The Pima County Coordinate System

Design Process and Final Defining Parameters

Putting "Grid" at "Ground"

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Where we are going…
…and how we will get there

- Introduction to ***Low Distortion Projections*** (LDPs)
- Where LDPs are being used
- Map projection concepts
- Map projection distortion — what is it?
- General approach to designing LDPs
- Design of the ***Pima County Coordinate System***

The problem

- Map distance ≠ “ground” distance
  - Due to map projection ***linear distortion***
  - Often called “grid vs. ground” problem
- A problem for some geospatial products
  - Engineering & construction plans
  - Survey plats and legal descriptions
  - As-built surveys and facilities management

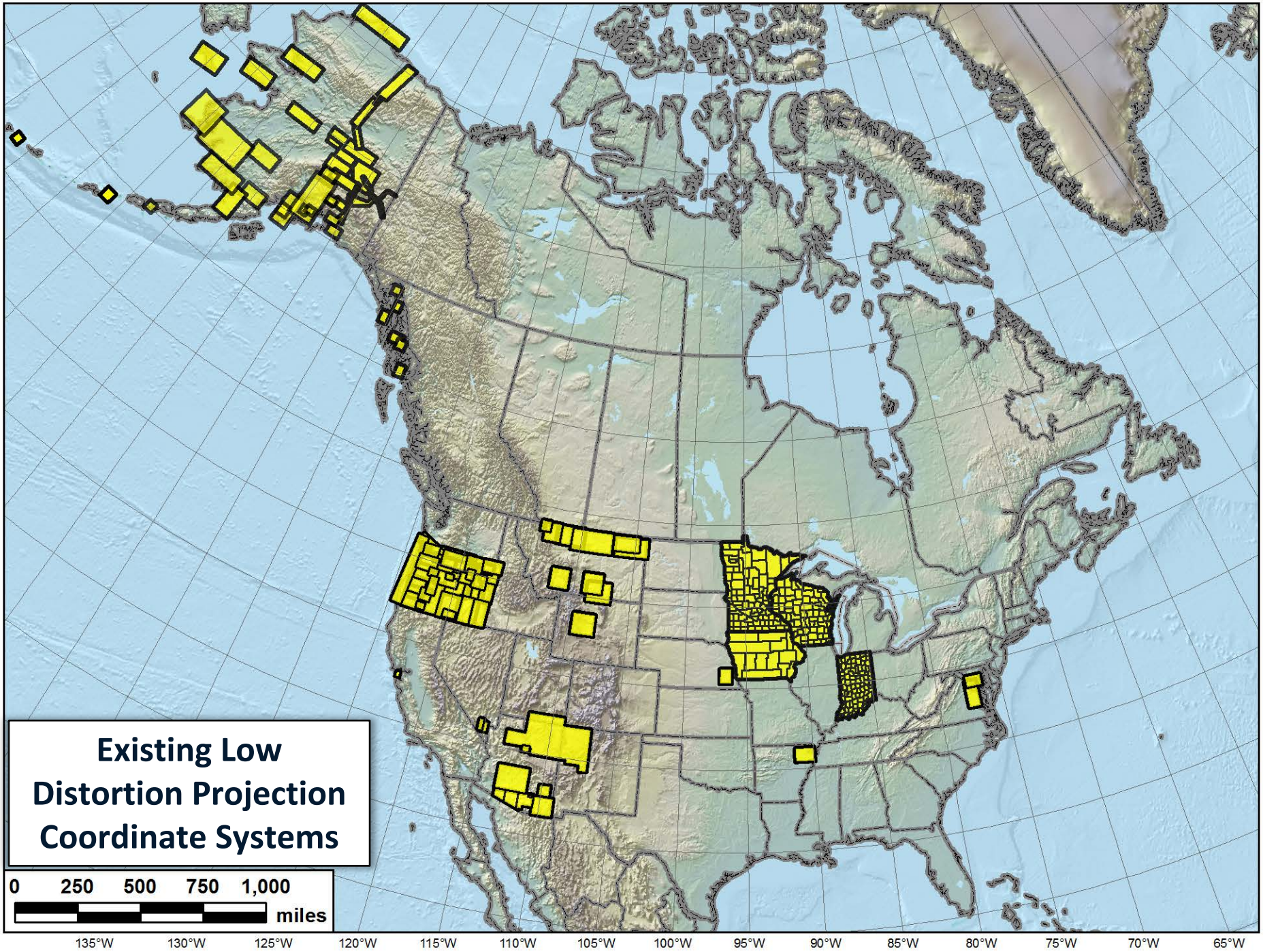
What is solution to distortion "problem"?

