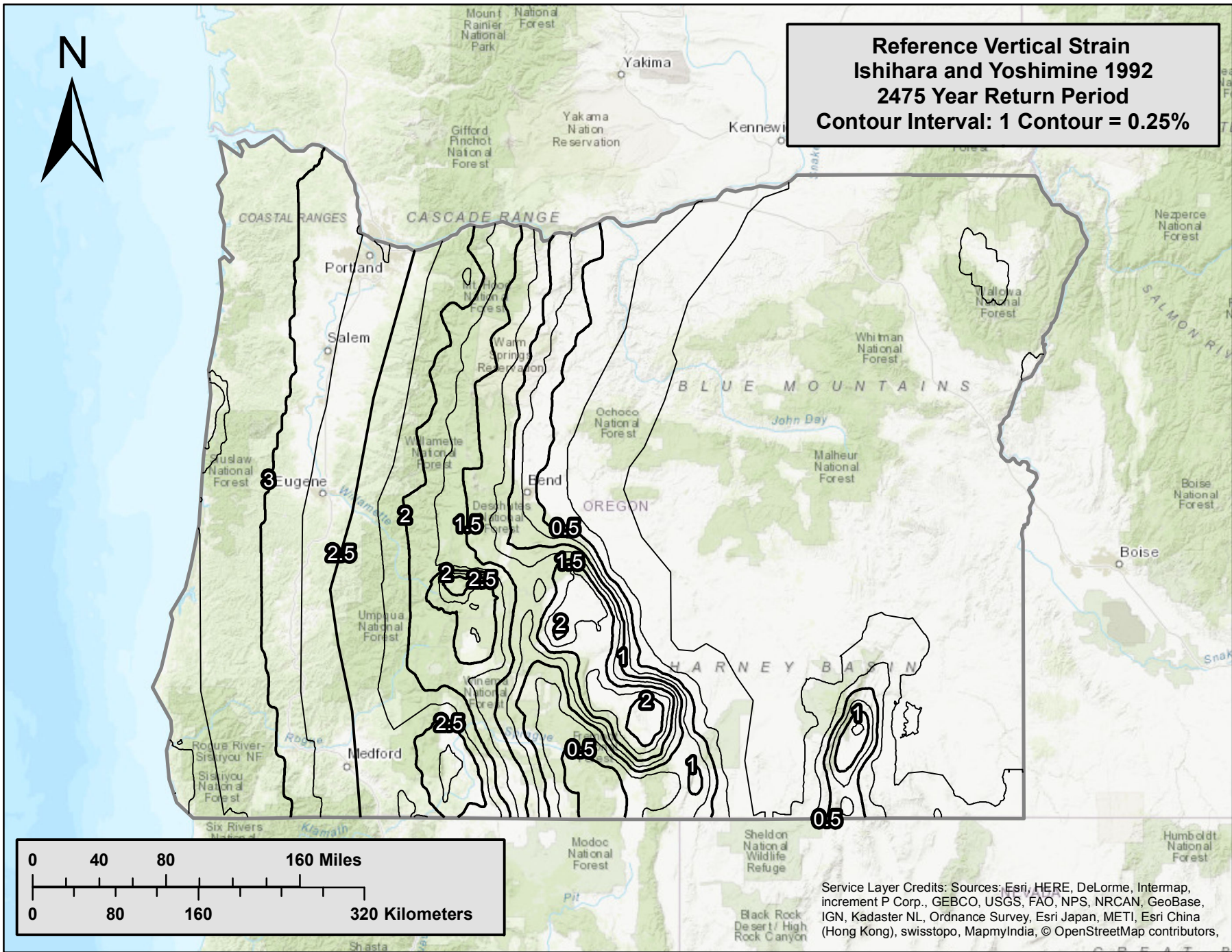


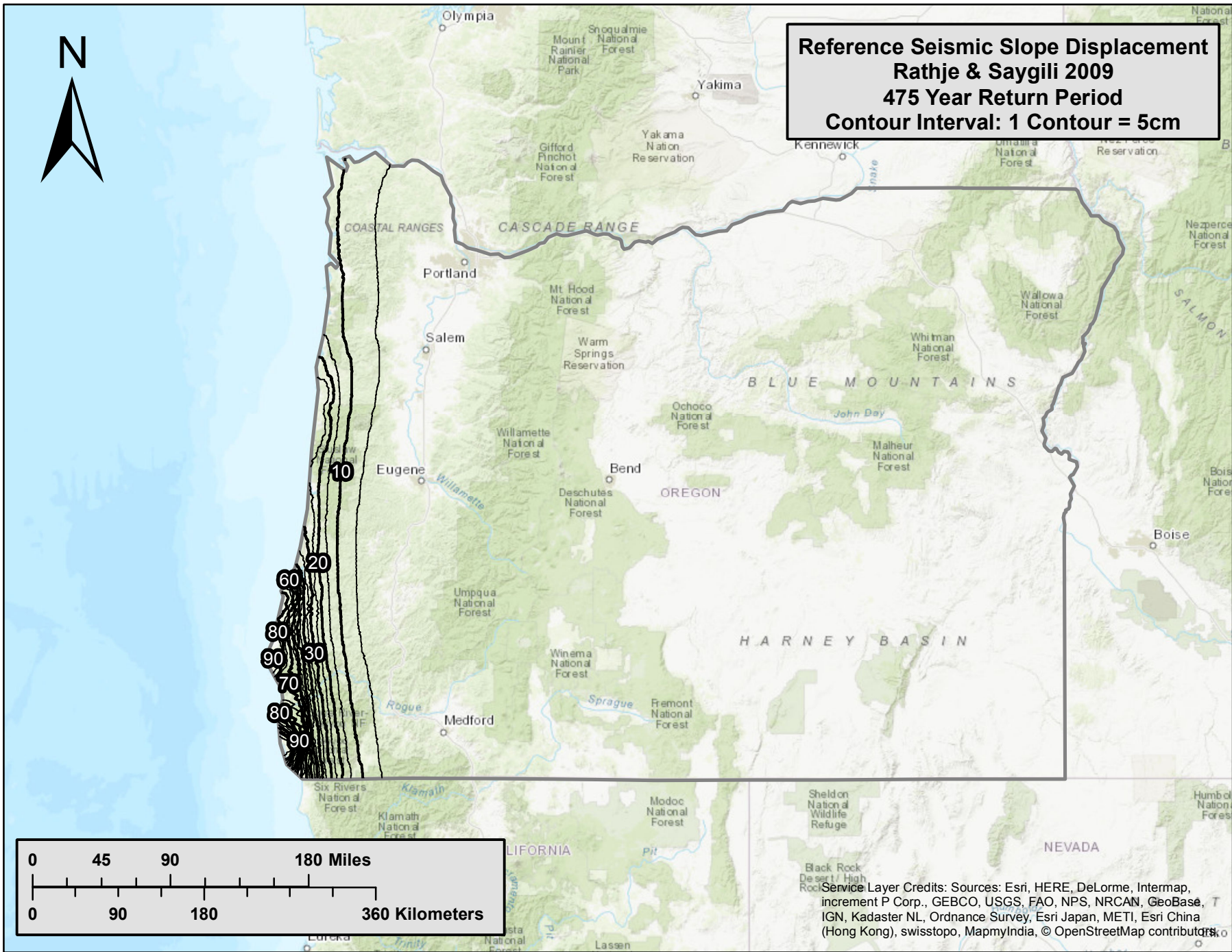


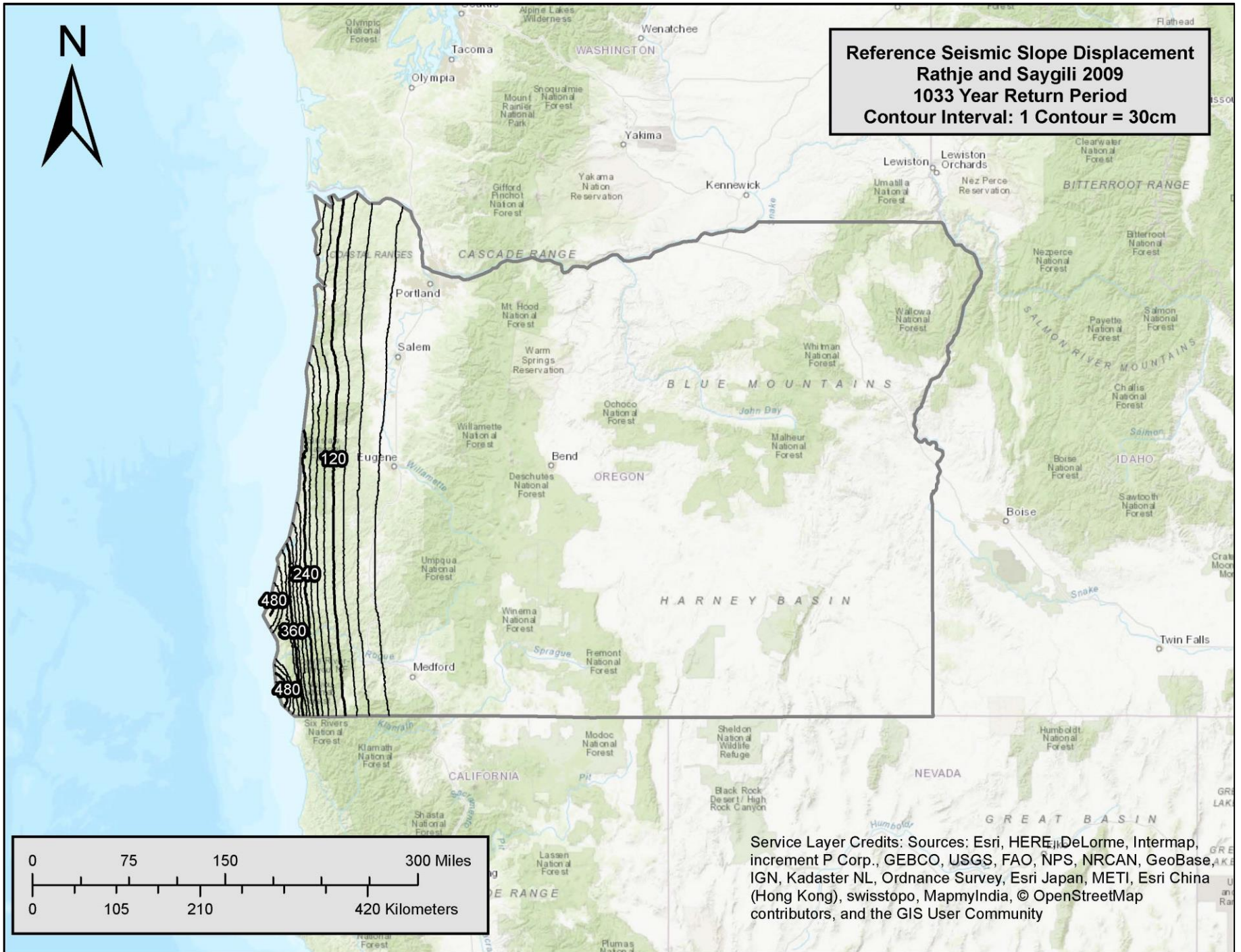


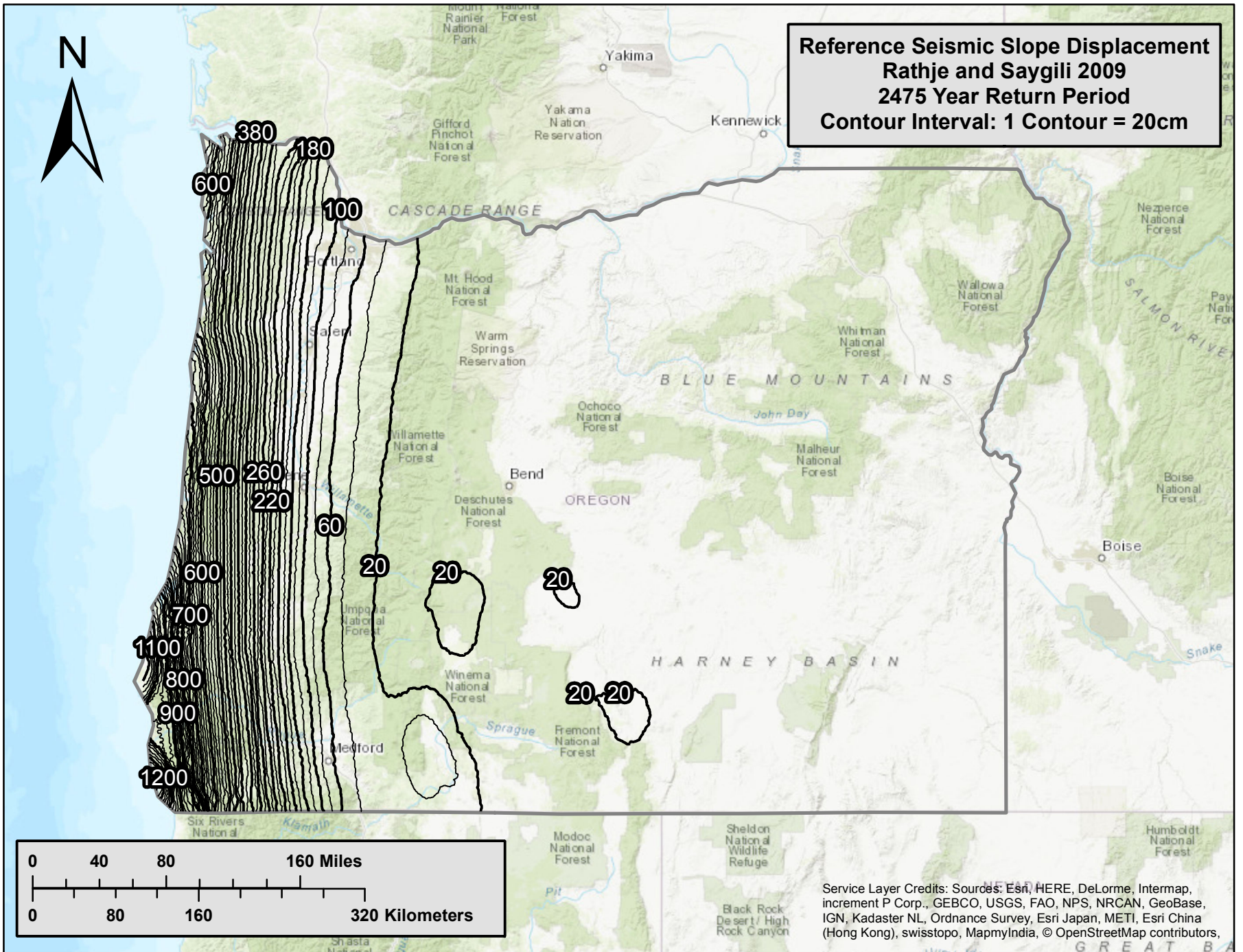


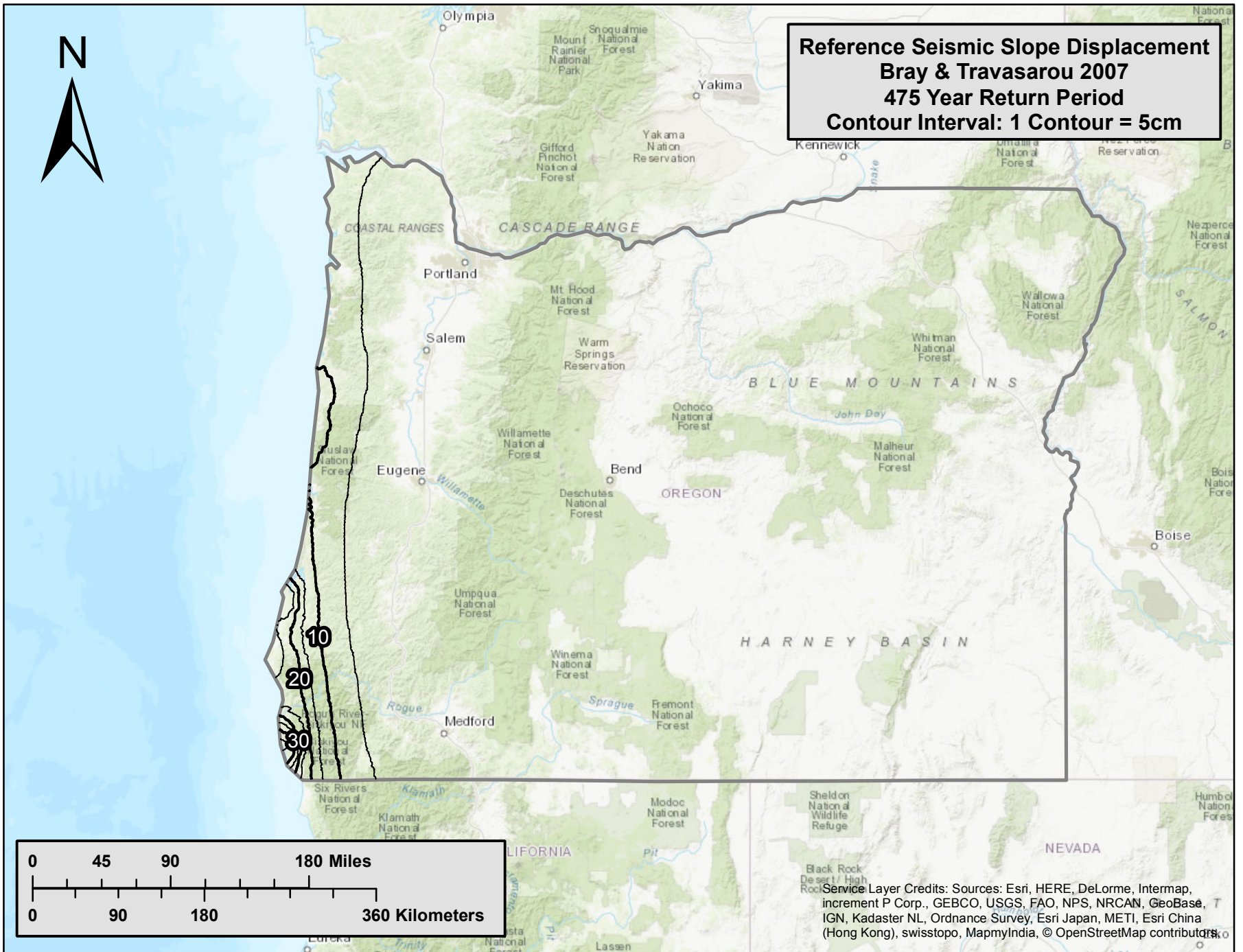


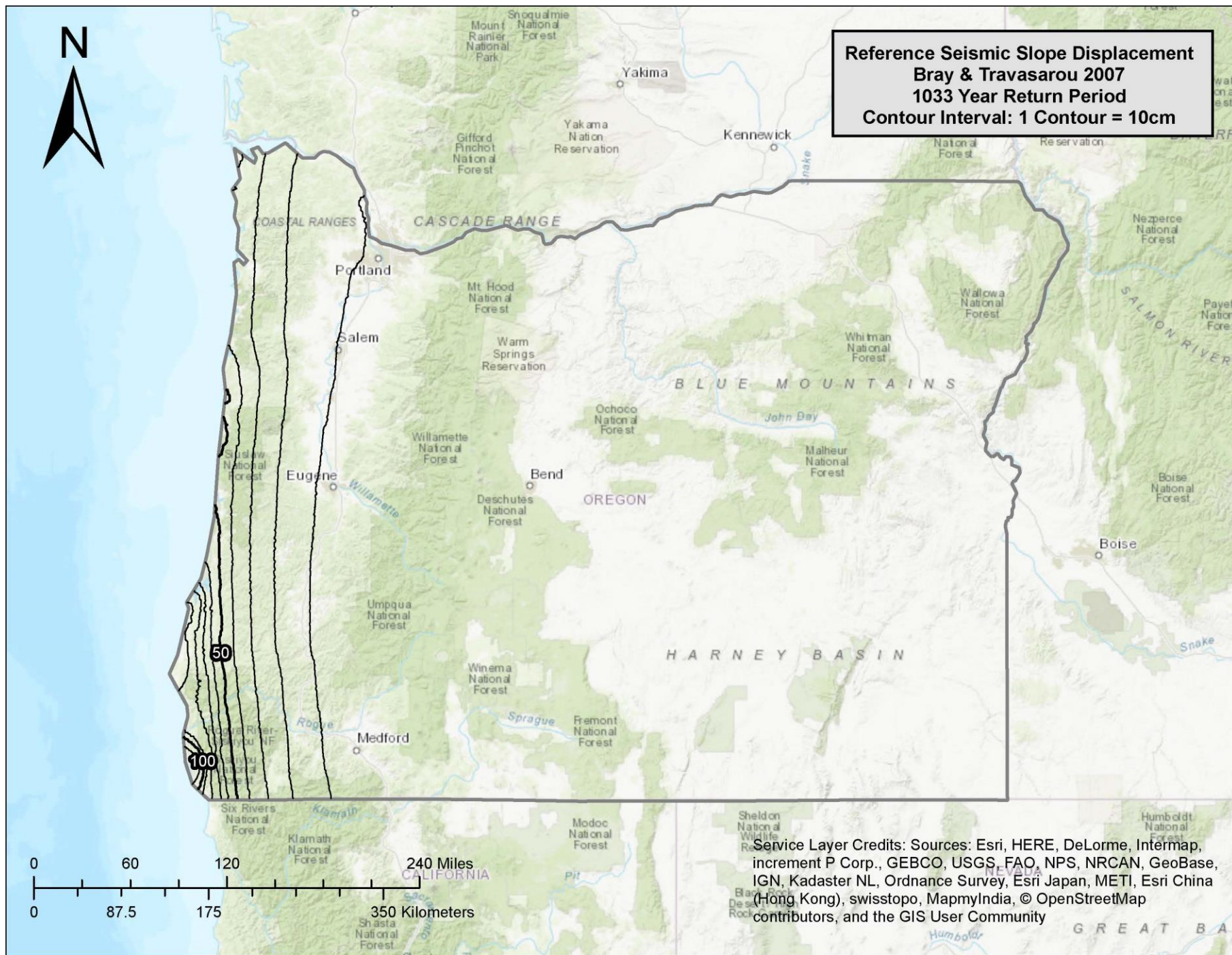


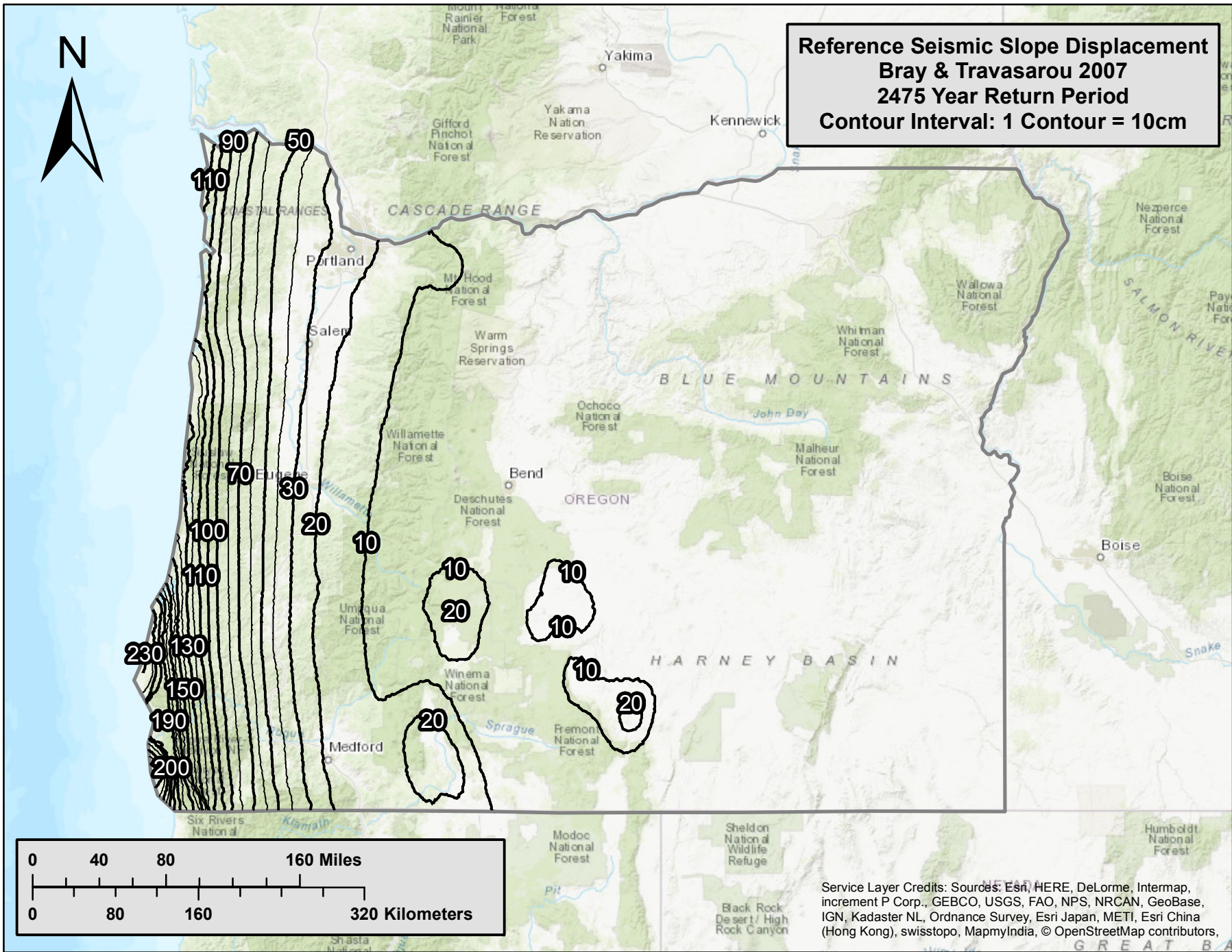




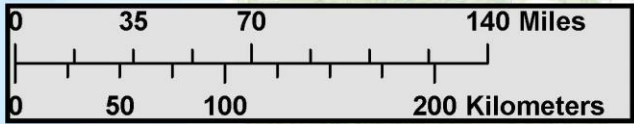
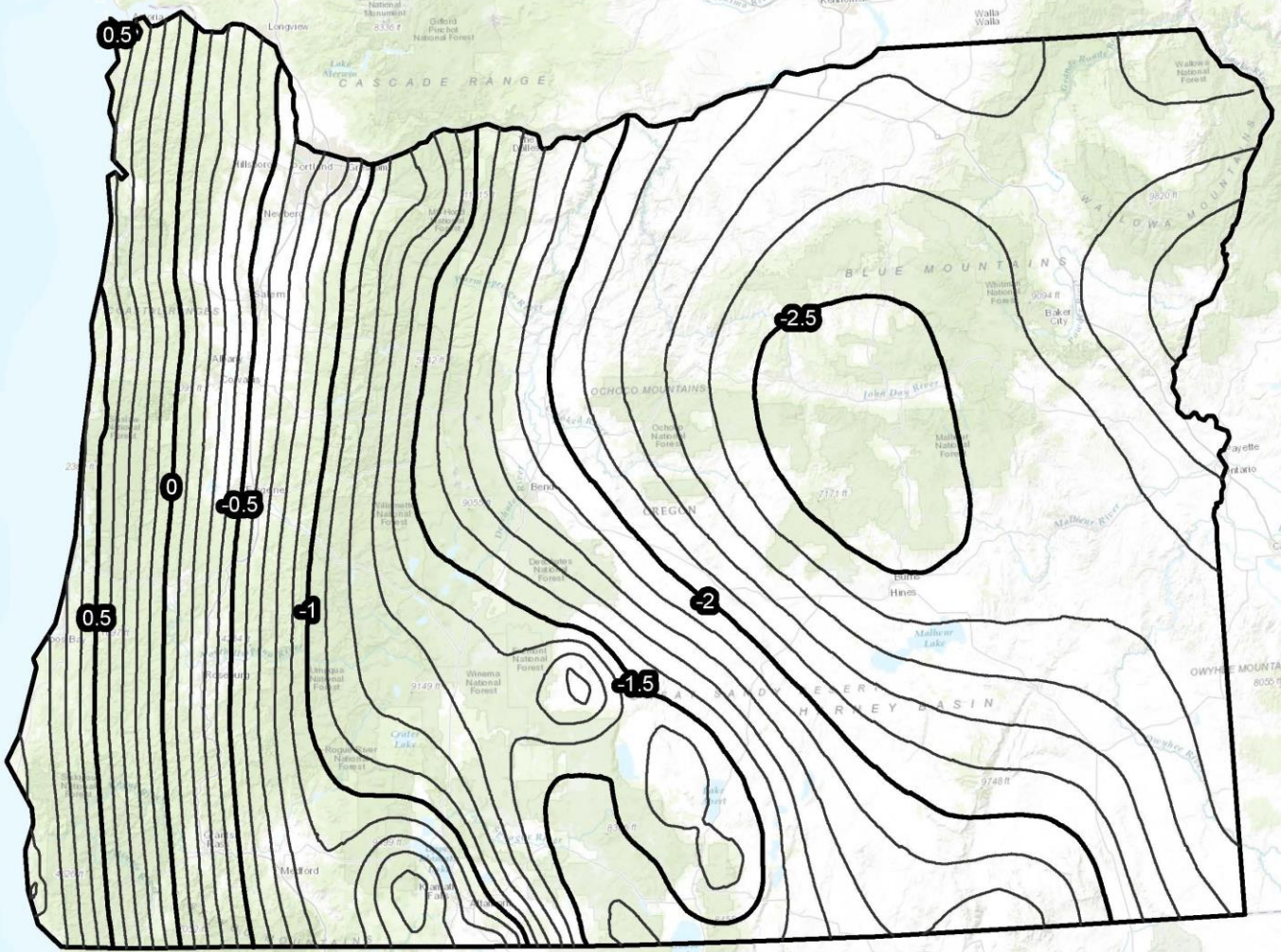






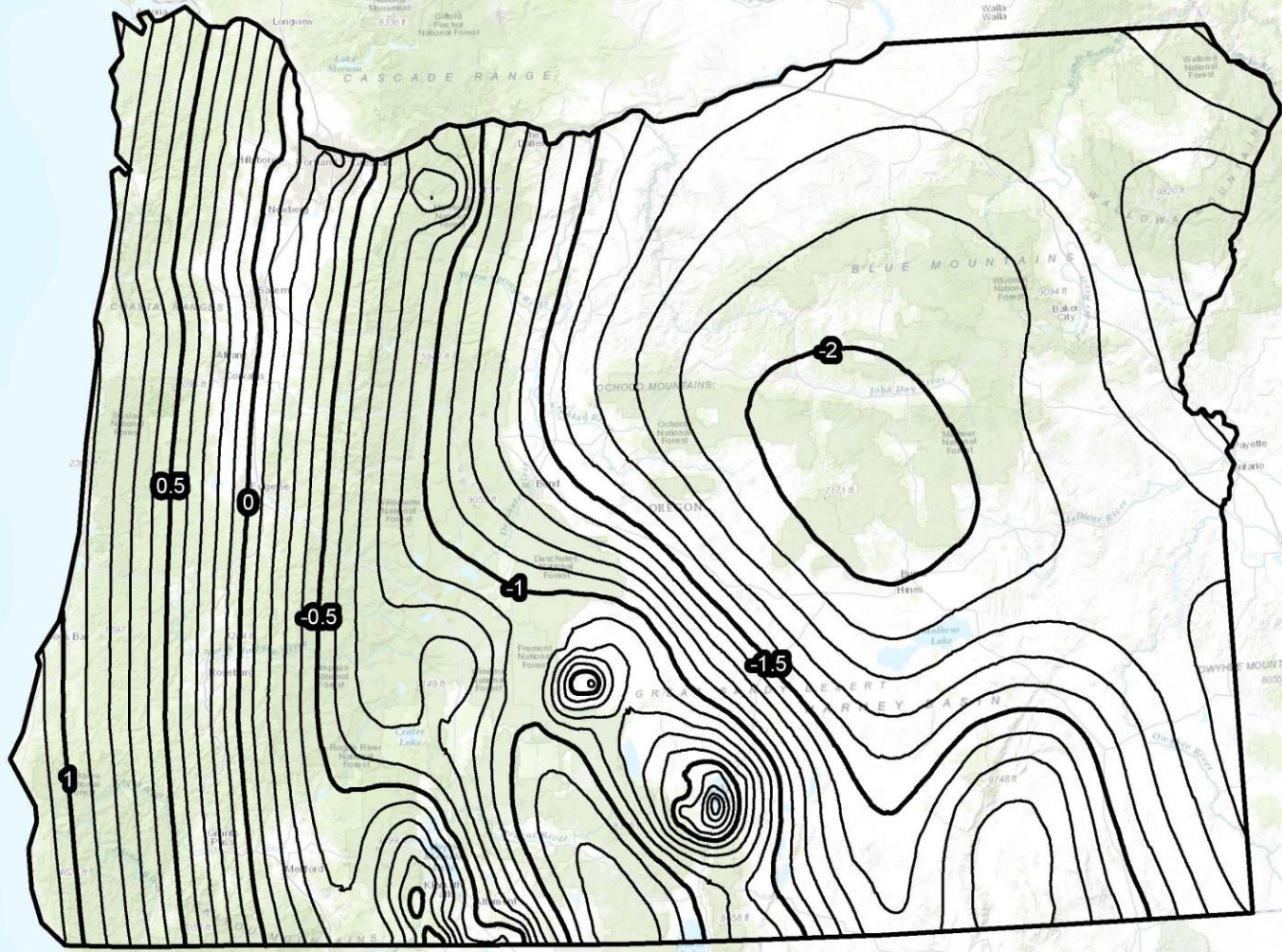