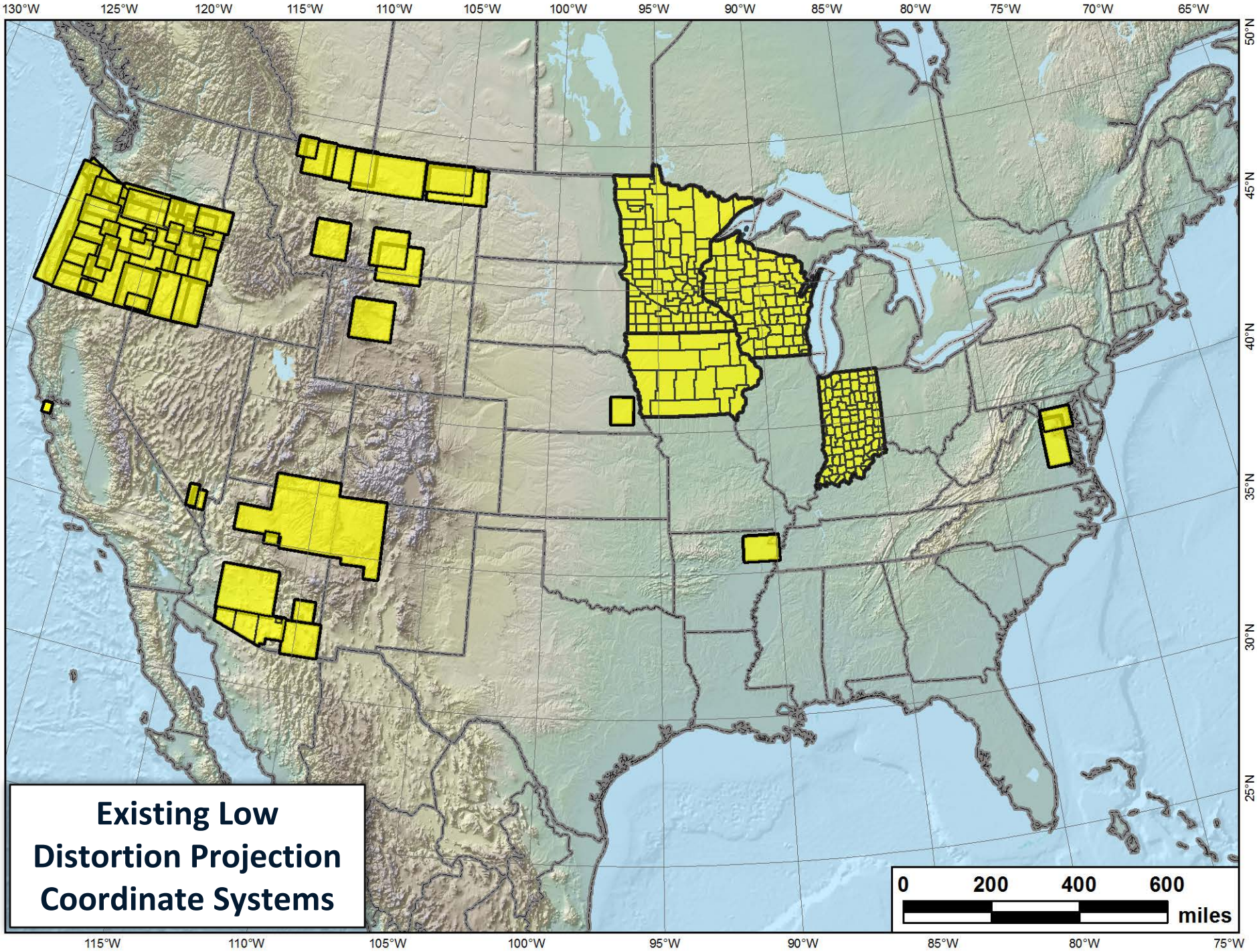
- Make map distance = "ground" distance?
  - This is ***IMPOSSIBLE***
  - No such thing as "ground" coordinates
  - However, linear distortion CAN be ***MINIMIZED***
- "Low distortion projections" (LDPs)
  - Based on existing ***CONFORMAL*** projection types
  - Linear distortion at point same in all directions
  - Only a few appropriate existing projections available