**Reference Lateral Spread Displacement
475 Year Return Period
Contour Interval: 1 Contour = 0.1 Log (Dh ref)**



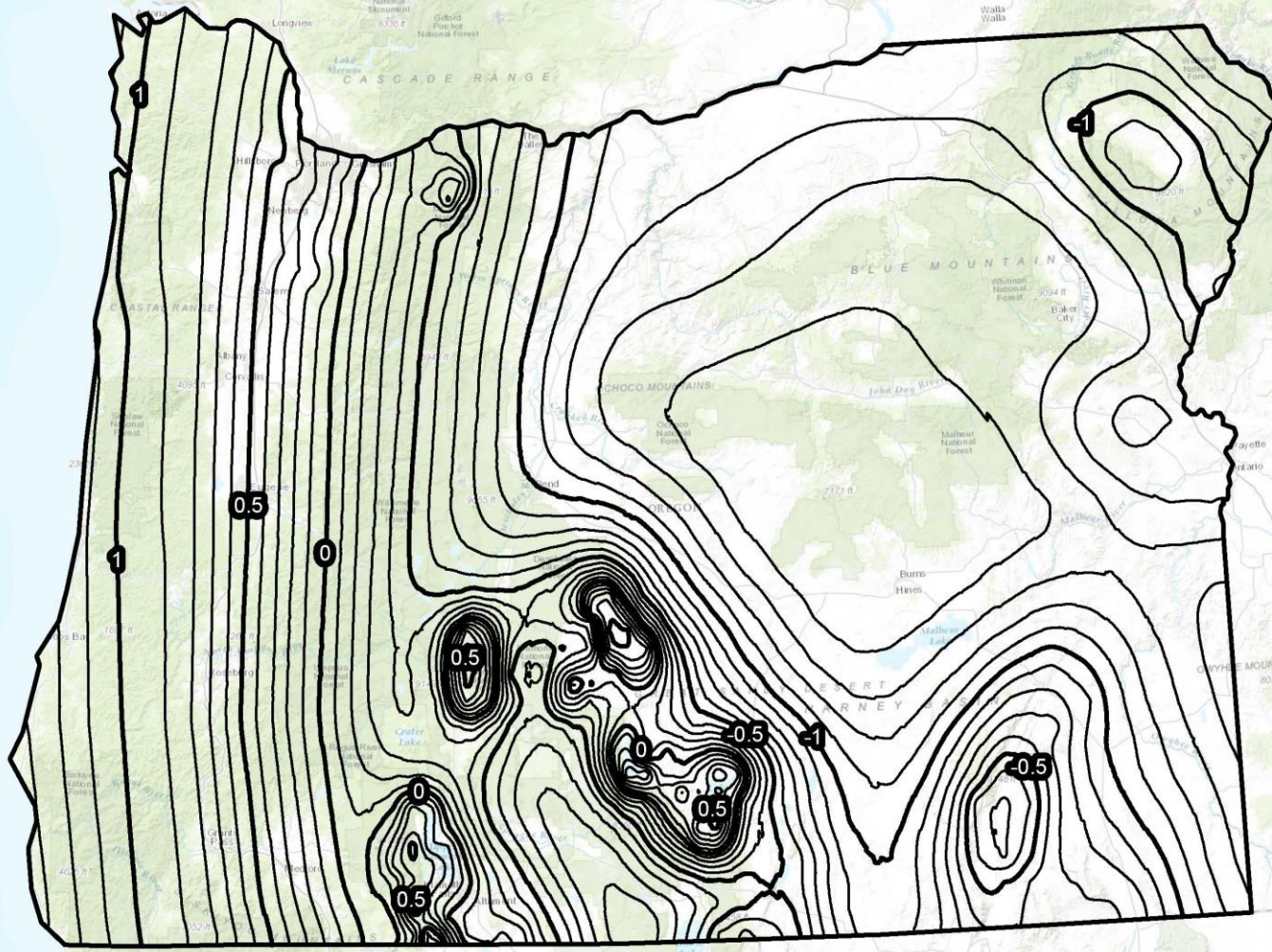
Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

**Reference Lateral Spread Displacement
1033 Year Return Period
Contour Interval: 1 Contour = 0.1 Log (Dh ref)**

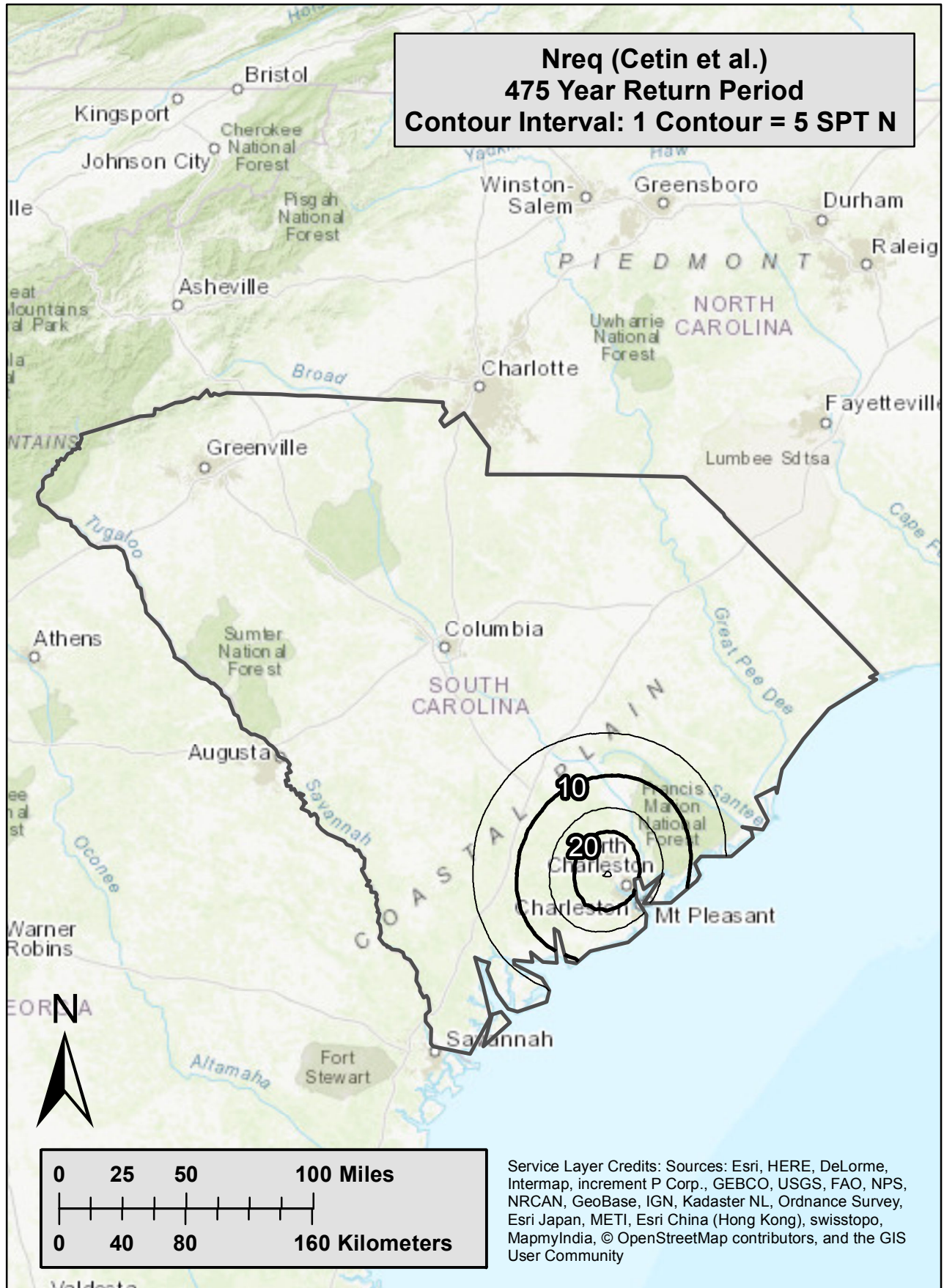


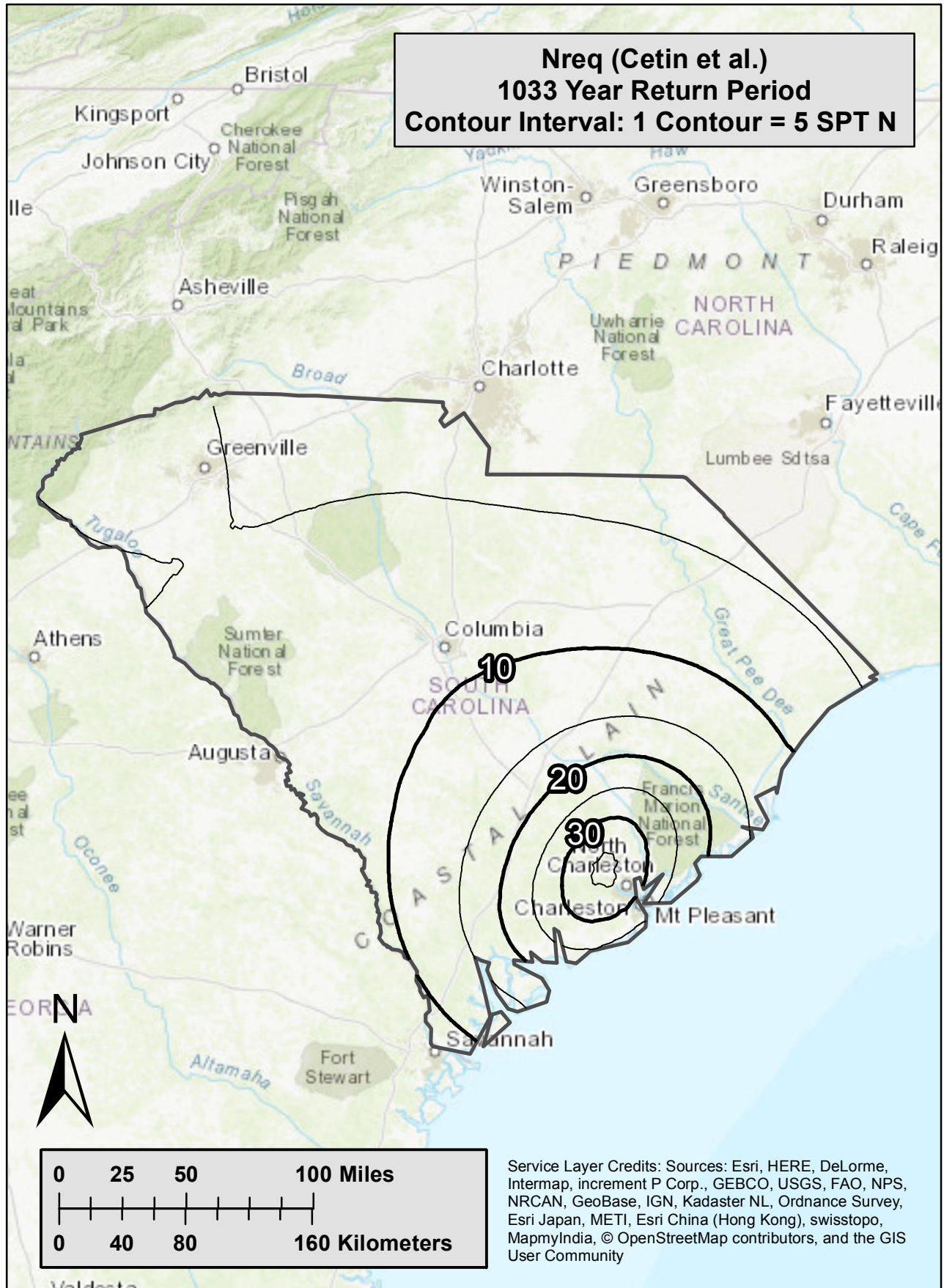
Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