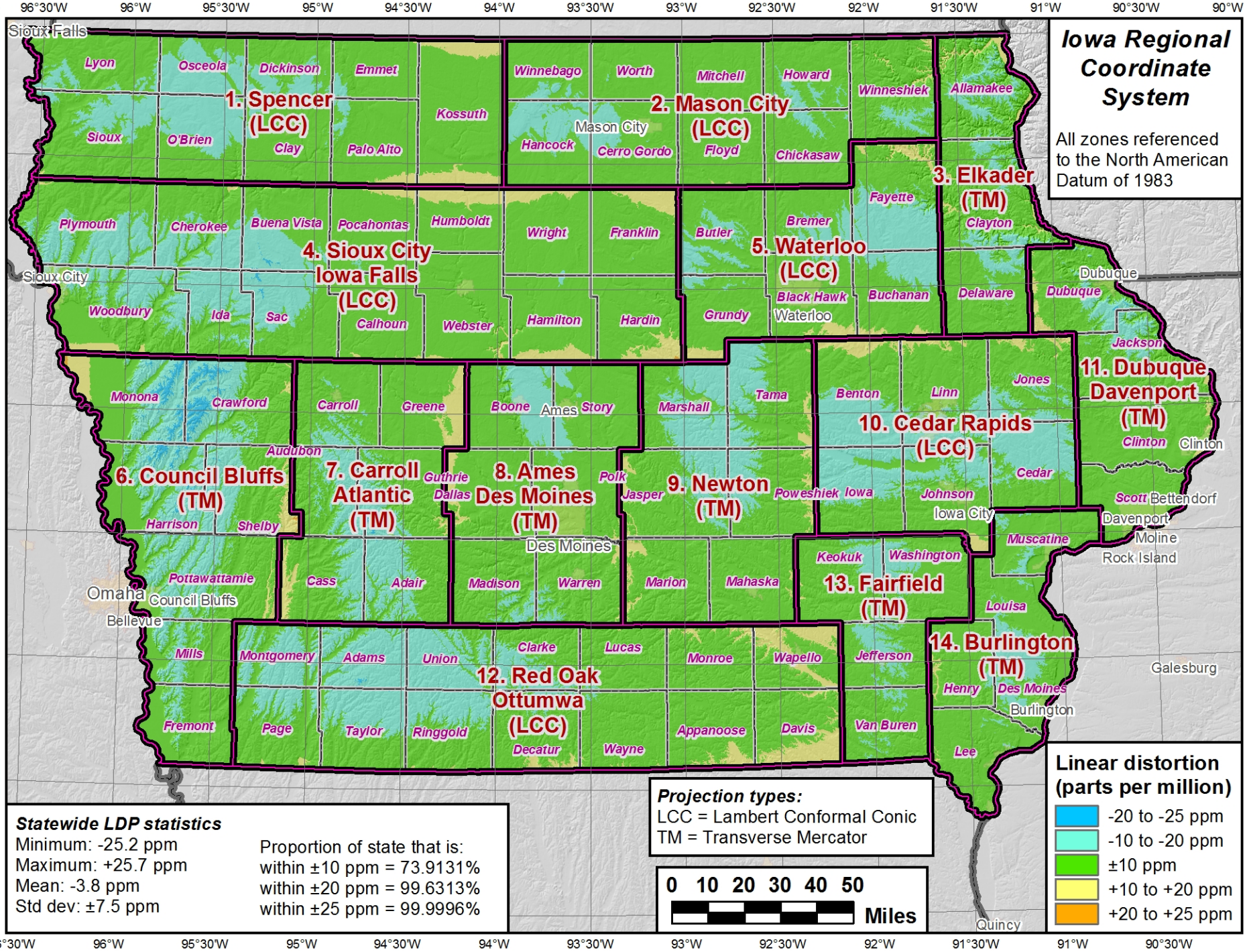
Why bother with LDPs?