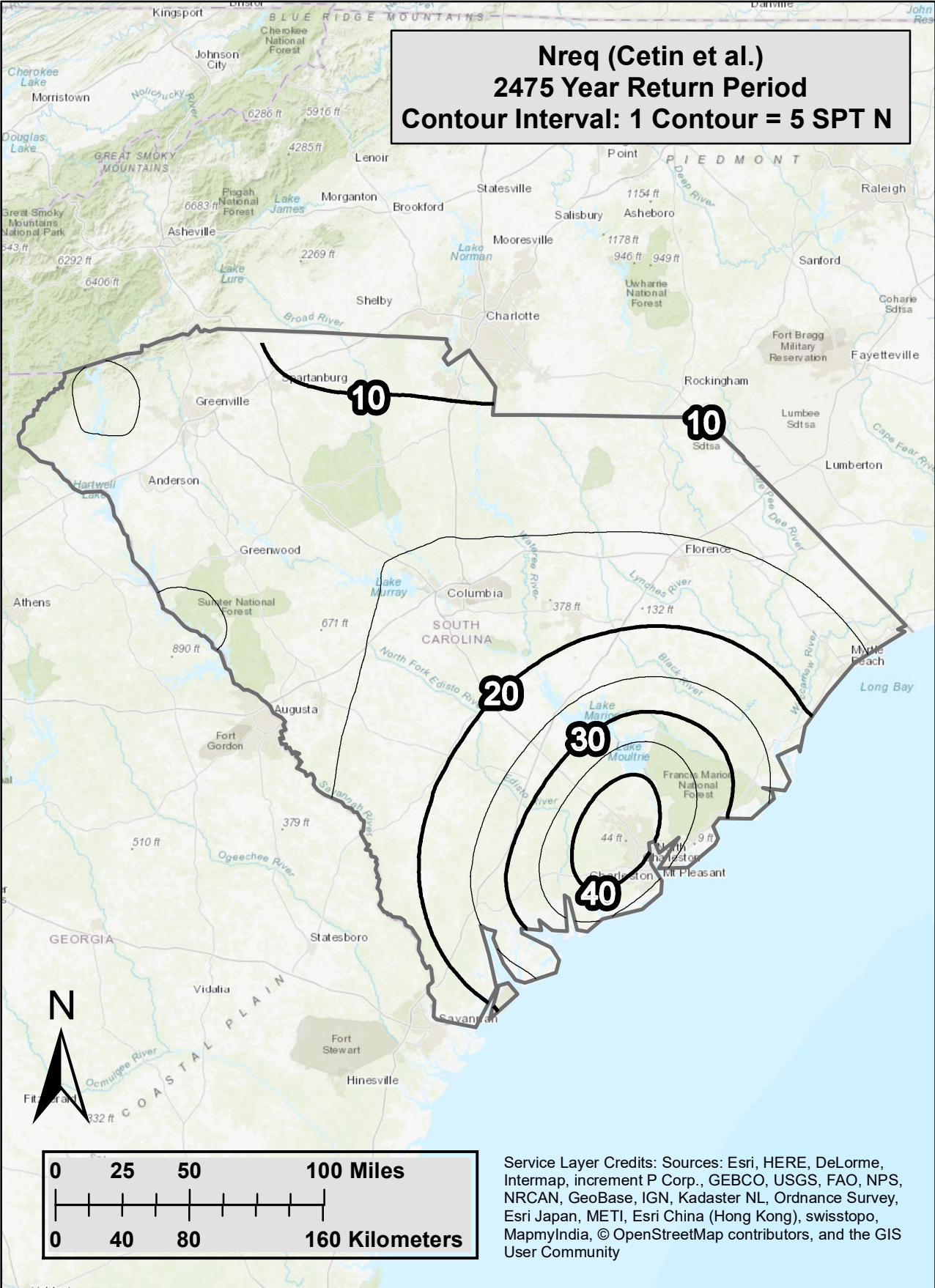
**Reference Lateral Spread Displacement
2475 Year Return Period
Contour Interval: 1 Contour = 0.1 Log (Dh ref)**



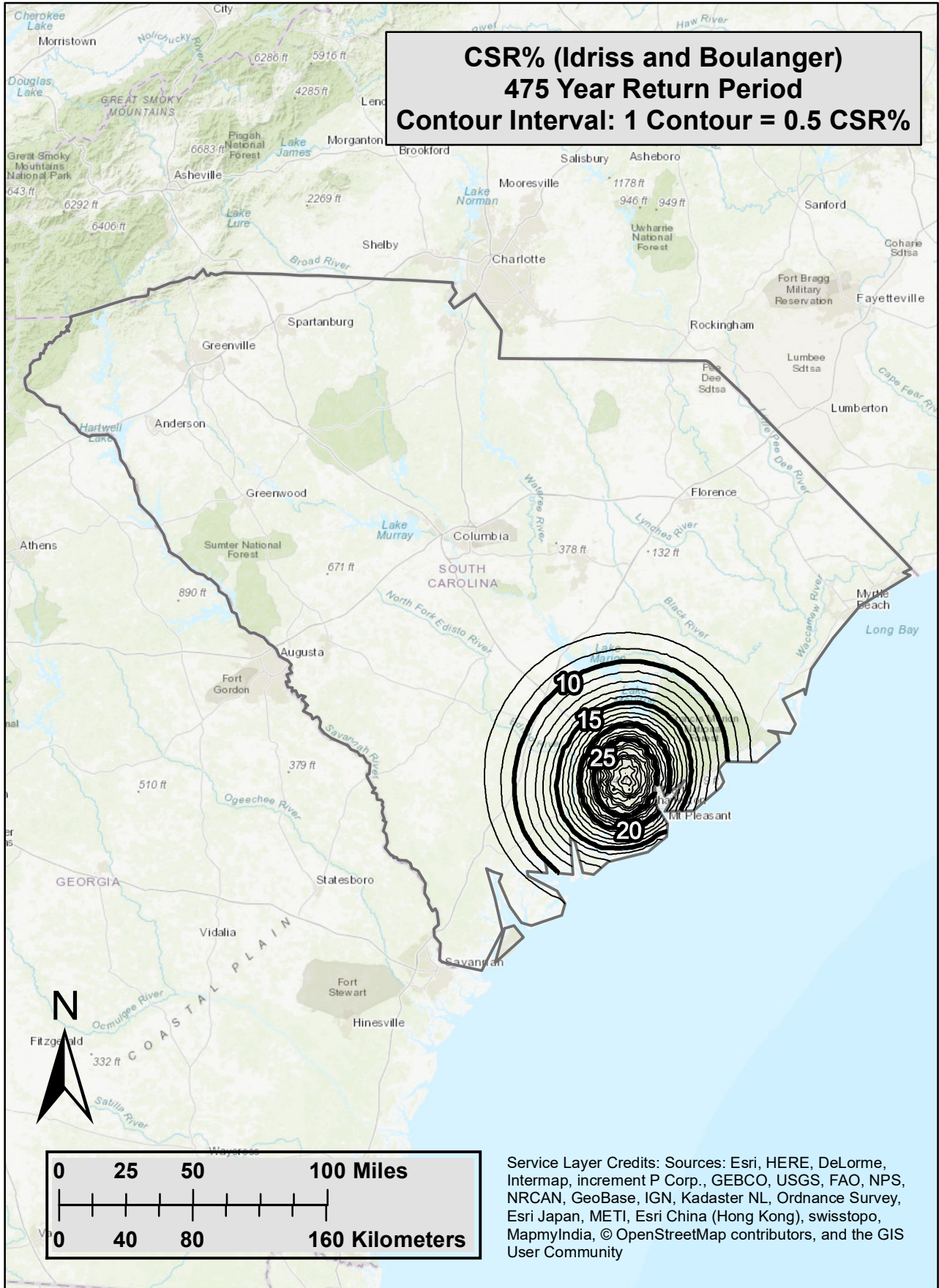
Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community



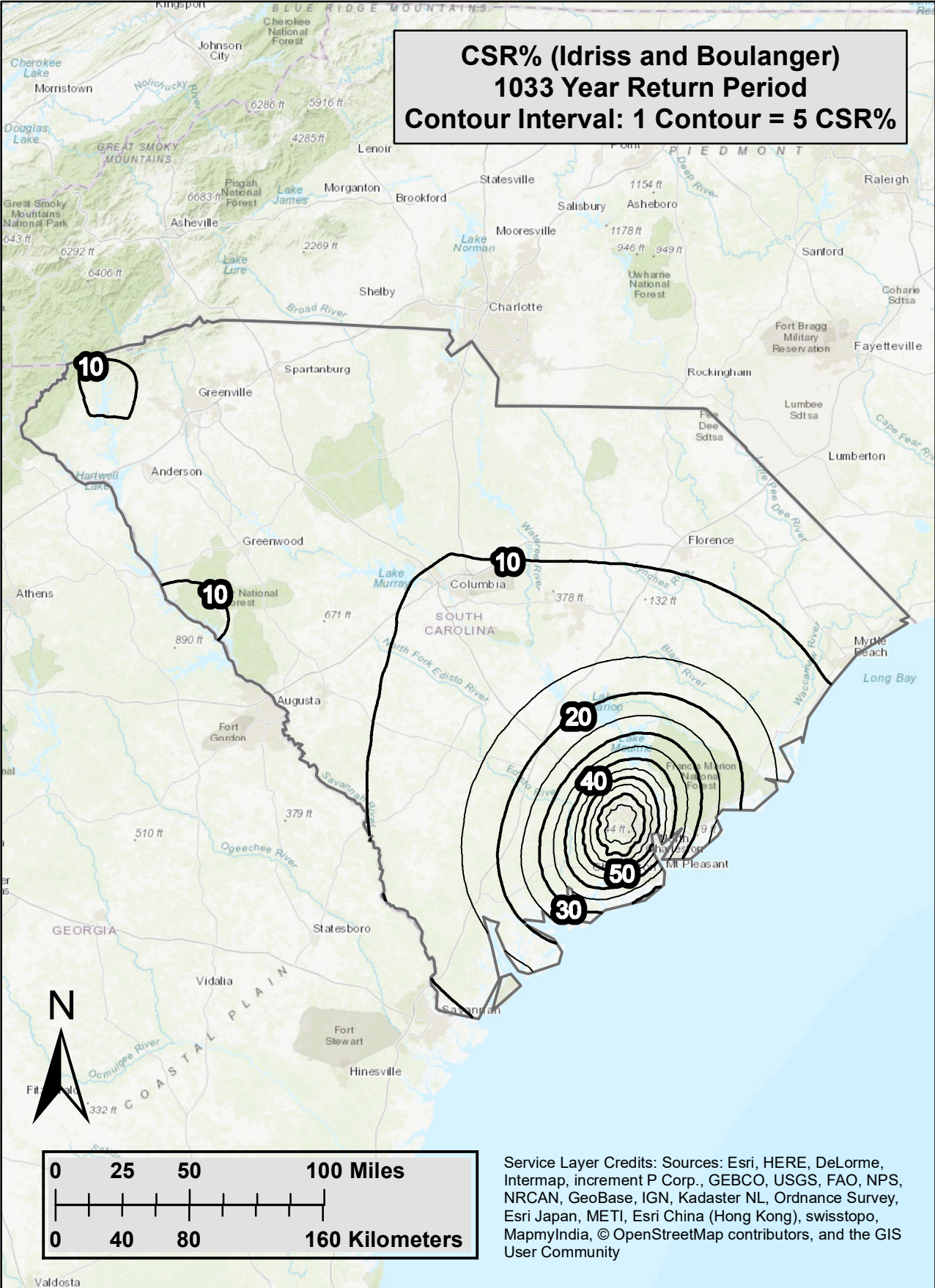




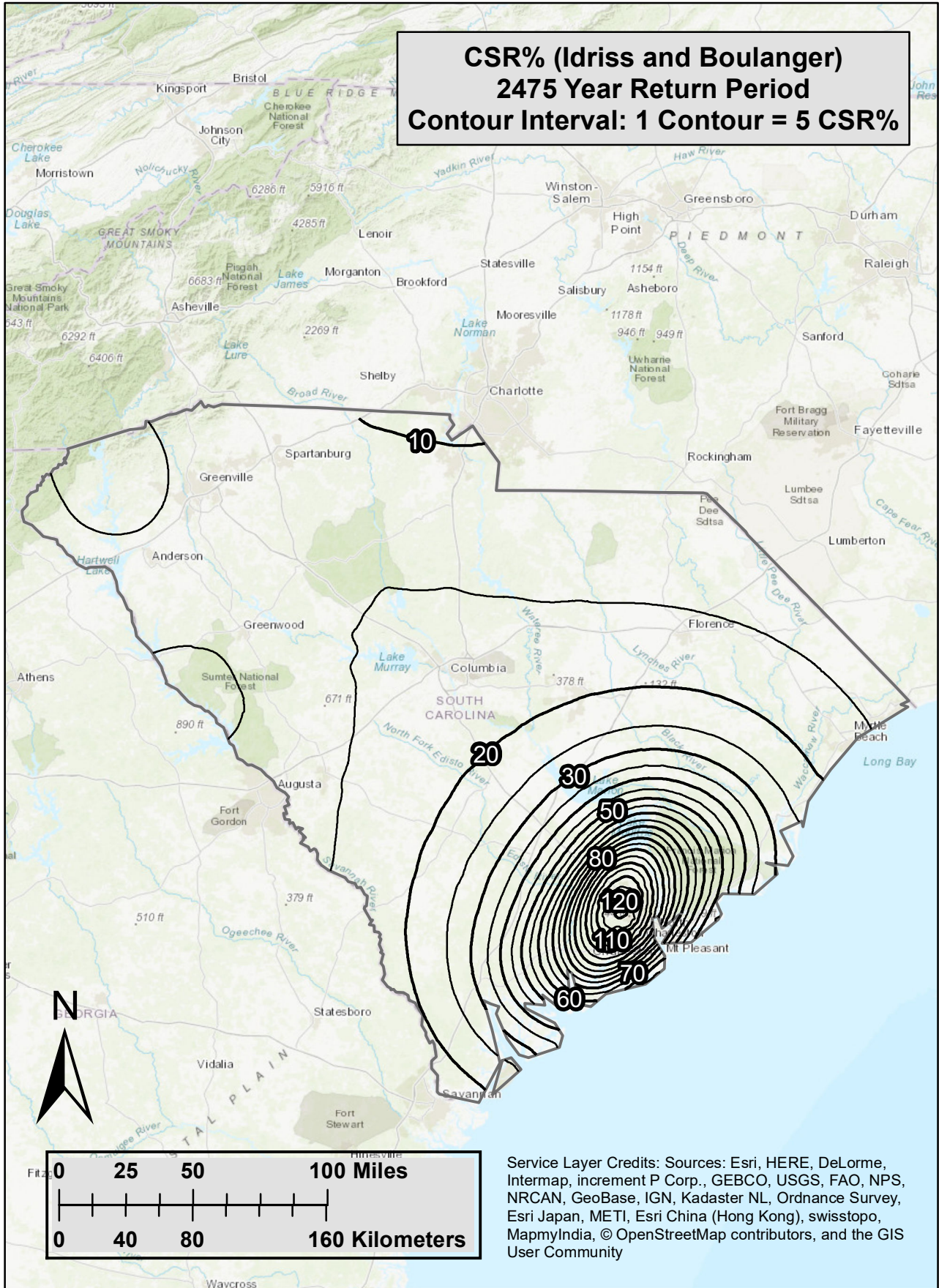
**CSR% (Idriss and Boulanger)
475 Year Return Period
Contour Interval: 1 Contour = 0.5 CSR%**



Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

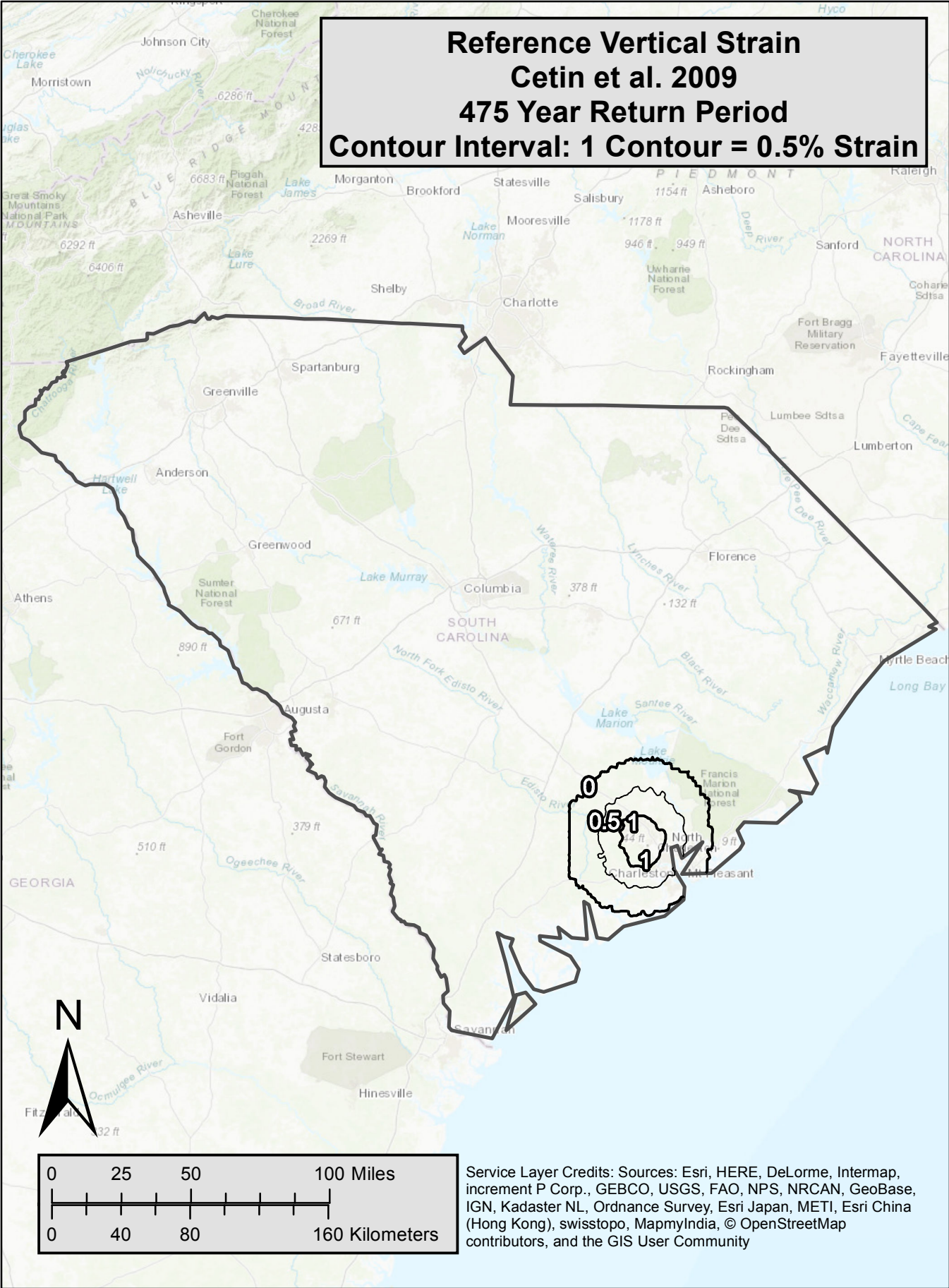


**CSR% (Idriss and Boulanger)
2475 Year Return Period
Contour Interval: 1 Contour = 5 CSR%**

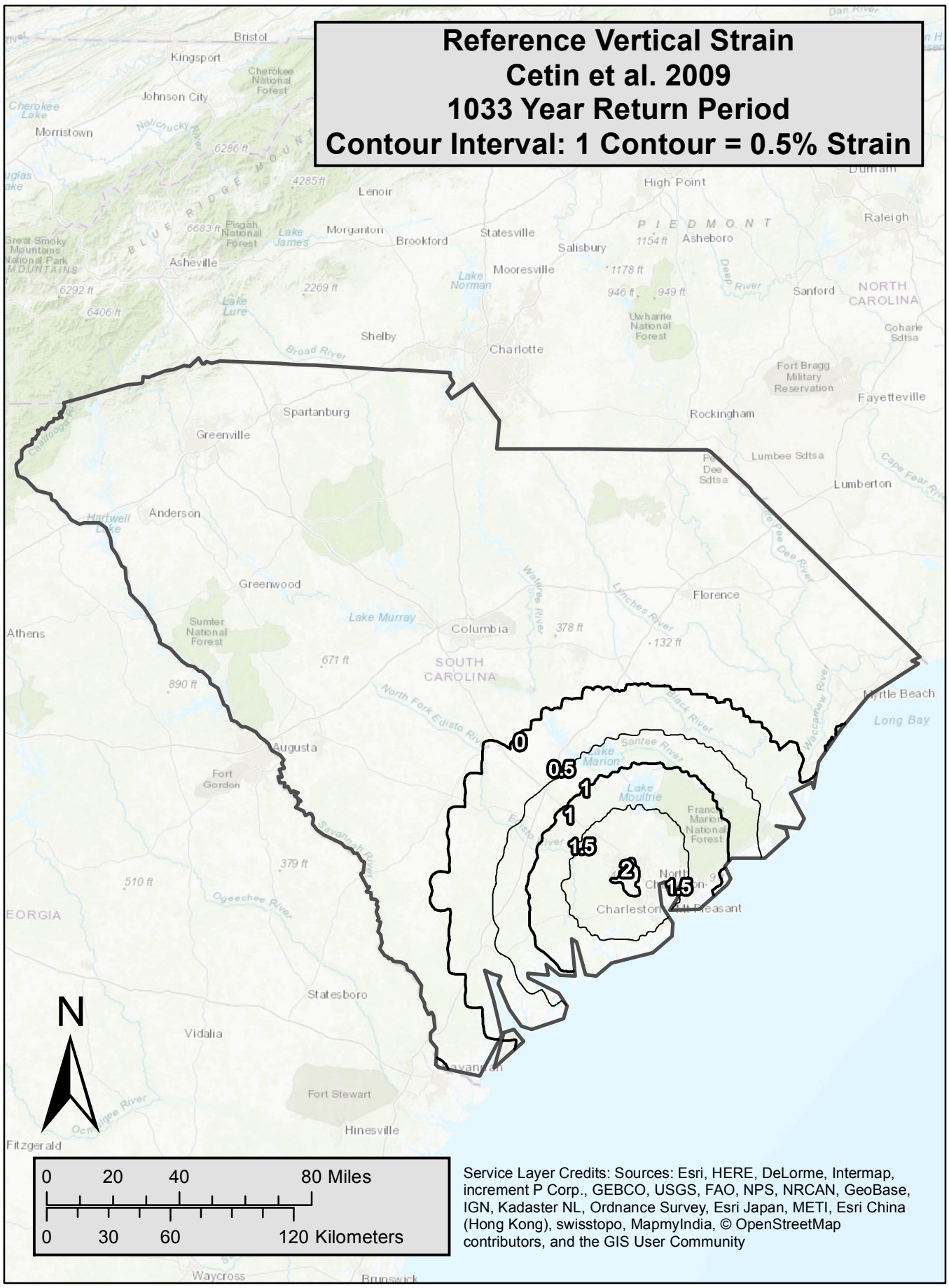


Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

**Reference Vertical Strain
Cetin et al. 2009
475 Year Return Period
Contour Interval: 1 Contour = 0.5% Strain**

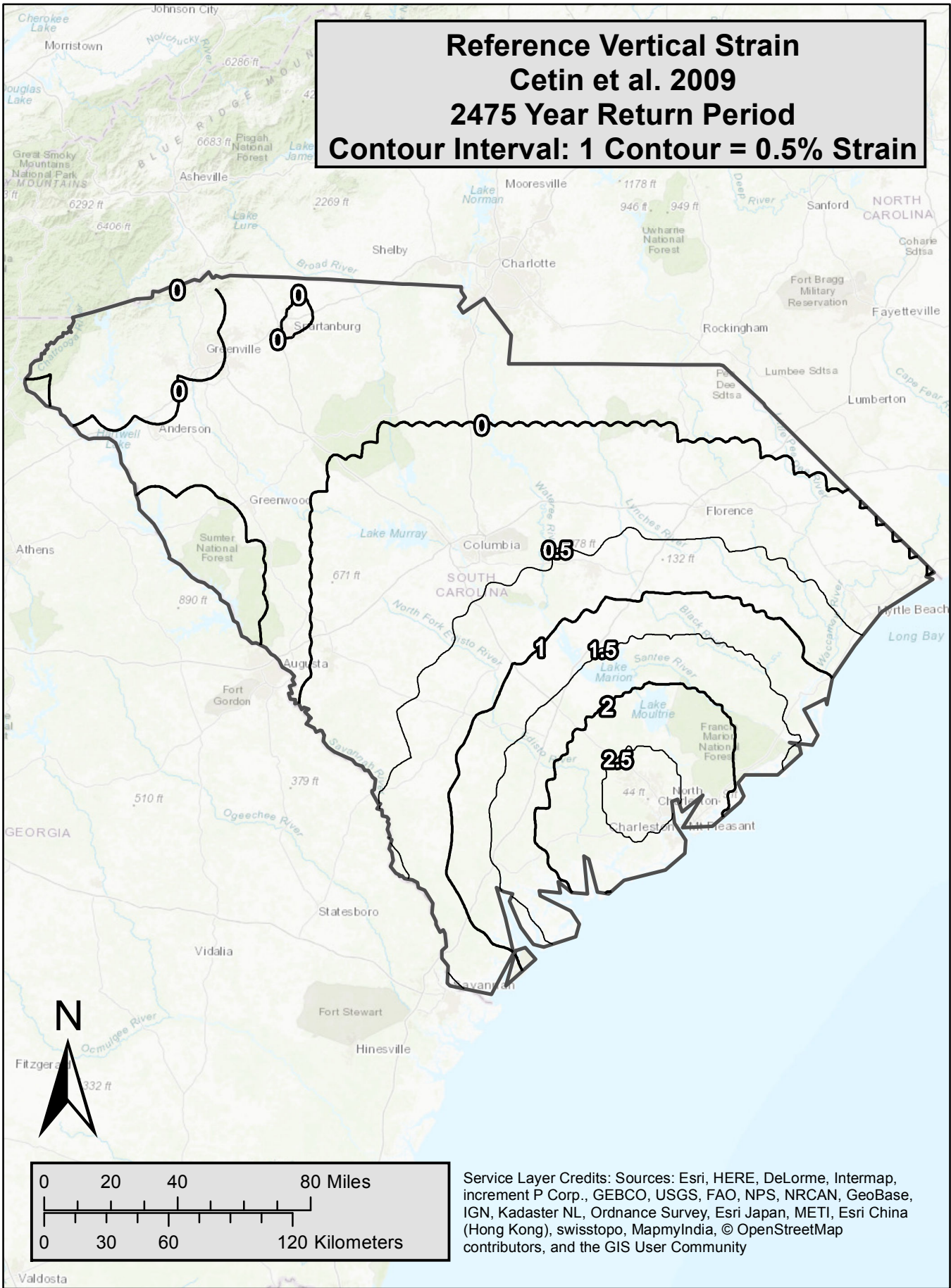


**Reference Vertical Strain
Cetin et al. 2009
1033 Year Return Period
Contour Interval: 1 Contour = 0.5% Strain**



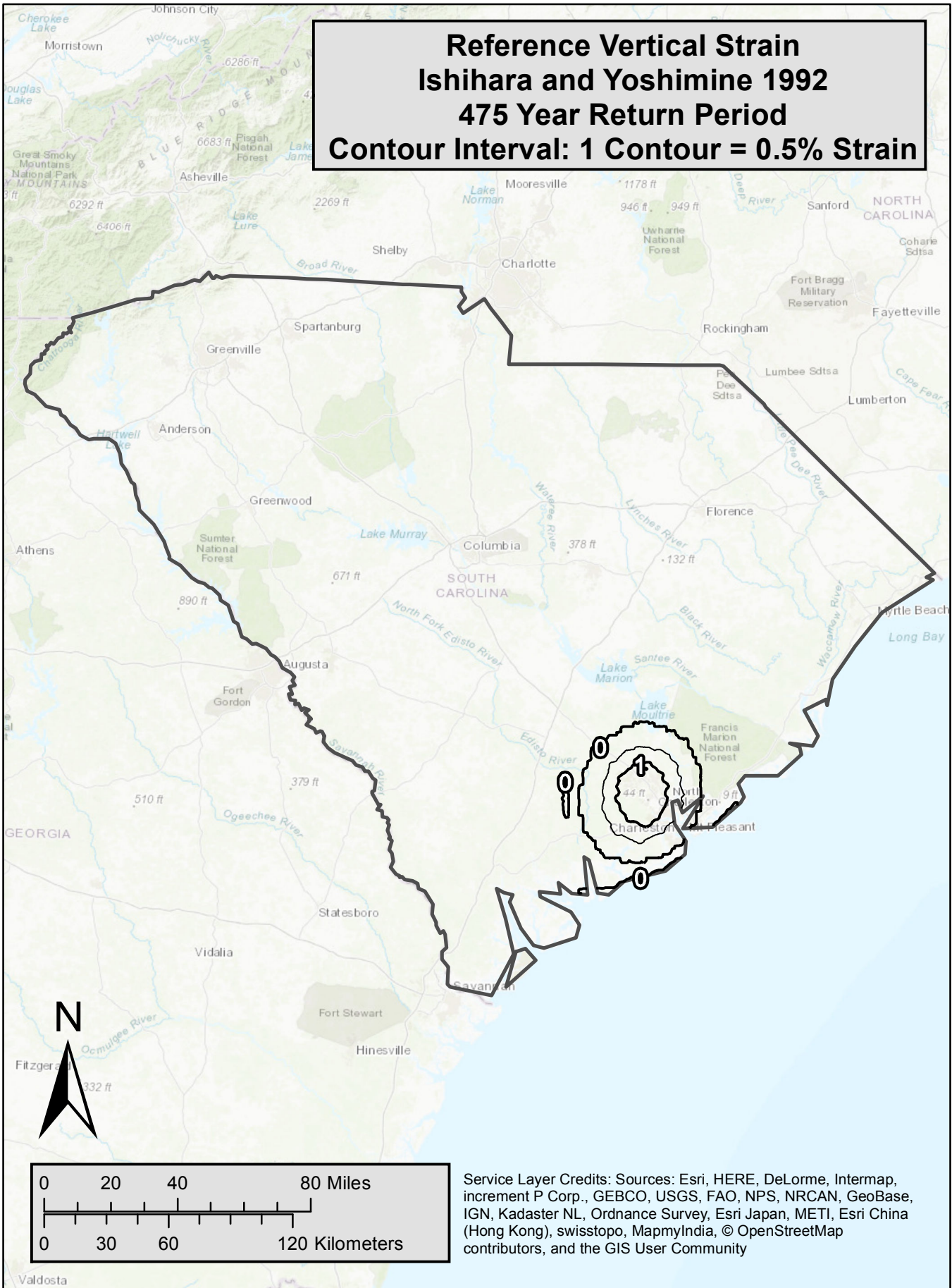
Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

**Reference Vertical Strain
Cetin et al. 2009
2475 Year Return Period
Contour Interval: 1 Contour = 0.5% Strain**



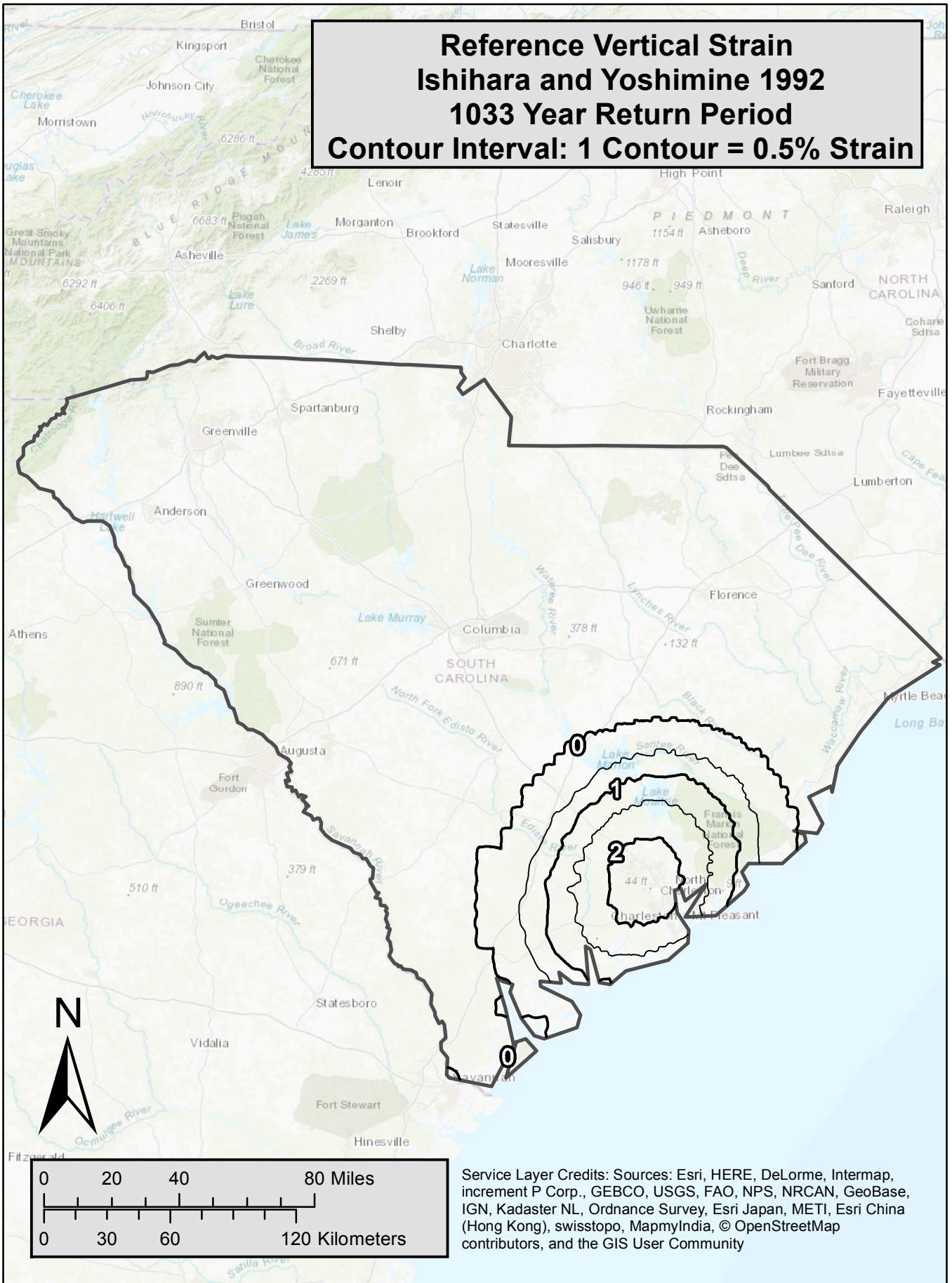
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**Reference Vertical Strain
Ishihara and Yoshimine 1992
475 Year Return Period
Contour Interval: 1 Contour = 0.5% Strain**

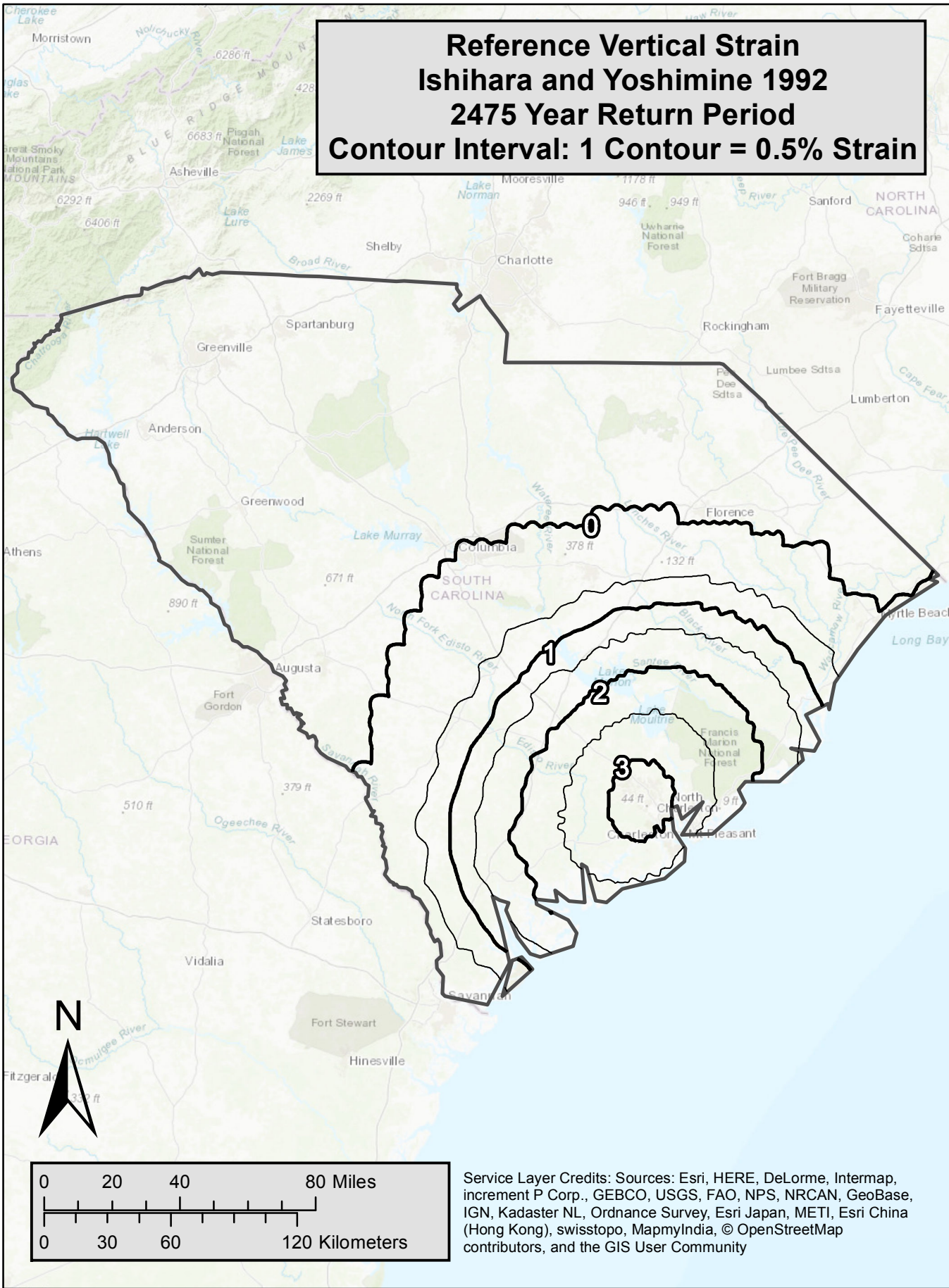


Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

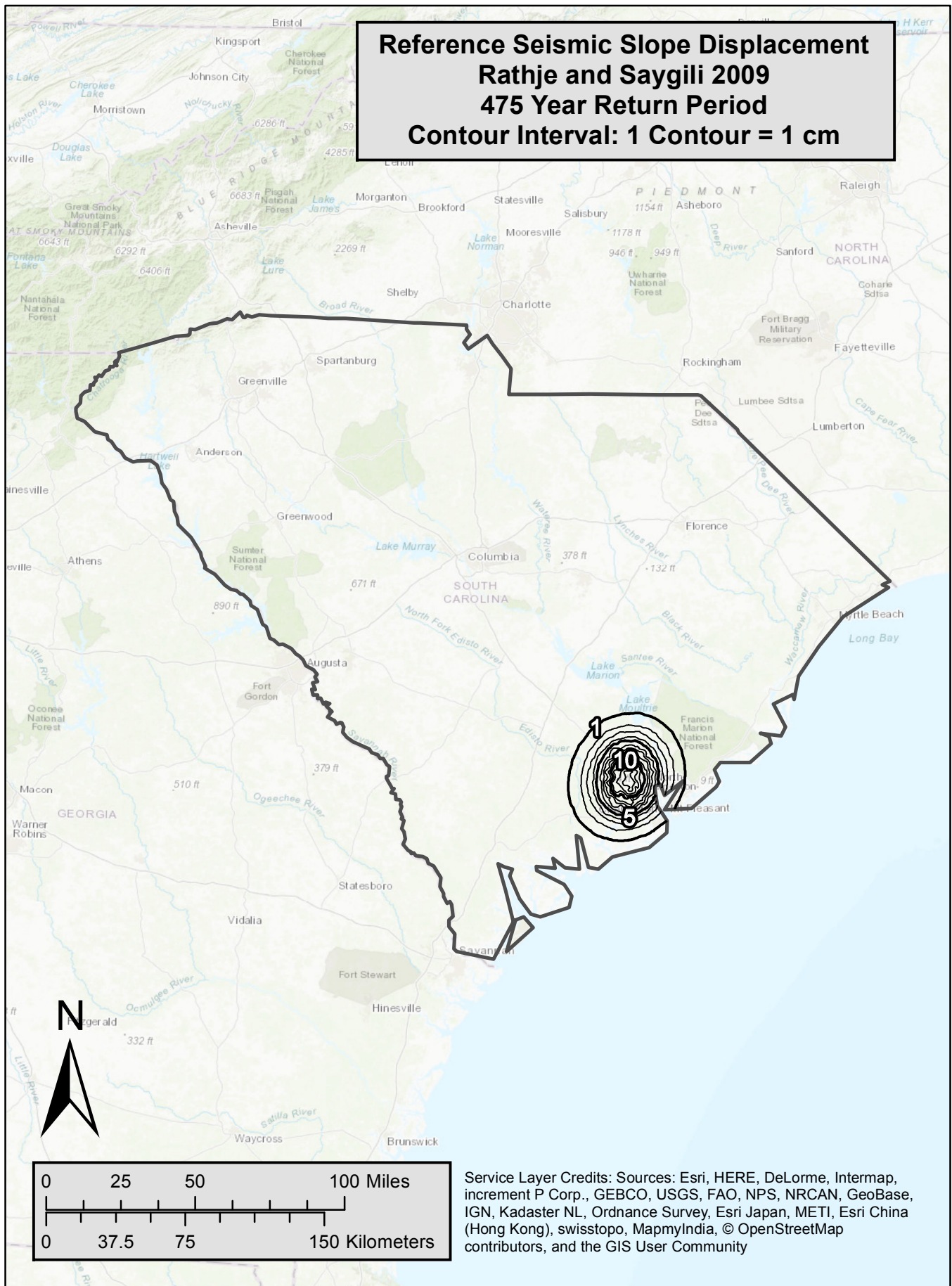
**Reference Vertical Strain
Ishihara and Yoshimine 1992
1033 Year Return Period
Contour Interval: 1 Contour = 0.5% Strain**



**Reference Vertical Strain
Ishihara and Yoshimine 1992
2475 Year Return Period
Contour Interval: 1 Contour = 0.5% Strain**

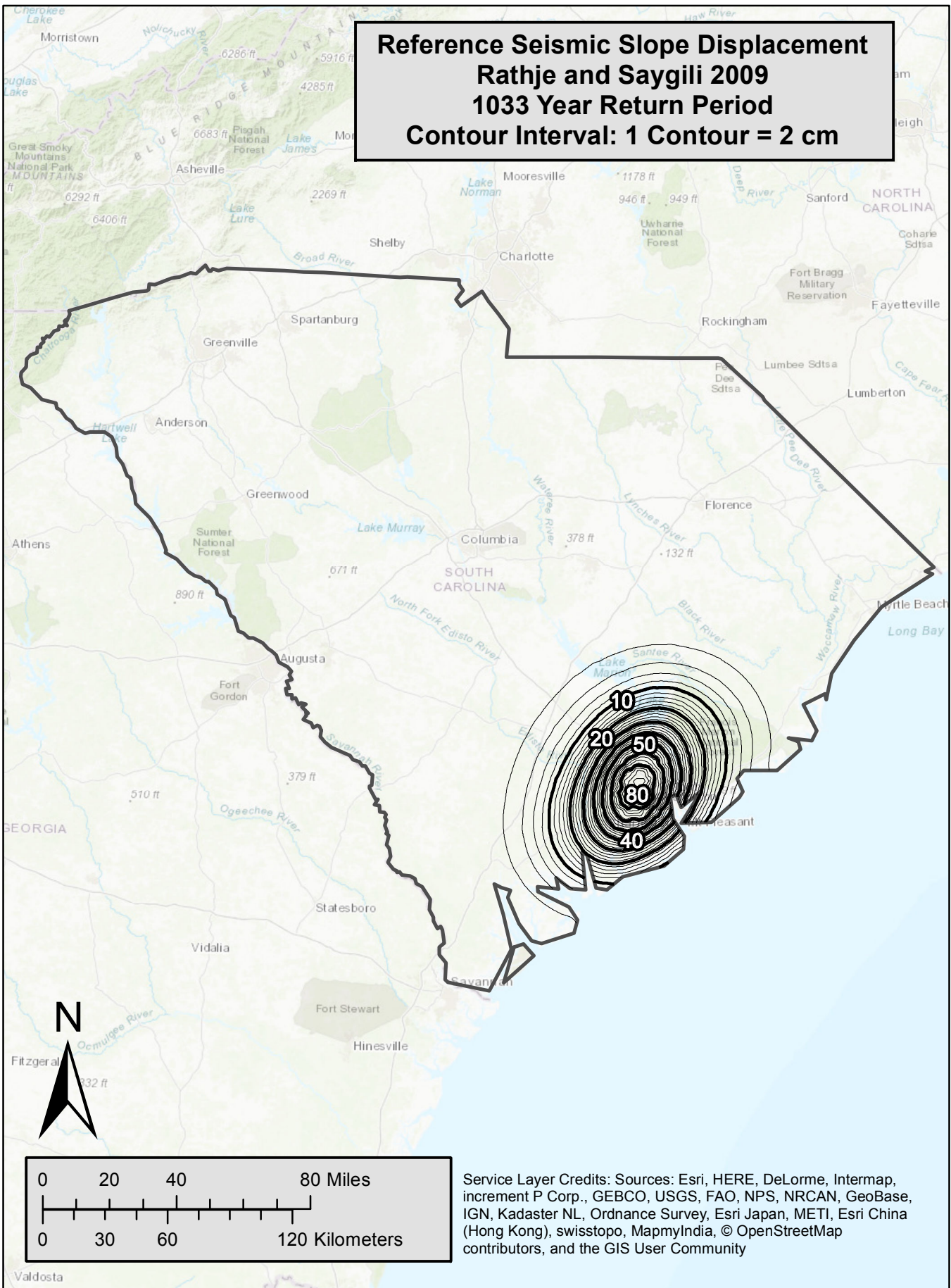


**Reference Seismic Slope Displacement
Rathje and Saygili 2009
475 Year Return Period
Contour Interval: 1 Contour = 1 cm**



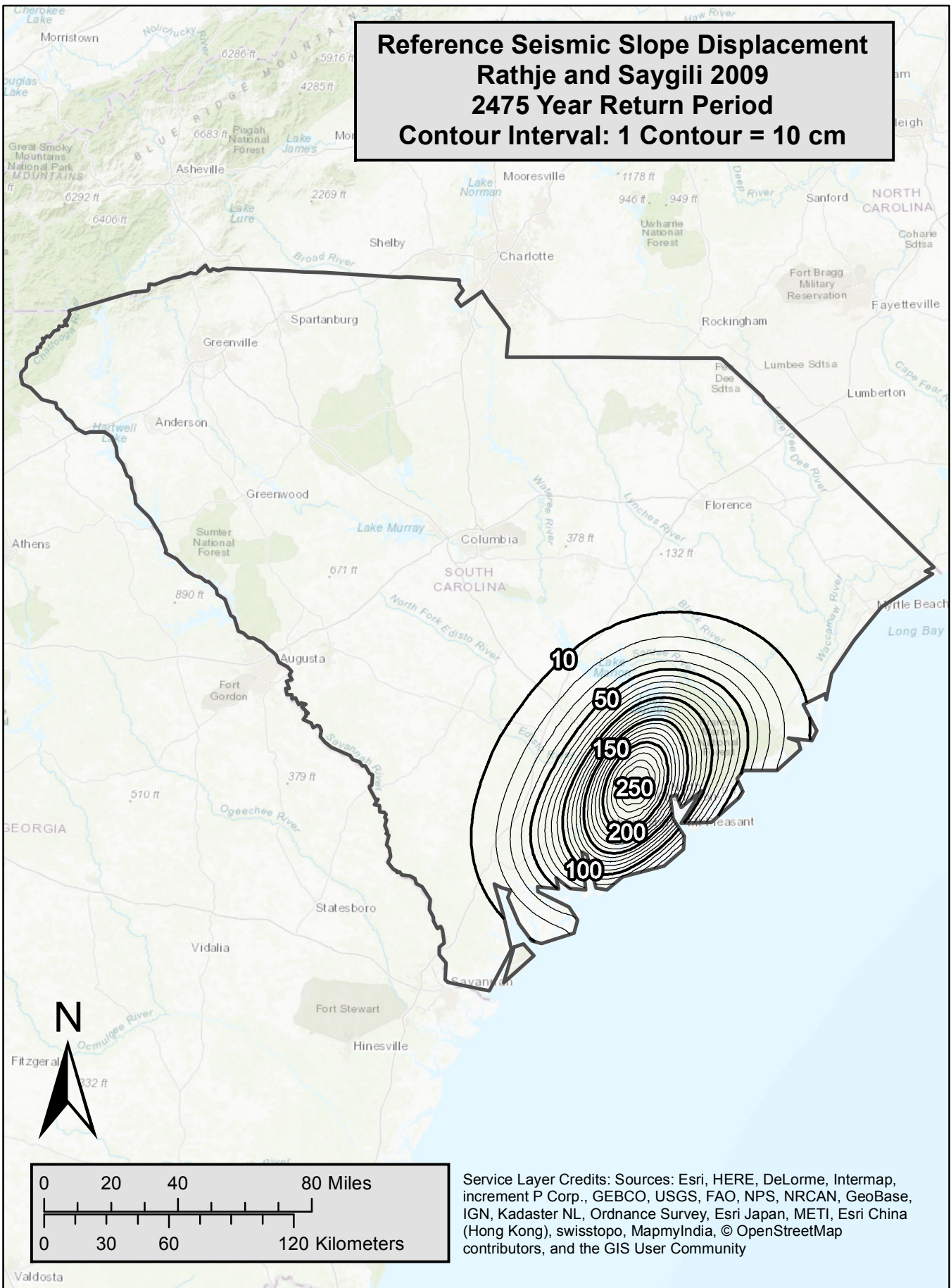
Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

**Reference Seismic Slope Displacement
Rathje and Saygili 2009
1033 Year Return Period
Contour Interval: 1 Contour = 2 cm**



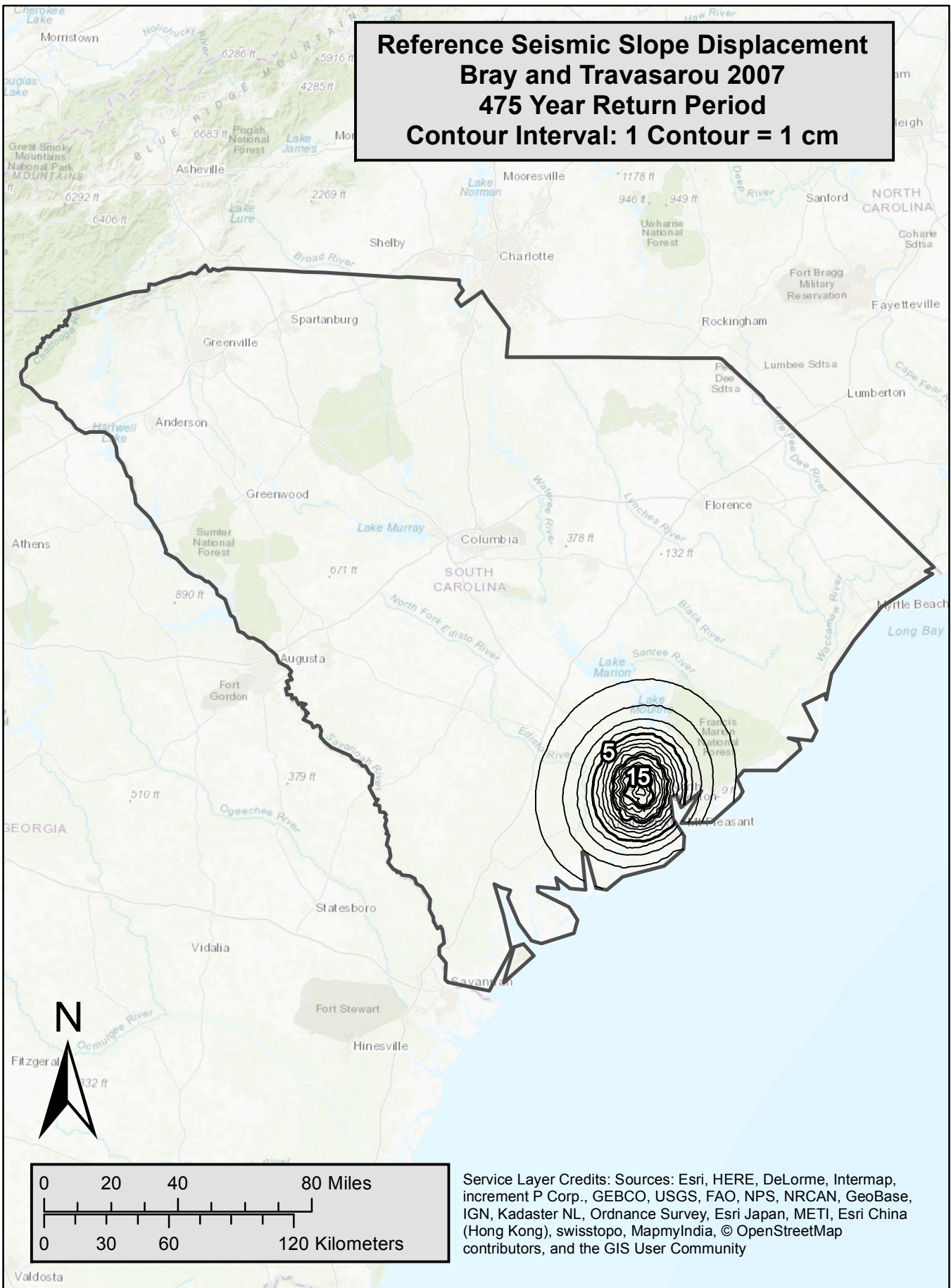
Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

**Reference Seismic Slope Displacement
Rathje and Saygili 2009
2475 Year Return Period
Contour Interval: 1 Contour = 10 cm**



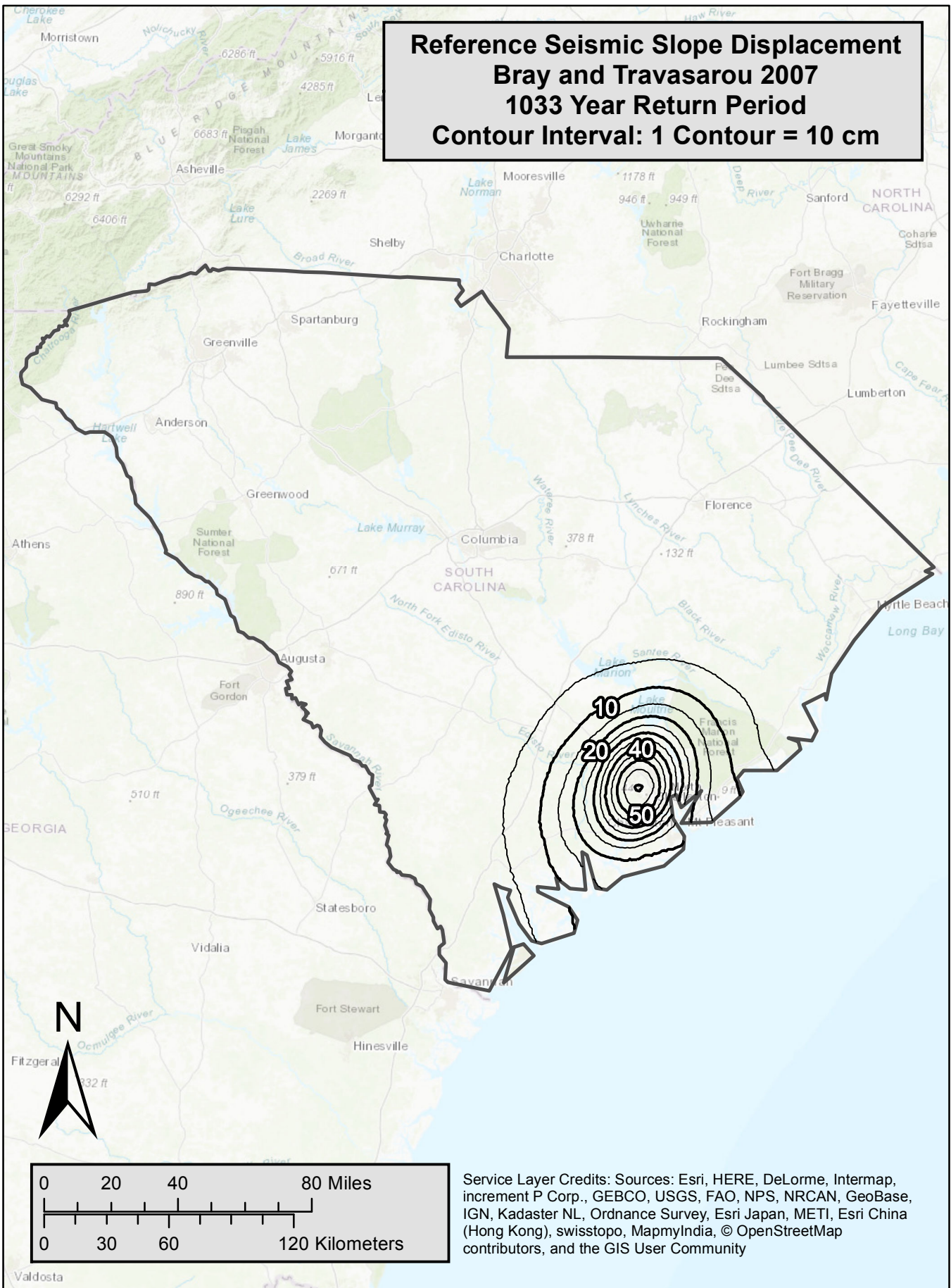
Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

**Reference Seismic Slope Displacement
 Bray and Travasarou 2007
 475 Year Return Period
 Contour Interval: 1 Contour = 1 cm**



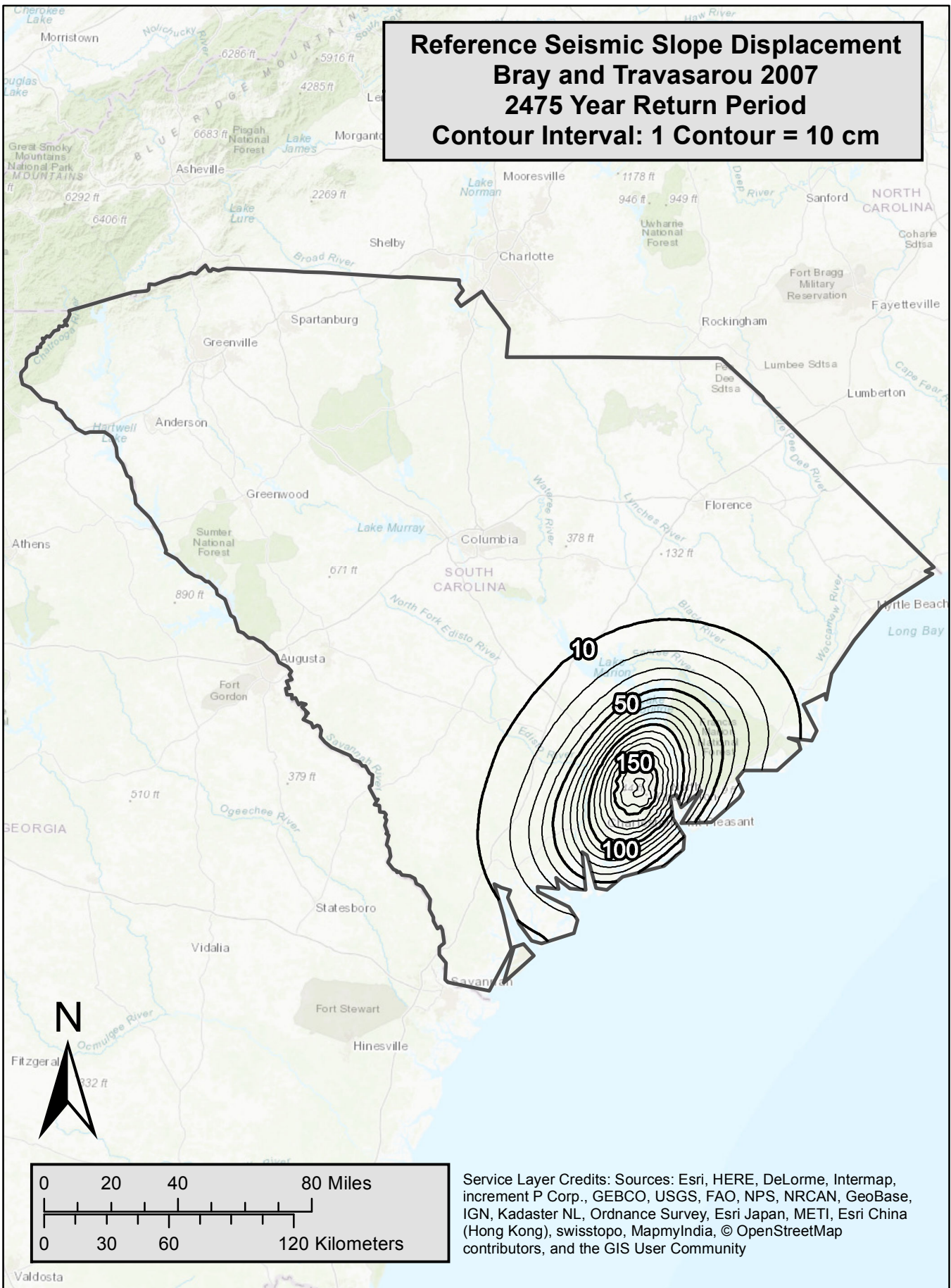
Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

**Reference Seismic Slope Displacement
Bray and Travararou 2007
1033 Year Return Period
Contour Interval: 1 Contour = 10 cm**

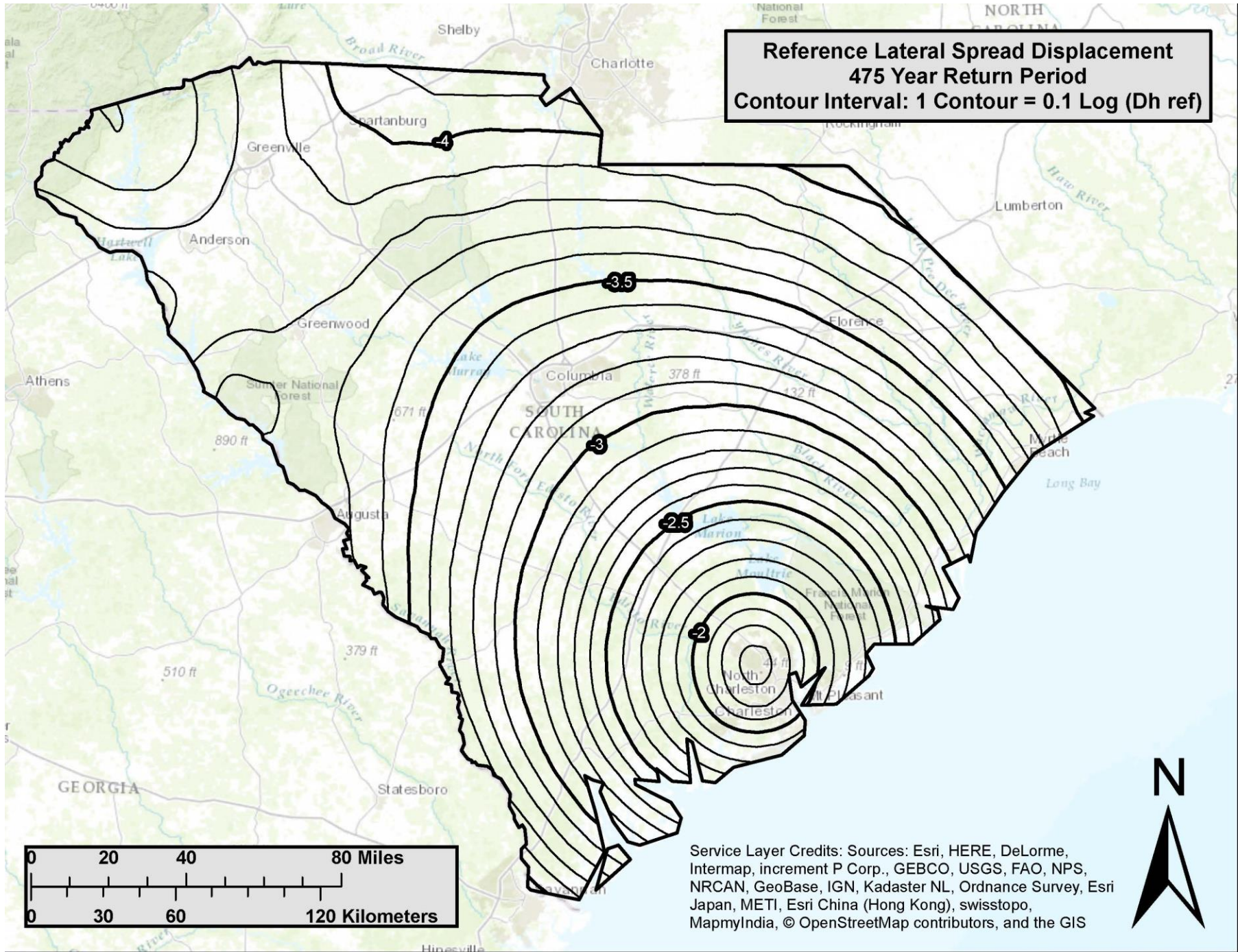


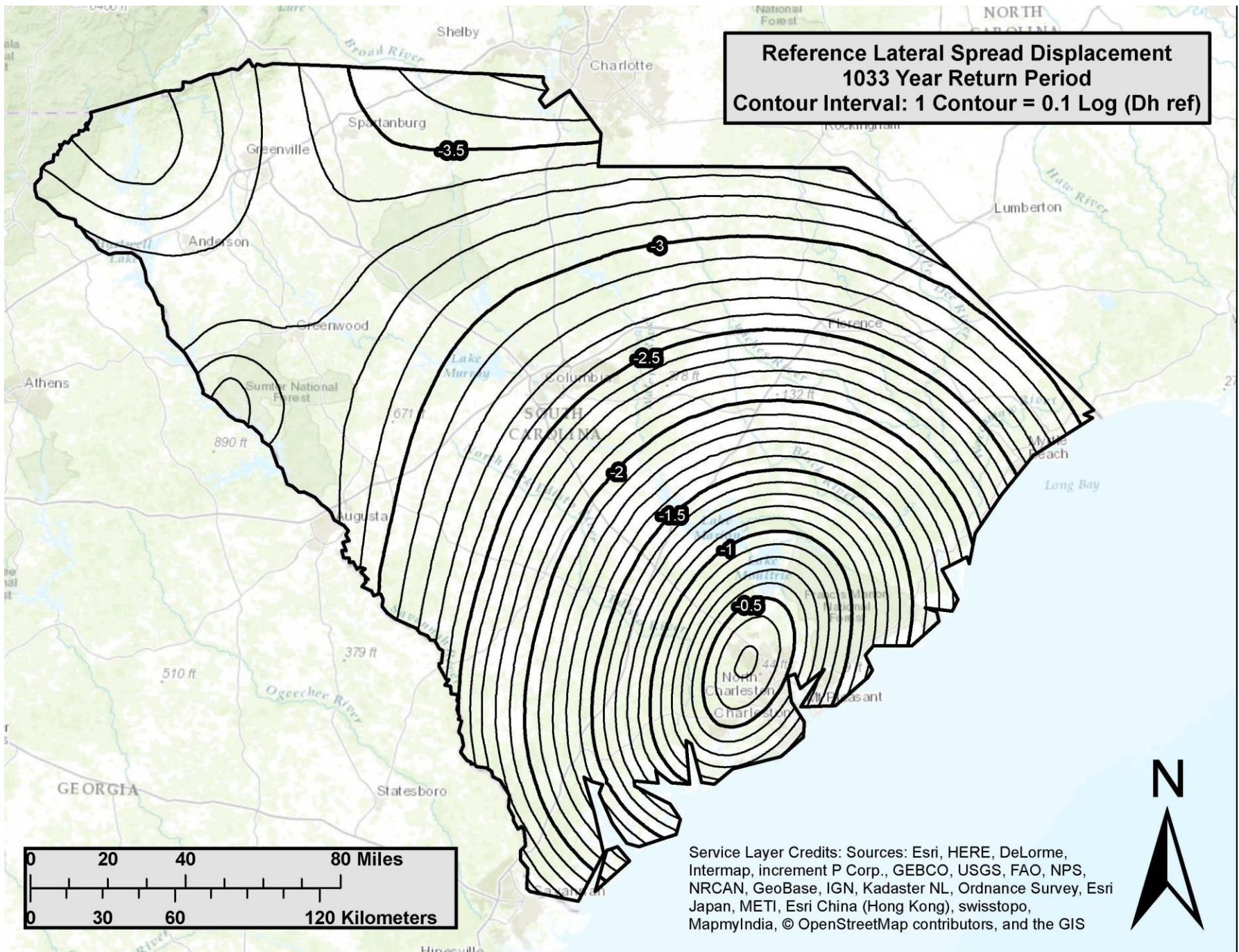
Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