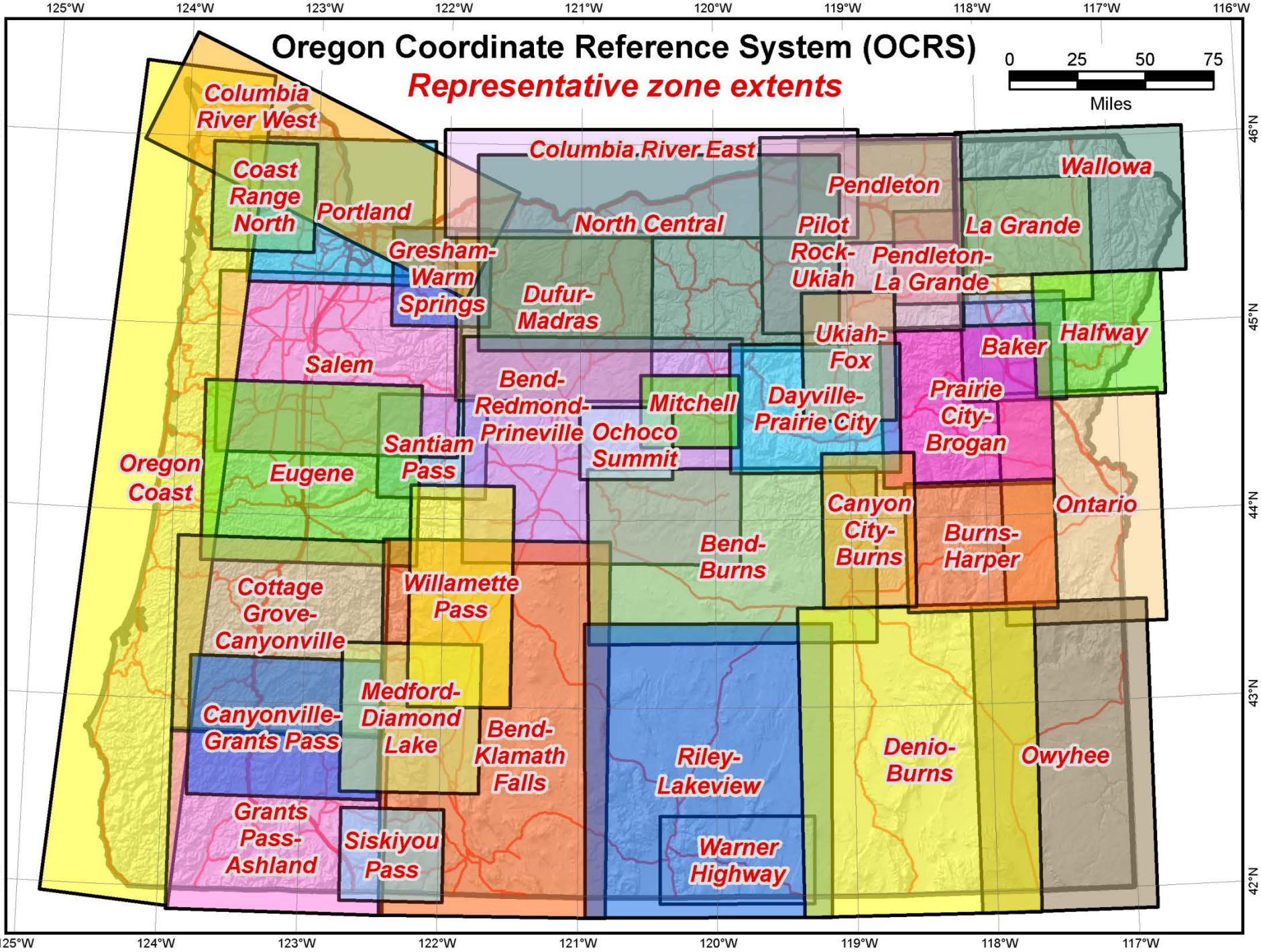
- Rigorously defined and widely supported
- Satisfies needs of surveying, engineering, and GIS
- Enables direct use of survey data in a GIS
- Reduces proliferation of local systems
- Facilitates data transferability
- ***Optimally minimize distortion over area of interest***

If designing a custom coordinate system, do it right the first time → maximize benefit