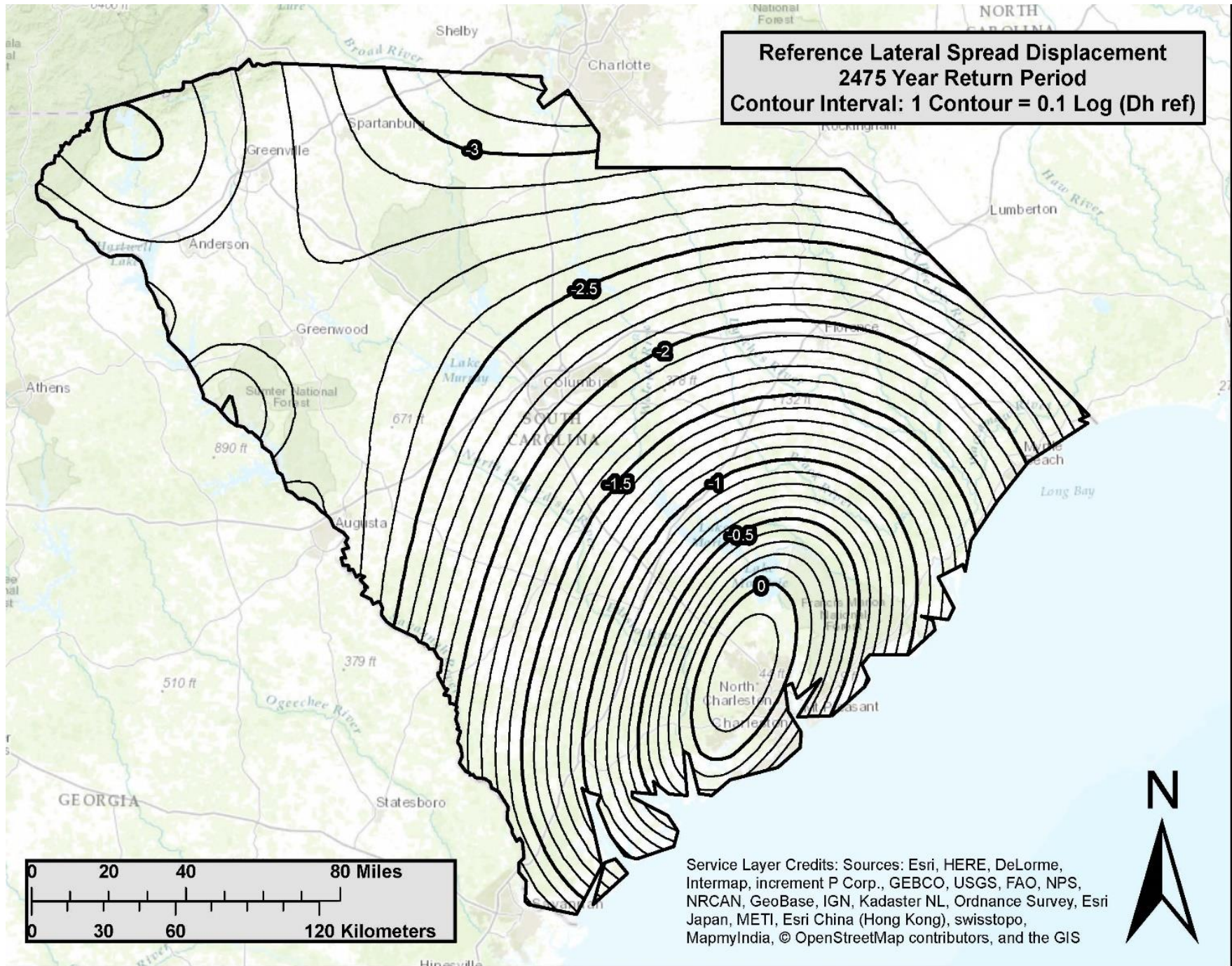
**Reference Seismic Slope Displacement
Bray and Travararou 2007
2475 Year Return Period
Contour Interval: 1 Contour = 10 cm**

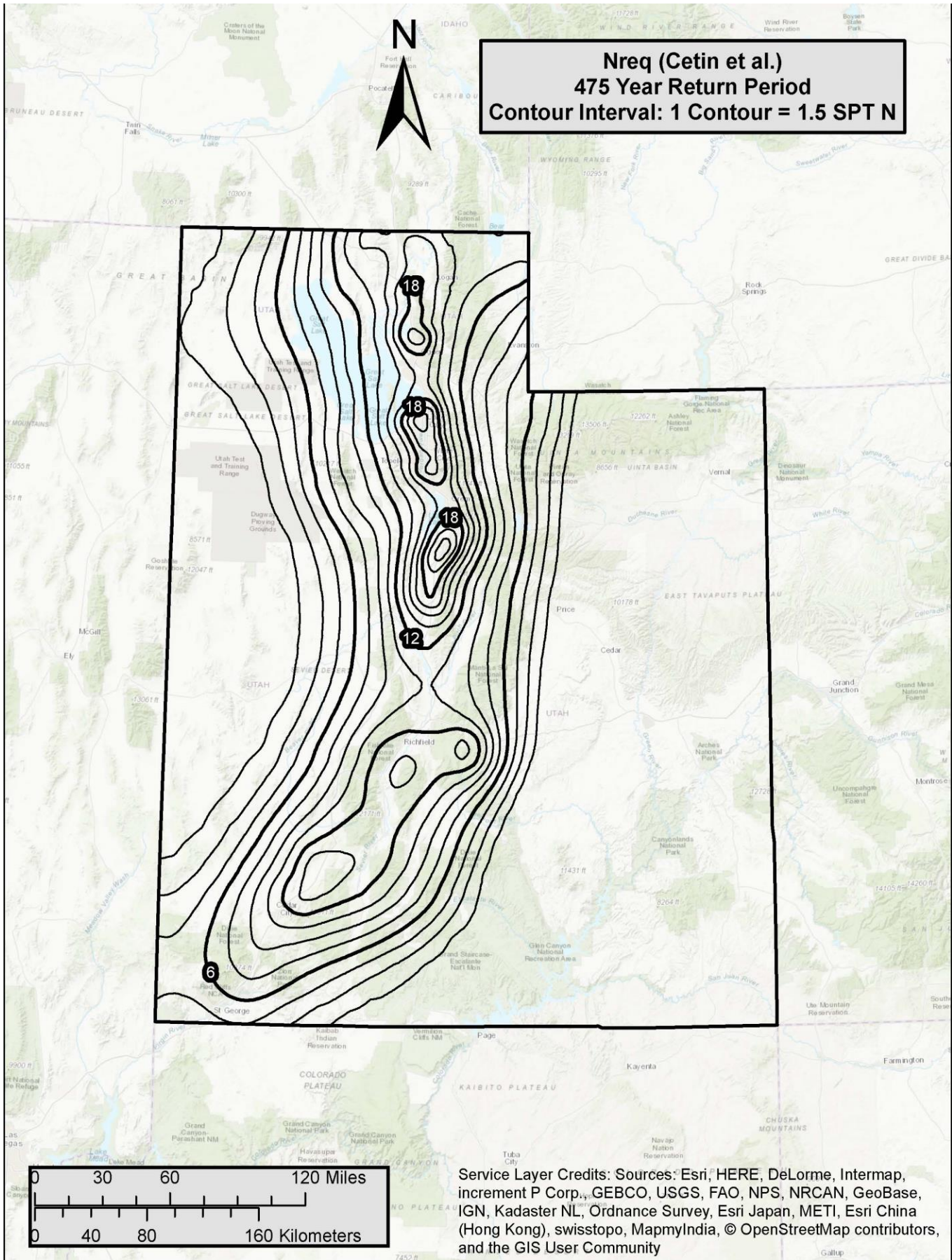


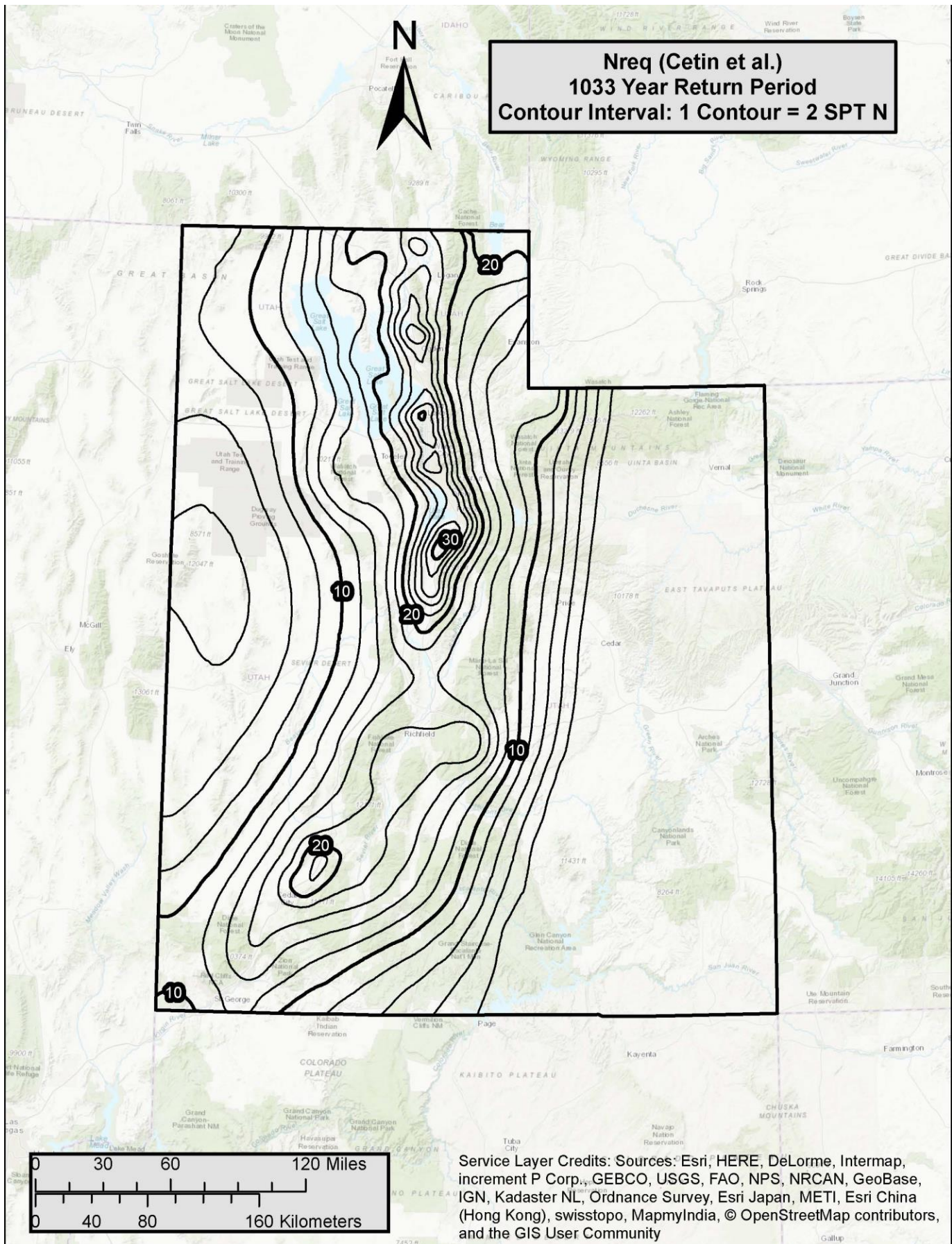
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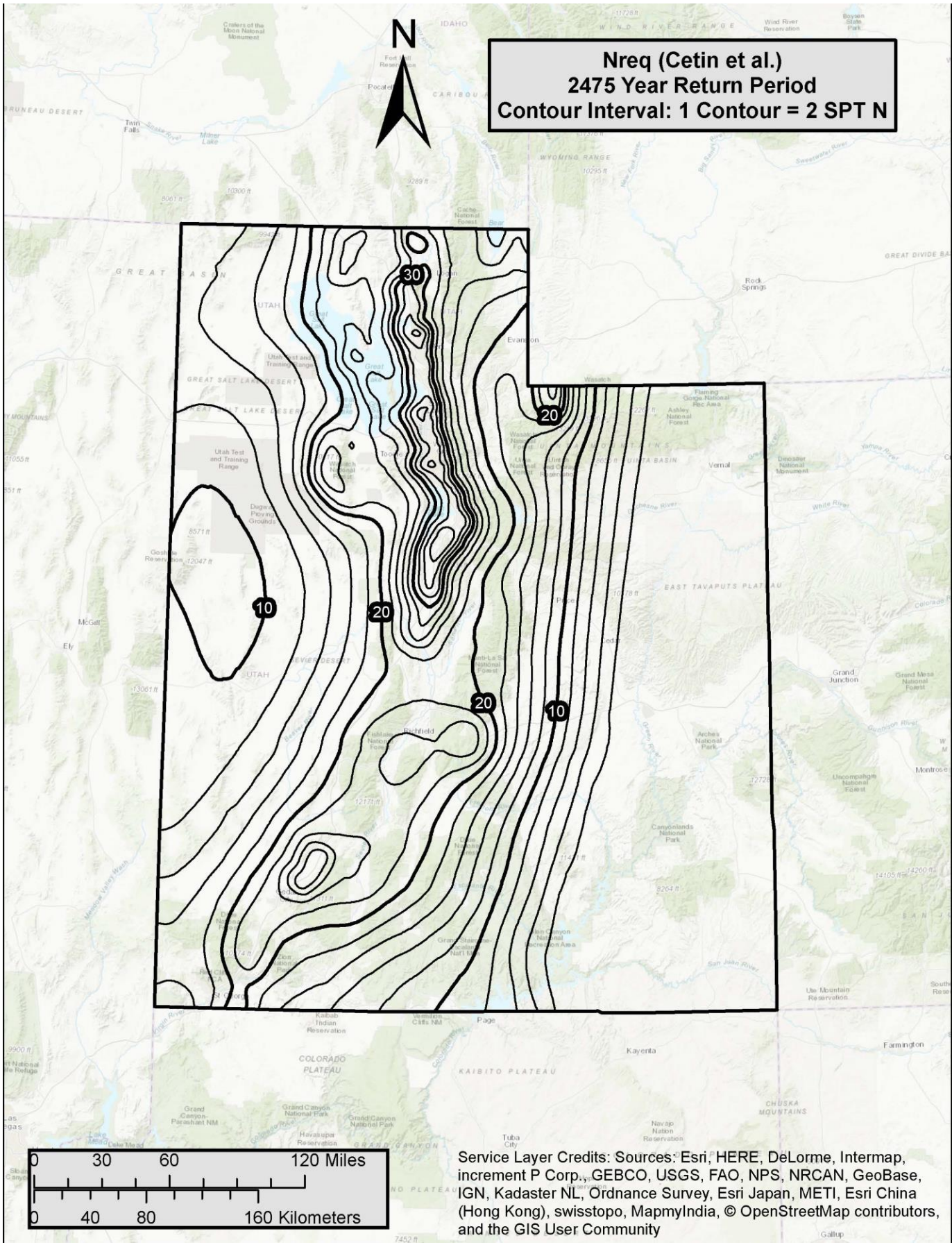




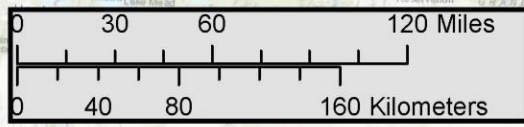




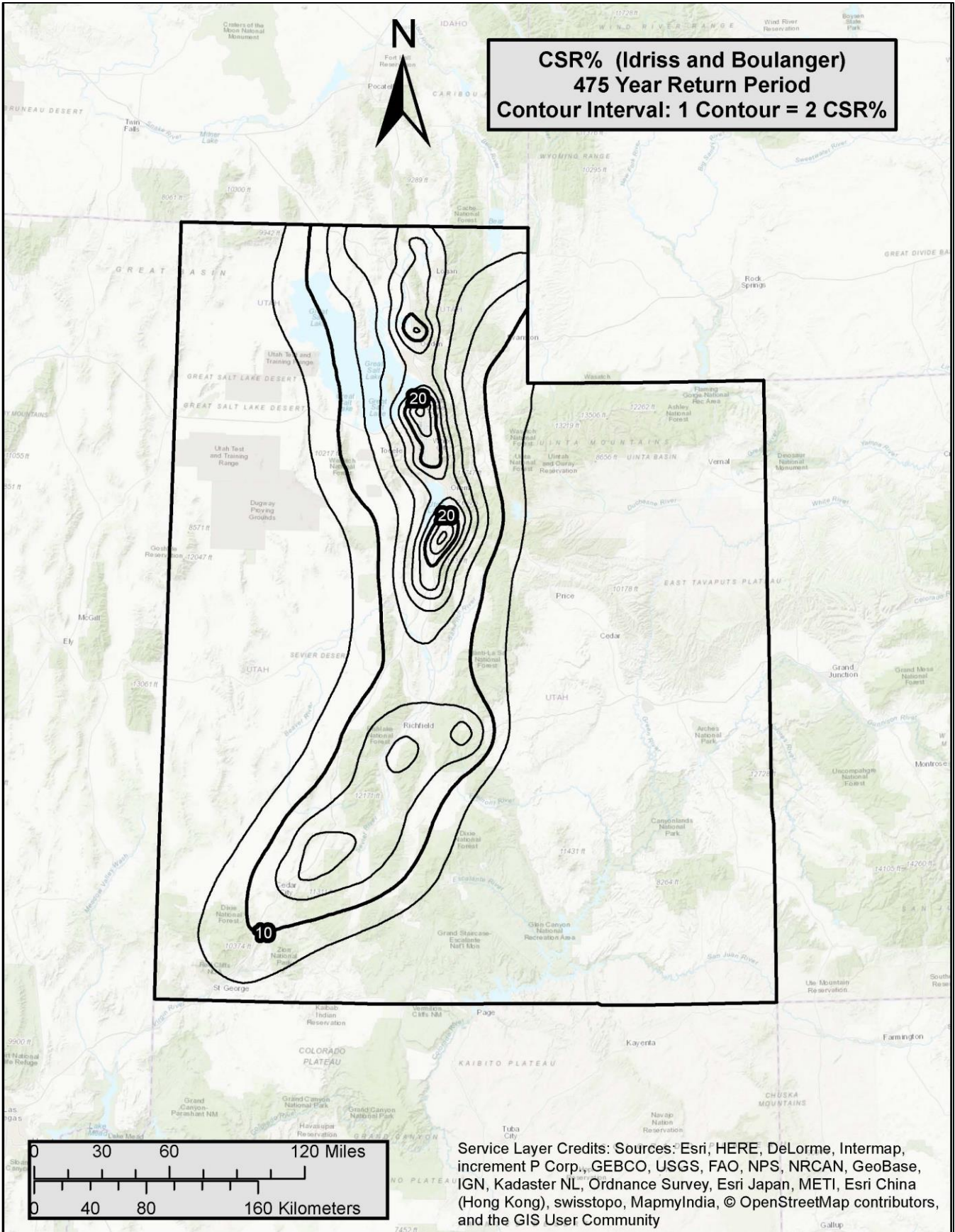


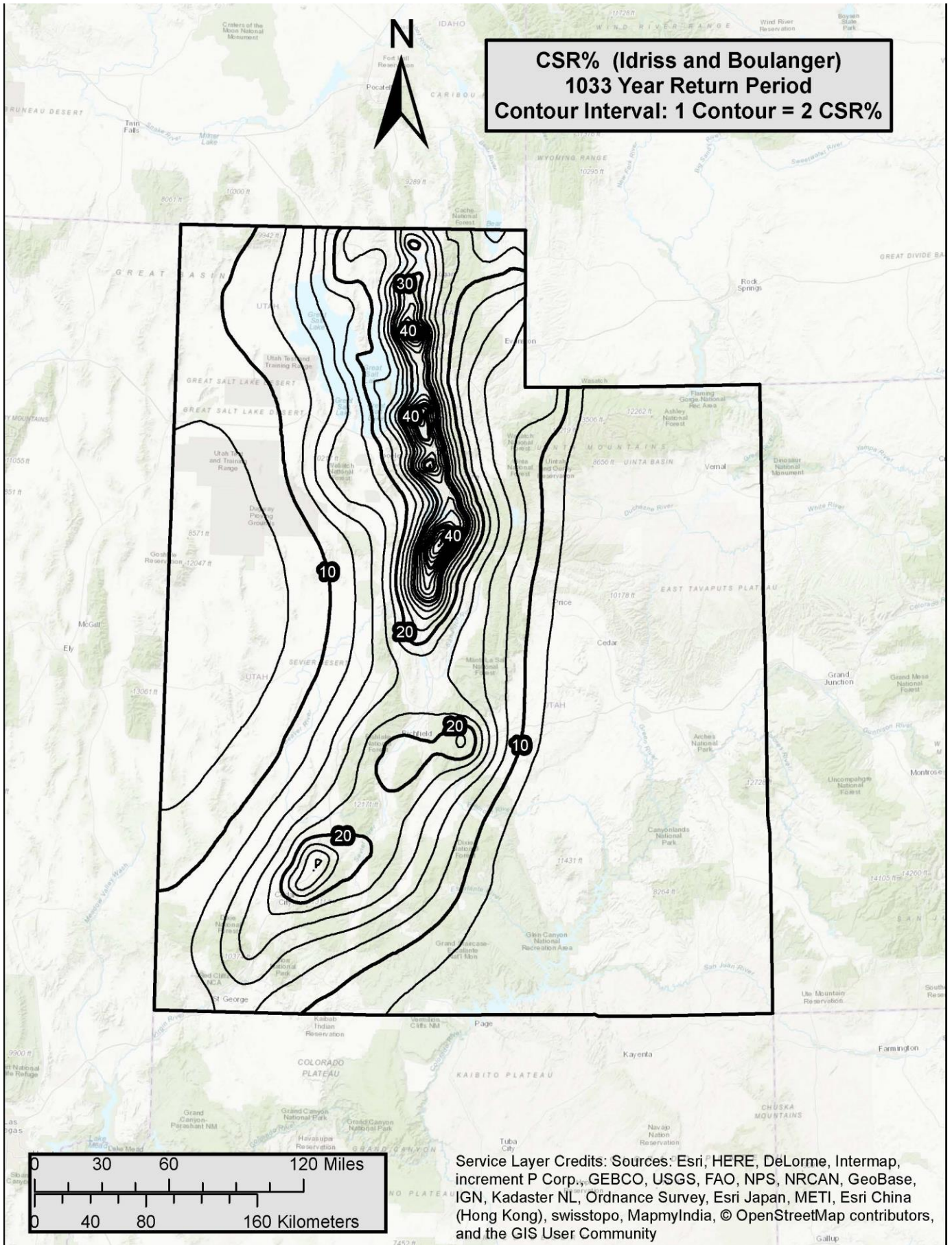


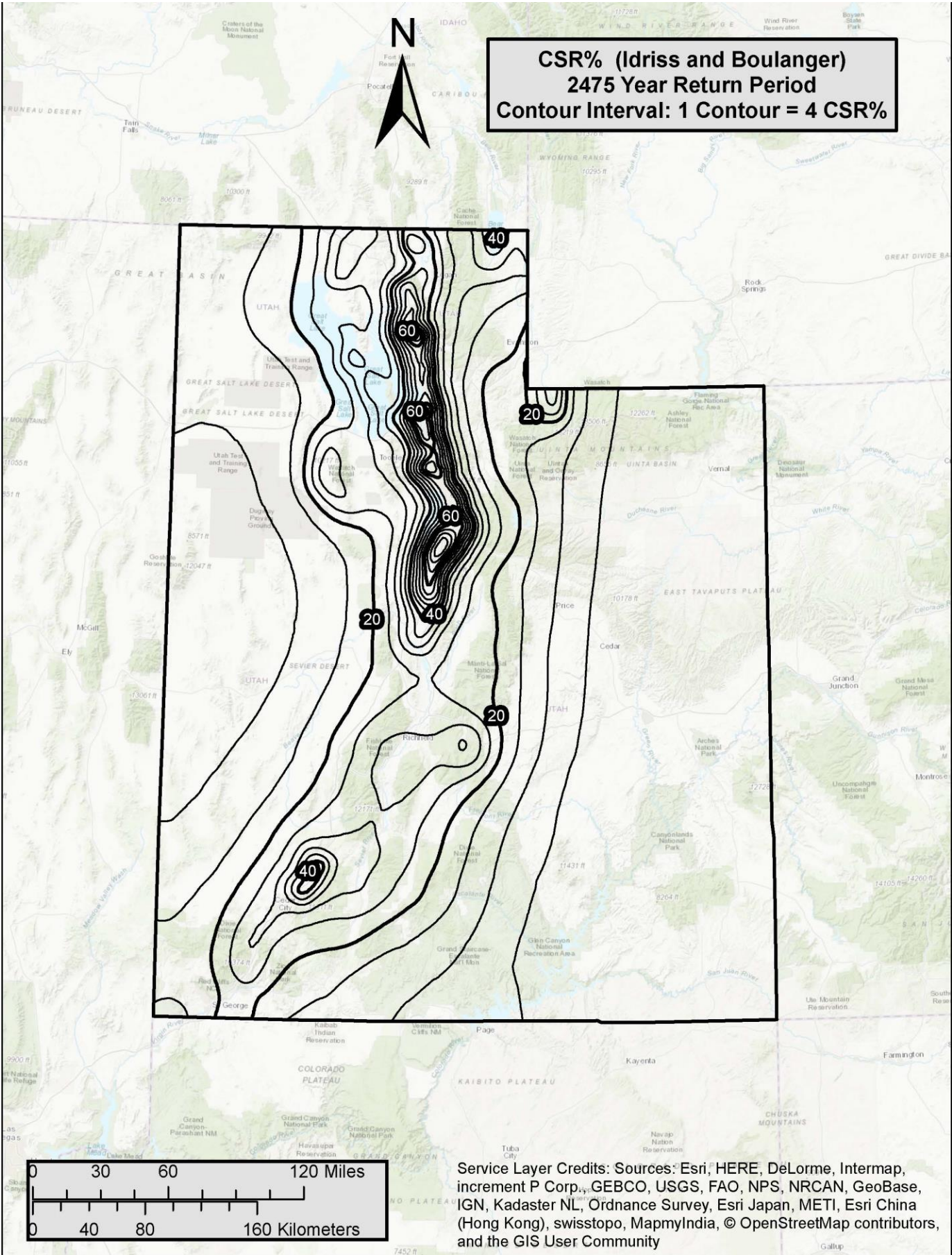
**Nreq (Cetin et al.)
2475 Year Return Period
Contour Interval: 1 Contour = 2 SPT N**

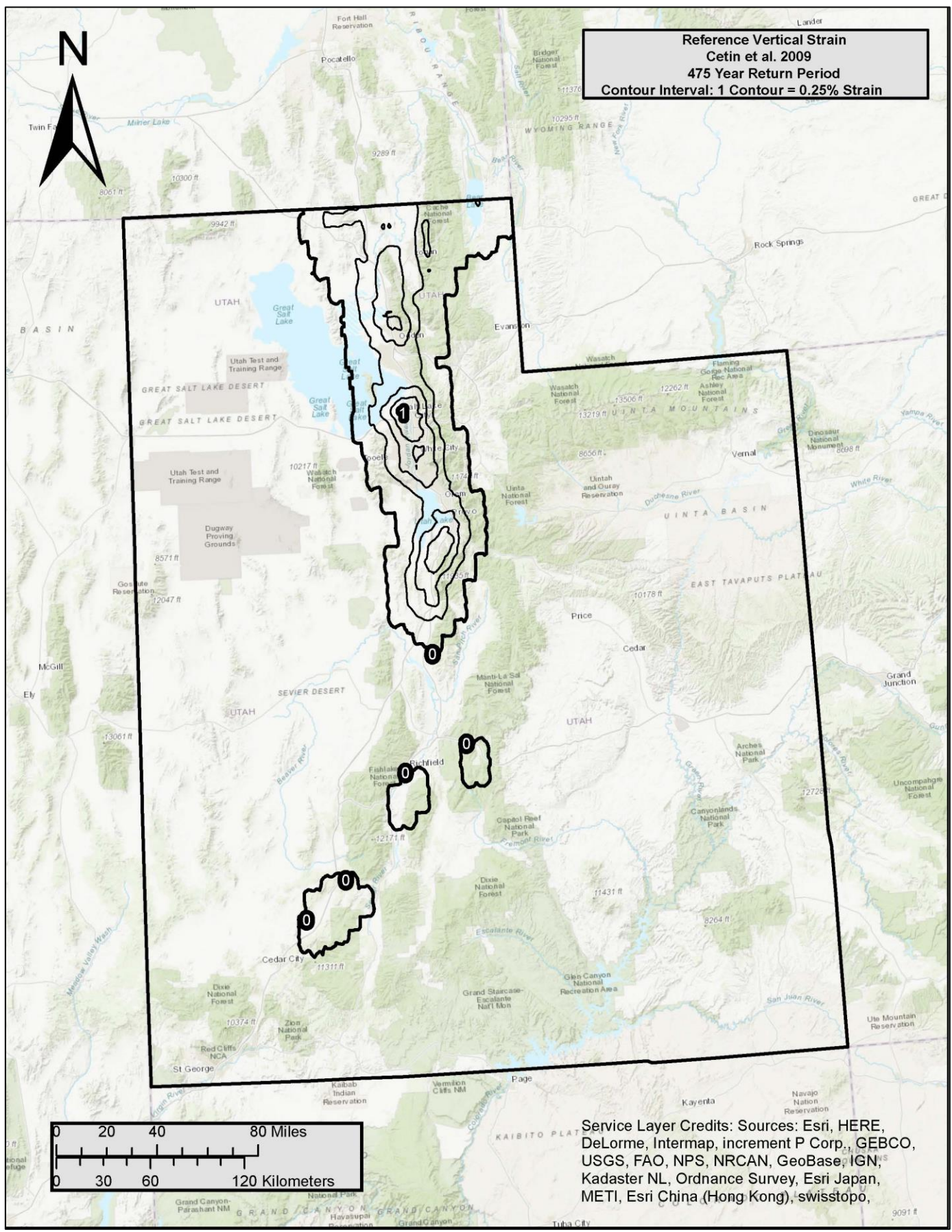


Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

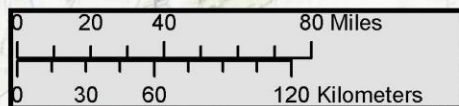




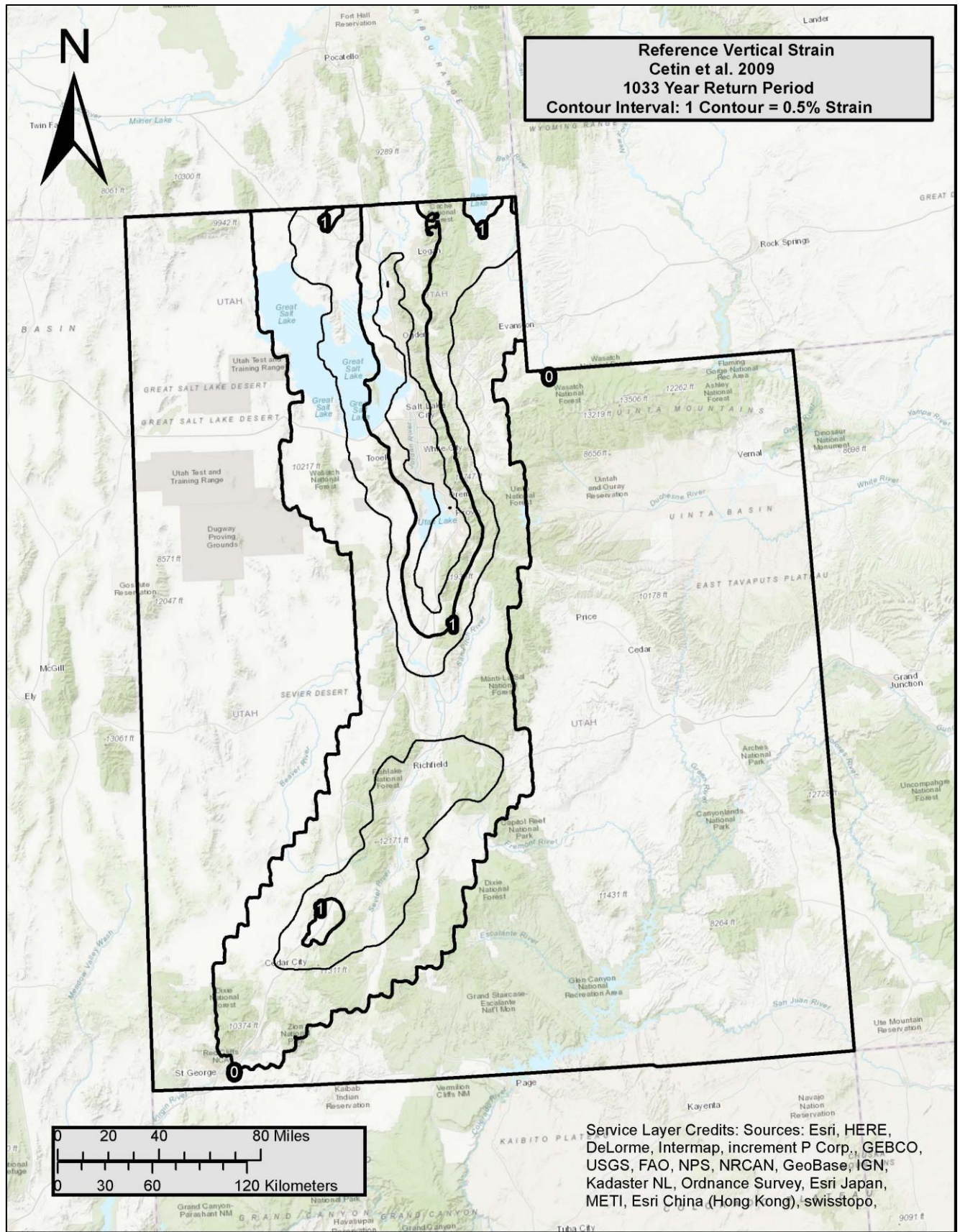




Reference Vertical Strain
 Cetin et al. 2009
 475 Year Return Period
 Contour Interval: 1 Contour = 0.25% Strain



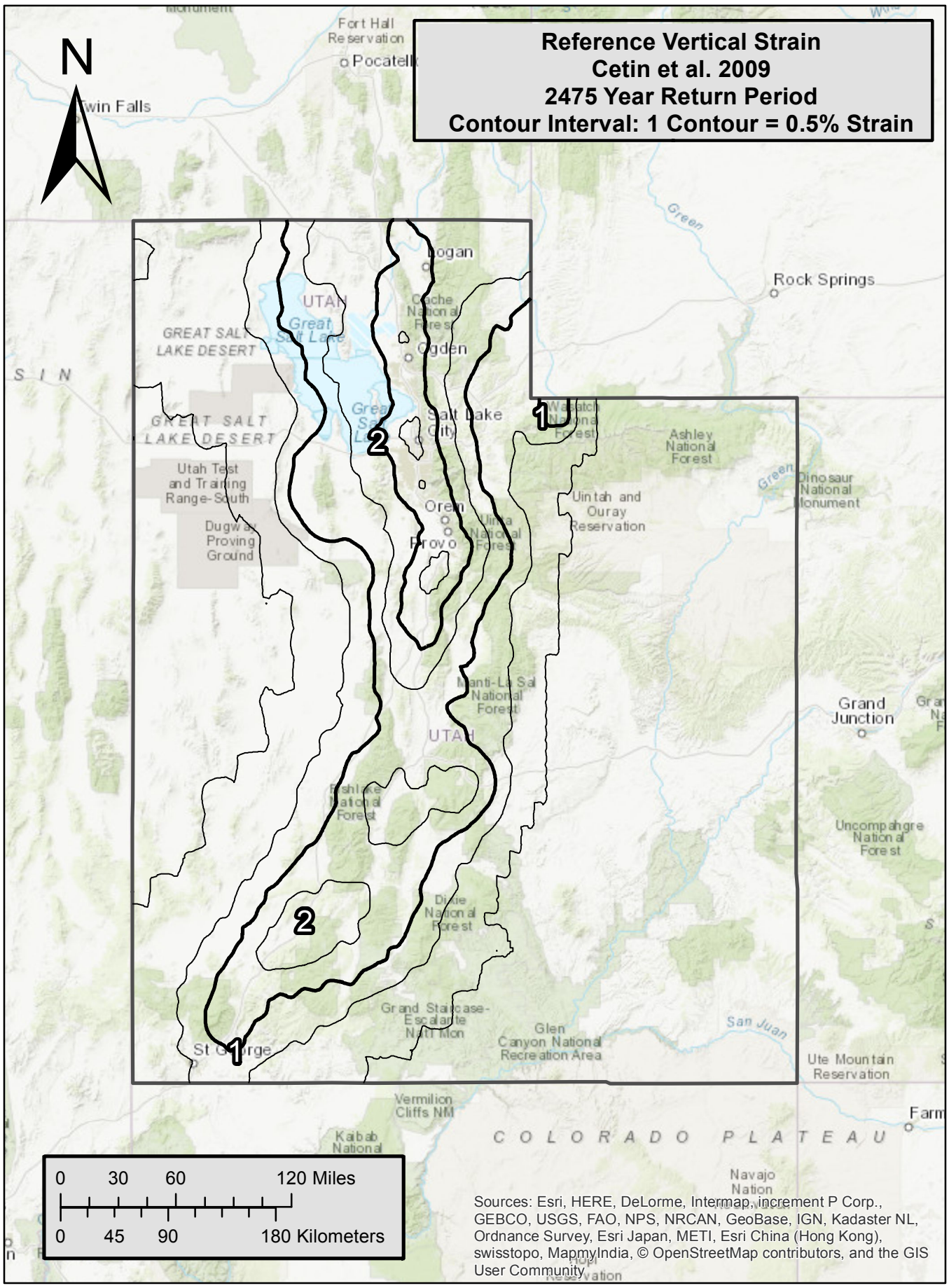
Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo,



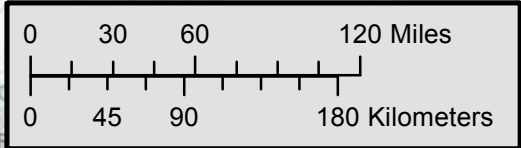
Reference Vertical Strain
 Cetin et al. 2009
 1033 Year Return Period
 Contour Interval: 1 Contour = 0.5% Strain



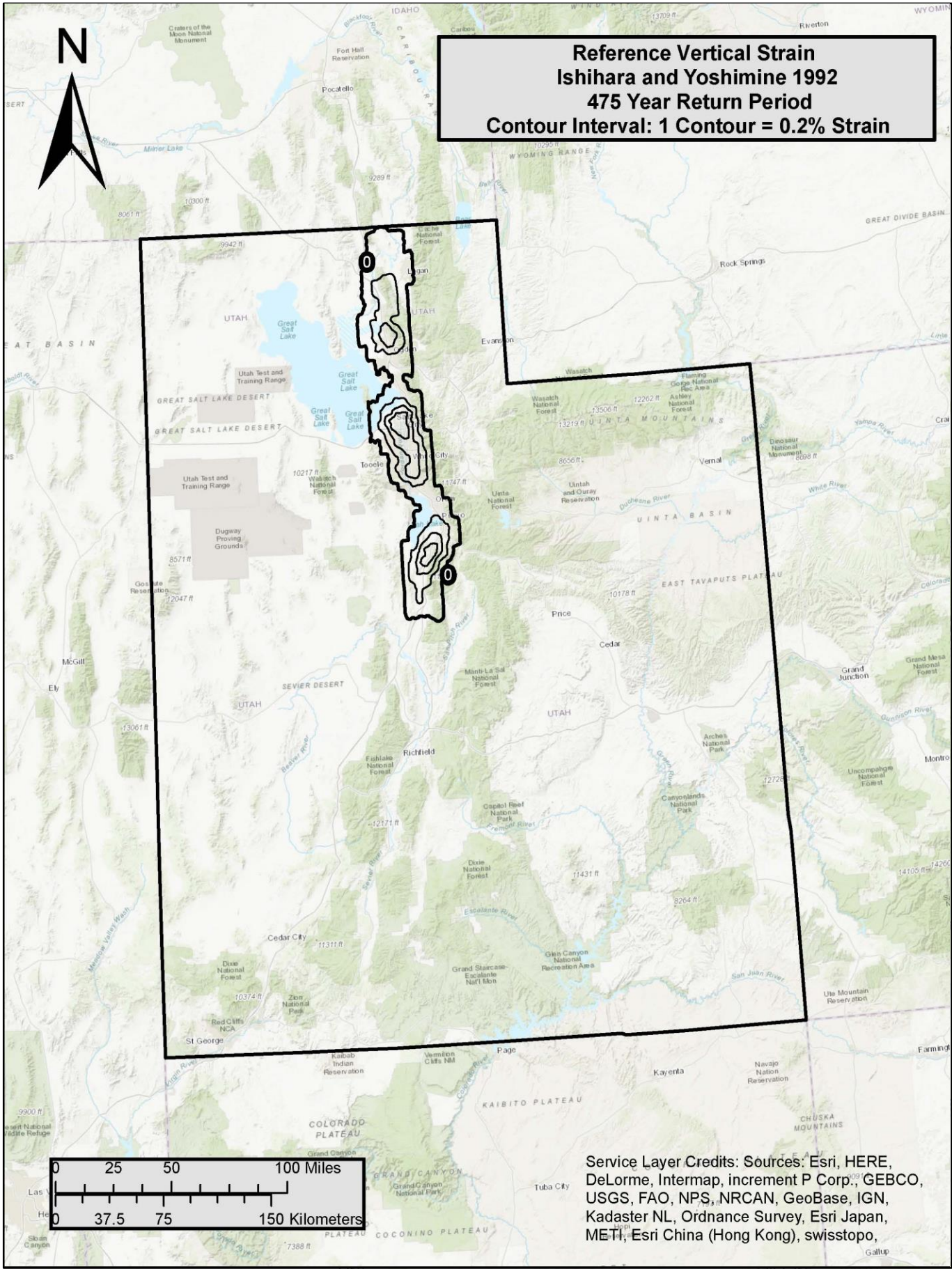
Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo,



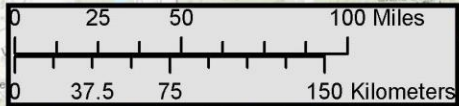
Reference Vertical Strain
Cetin et al. 2009
2475 Year Return Period
Contour Interval: 1 Contour = 0.5% Strain



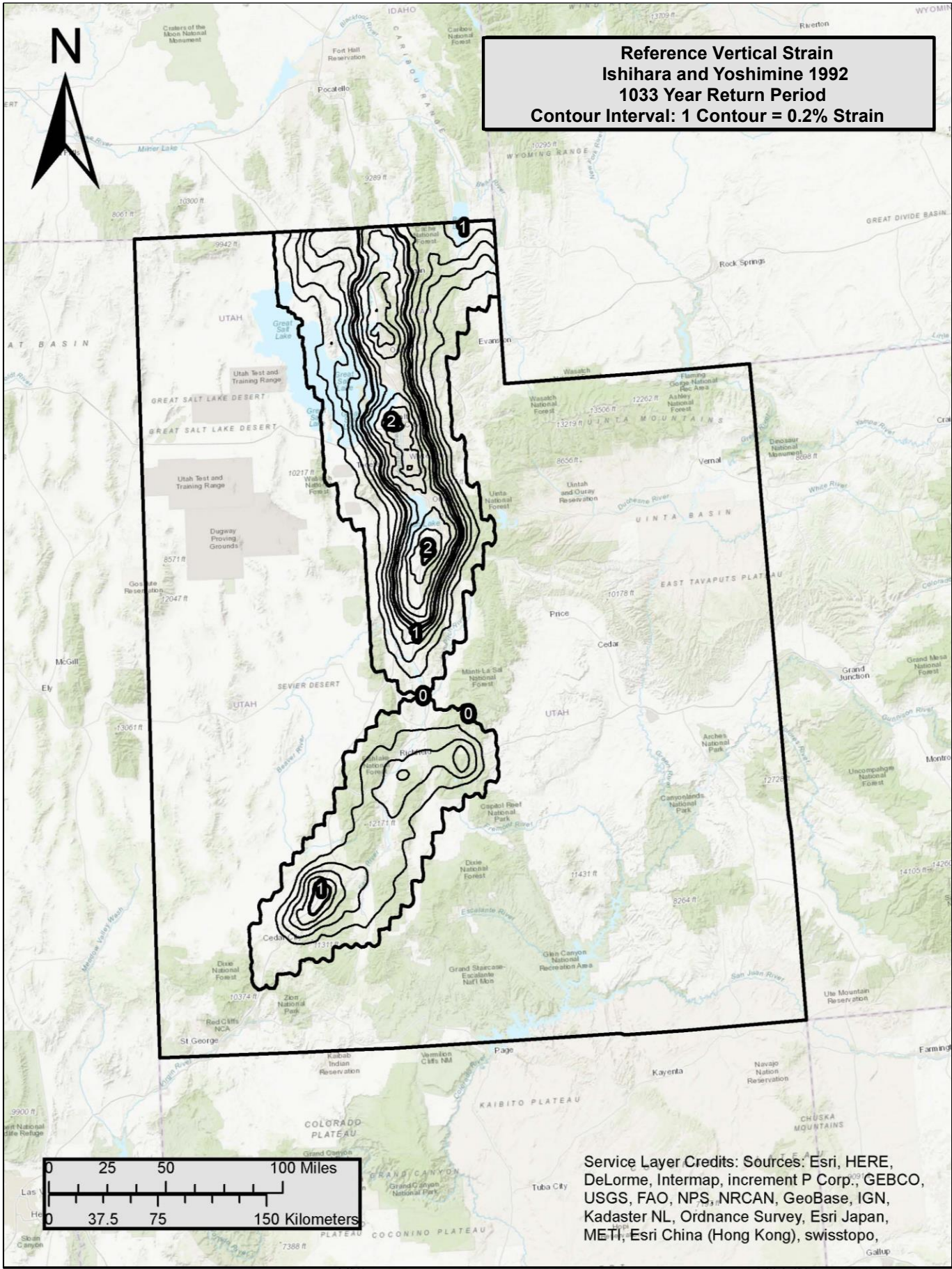
Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community



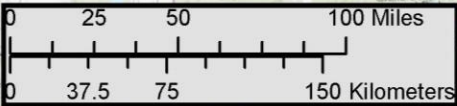
**Reference Vertical Strain
Ishihara and Yoshimine 1992
475 Year Return Period
Contour Interval: 1 Contour = 0.2% Strain**



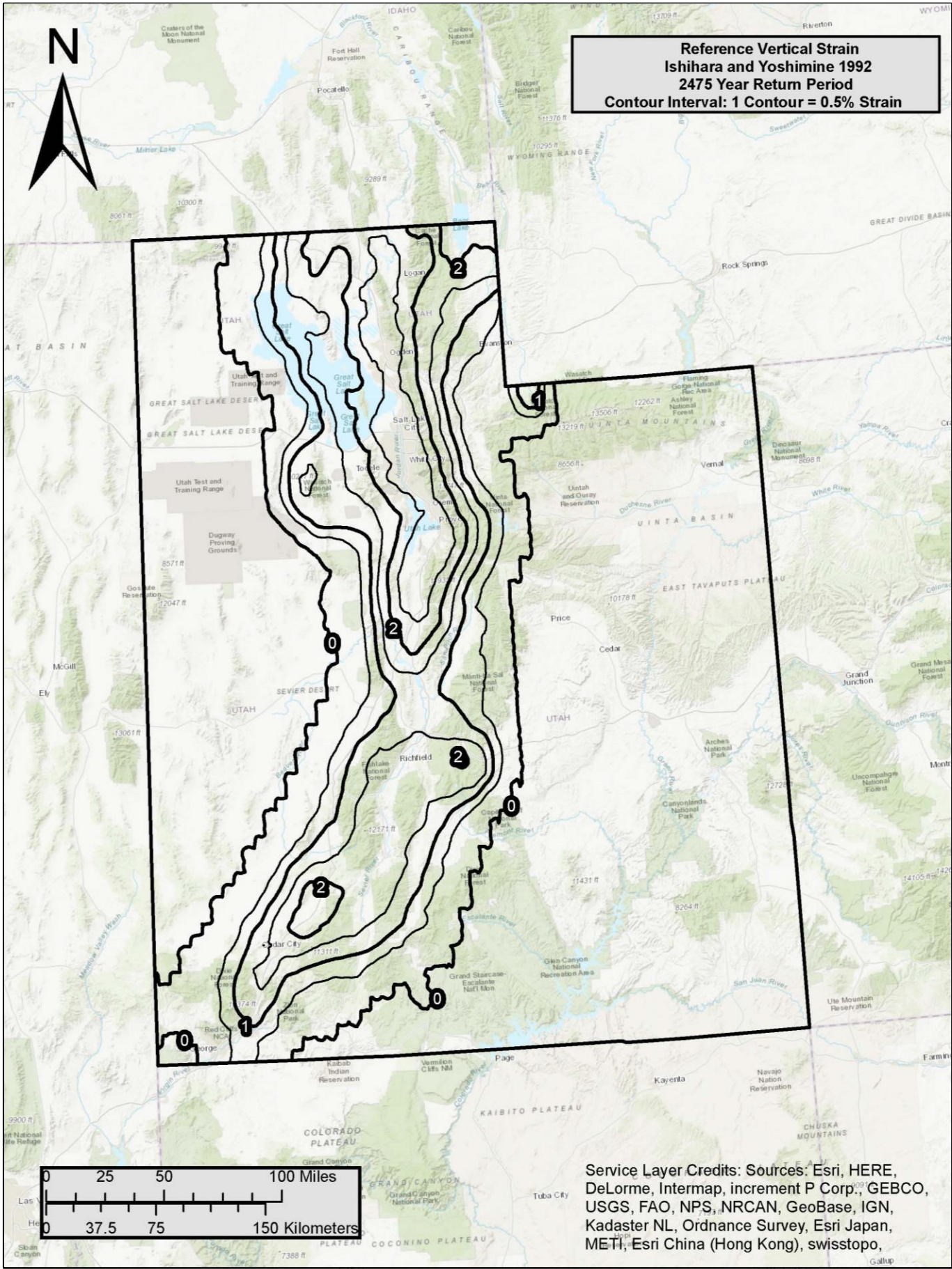
Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo,

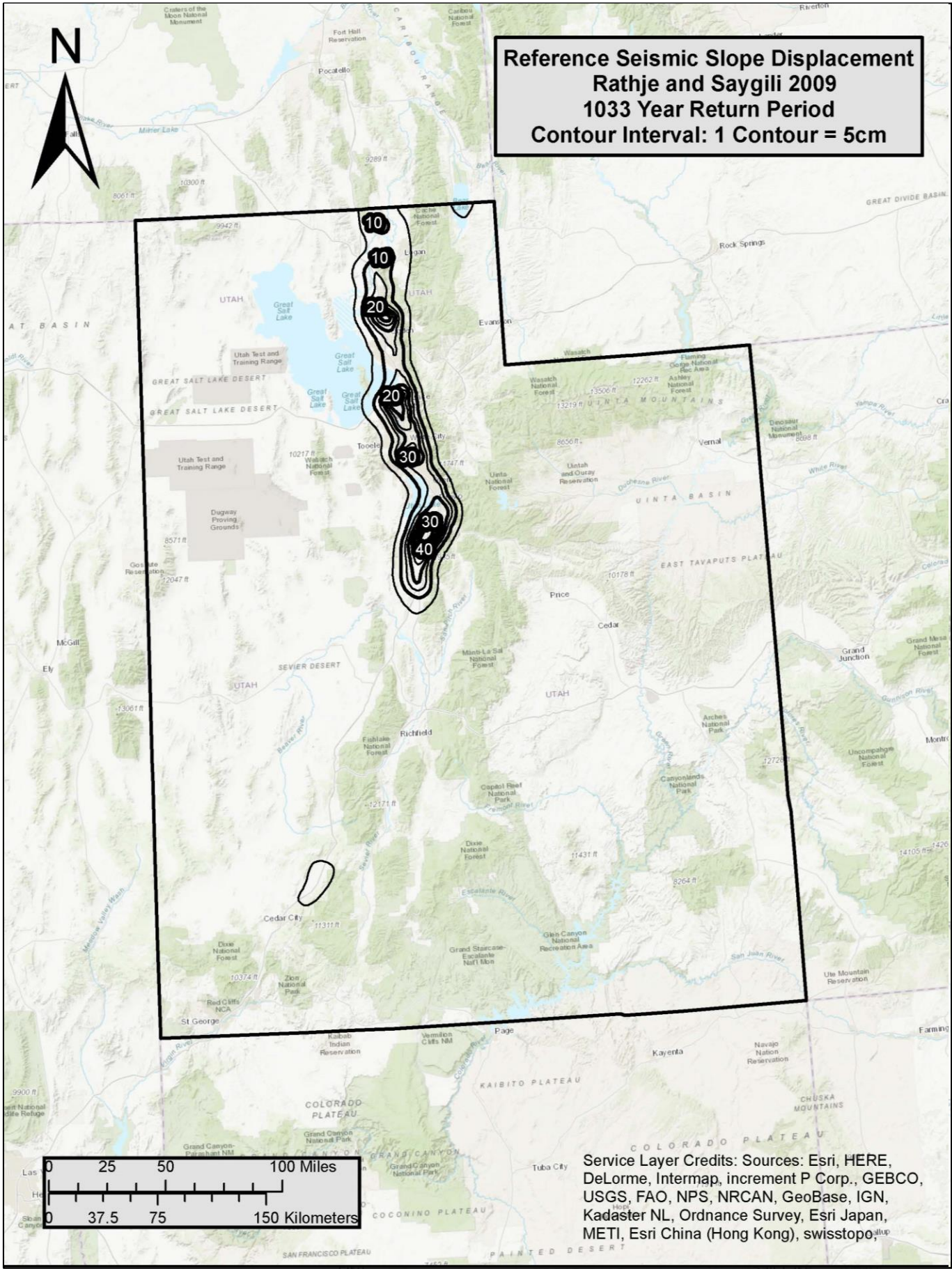


**Reference Vertical Strain
Ishihara and Yoshimine 1992
1033 Year Return Period
Contour Interval: 1 Contour = 0.2% Strain**

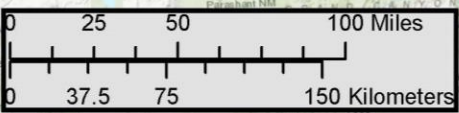


Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo,

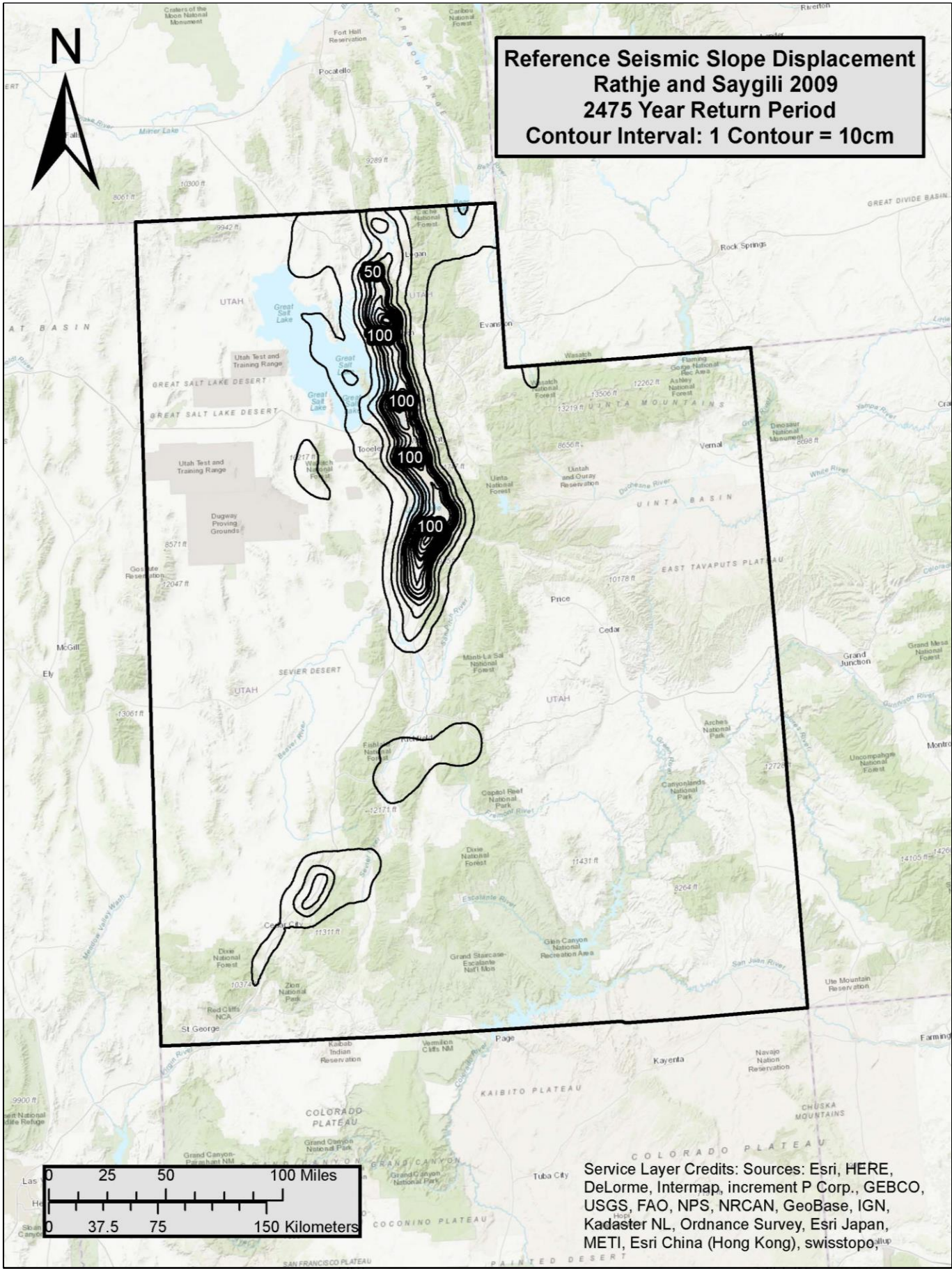


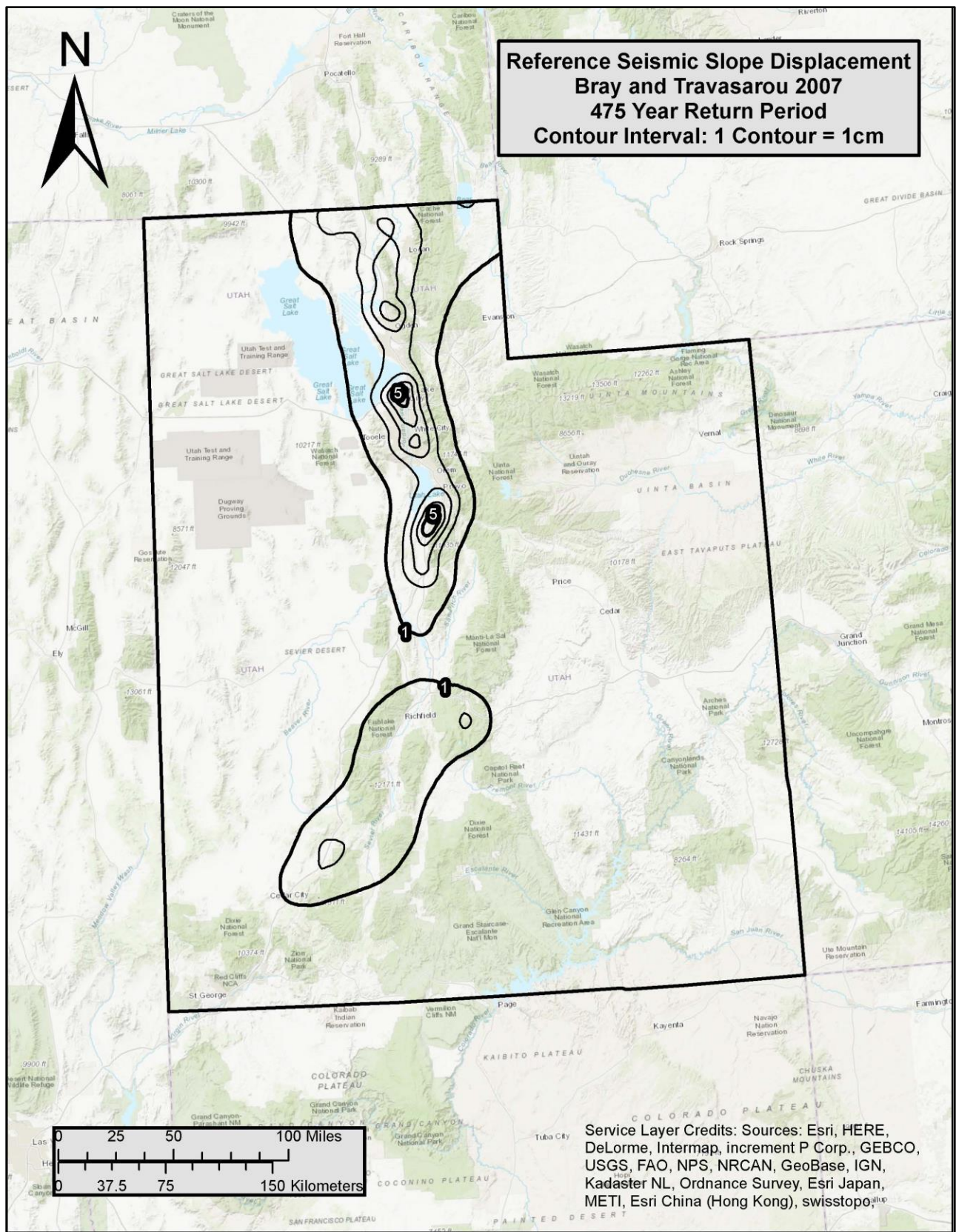


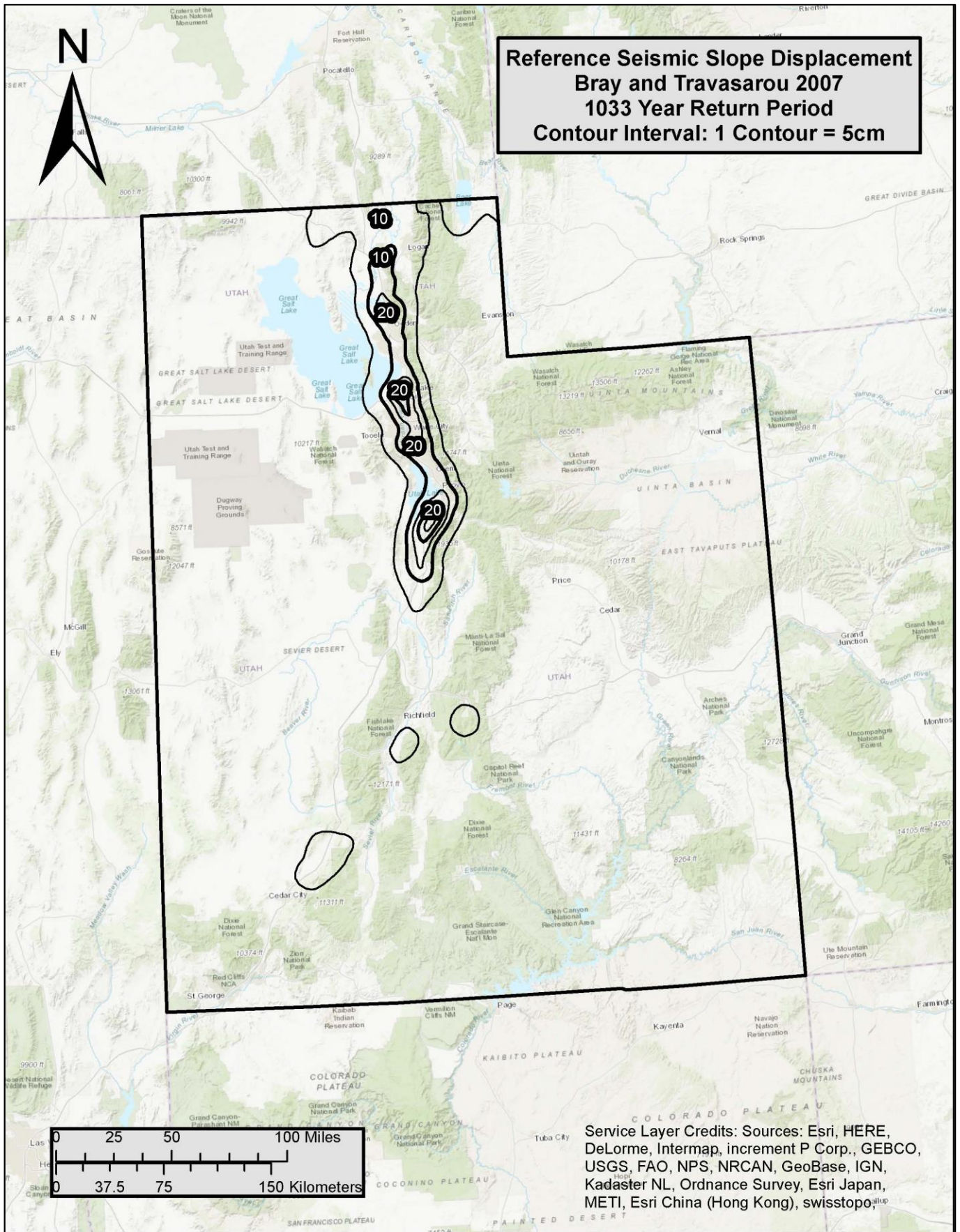
Reference Seismic Slope Displacement
Rathje and Saygili 2009
1033 Year Return Period
Contour Interval: 1 Contour = 5cm



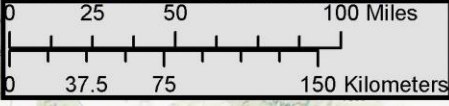
Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo,



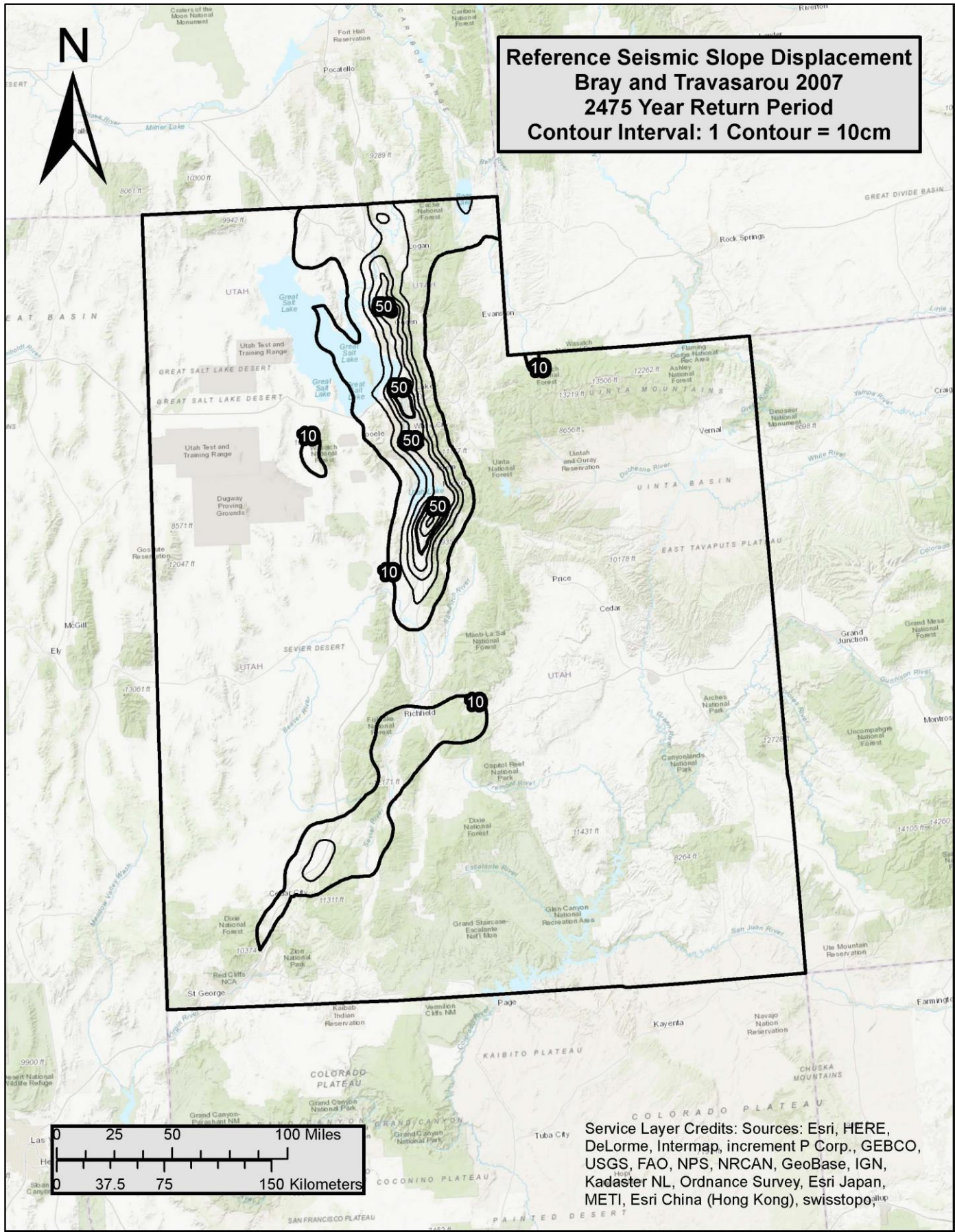




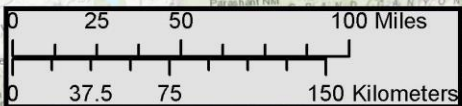
**Reference Seismic Slope Displacement
Bray and Travararou 2007
1033 Year Return Period
Contour Interval: 1 Contour = 5cm**



Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo,



**Reference Seismic Slope Displacement
Bray and Travararou 2007
2475 Year Return Period
Contour Interval: 1 Contour = 10cm**



Service Layer Credits: Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo,