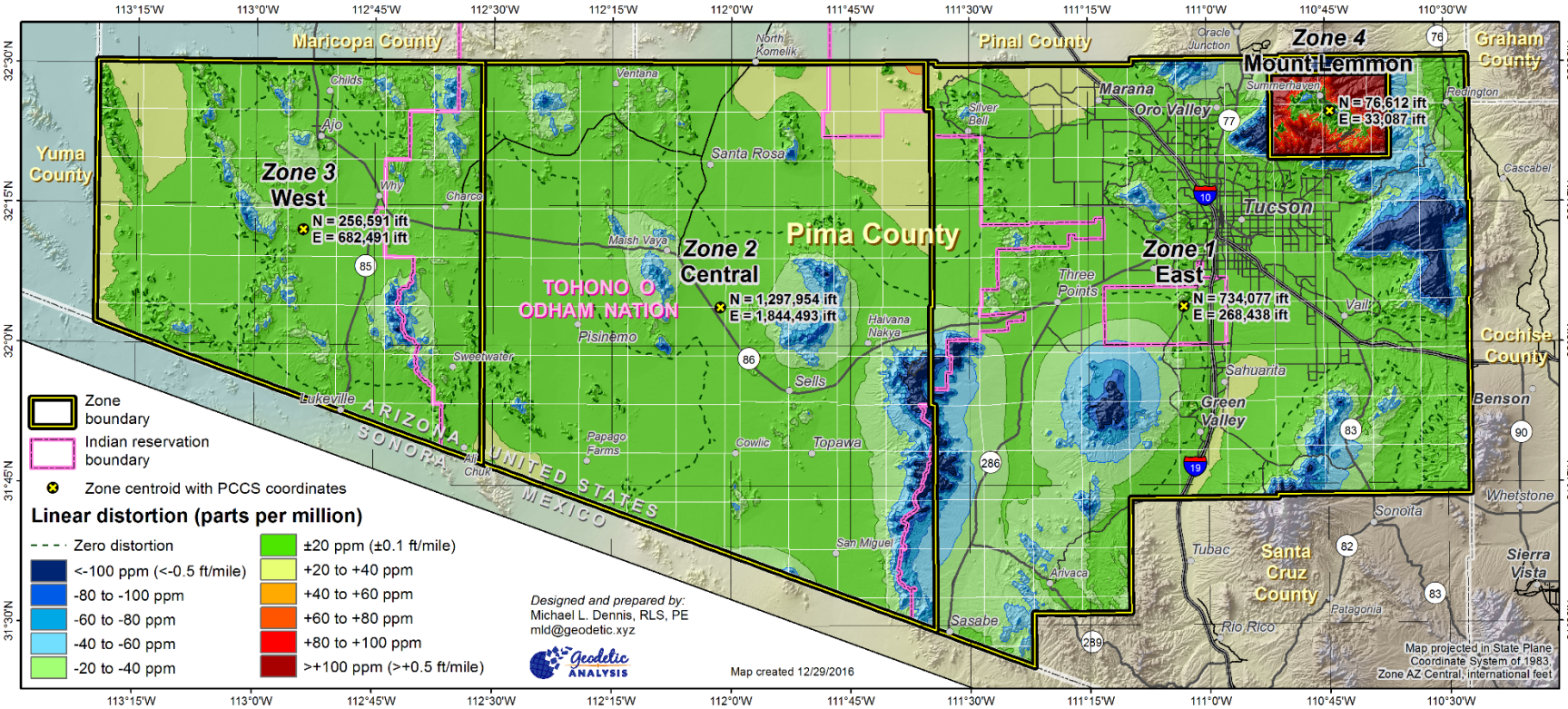

Existing Low Distortion Projection Coordinate Systems
0 250 500 750 1,000
miles
175°E 180° 175°W 170°W 165°W 160°W 150°W 140°W 130°W 120°W 110°W 100°W 90°W 80°W 70°W 60°W 50°W 40°W 35°W 30°W 25°W 20°W
55°N 50°N 45°N 40°N 35°N 30°N 25°N 20°N 15°N
65°N 60°N 55°N 50°N 45°N 40°N 35°N 30°N 25°N 20°N
135°W 130°W 125°W 120°W 115°W 110°W 105°W 100°W 95°W 90°W 85°W 80°W 75°W 70°W 65°W


Existing Low Distortion Projection Coordinate Systems
130°W
125°W
120°W
115°W
110°W
105°W
100°W
95°W
90°W
85°W
80°W
75°W
70°W
65°W
50°N
45°N
40°N
35°N
30°N
25°N
0
200
400
600
miles


Iowa Regional Coordinate System
All zones referenced to the North American Datum of 1983
1. Spencer (LCC)
2. Mason City (LCC)
3. Elkader (TM)
4. Sioux City Iowa Falls (LCC)
5. Waterloo (LCC)
6. Council Bluffs (TM)
7. Carroll Atlantic (TM)
8. Ames Des Moines (TM)
9. Newton (TM)
10. Cedar Rapids (LCC)
11. Dubuque Davenport (TM)
12. Red Oak Ottumwa (LCC)
13. Fairfield (TM)
14. Burlington (TM)
Lyon
Osceola
Dickinson
Emmet
Winnebago
Worth
Mitchell
Howard
Winneshiek
Allamakee
Sioux
O'Brien
Clay
Palo Alto
Kossuth
Hancock
Cerro Gordo
Floyd
Chickasaw
Plymouth
Cherokee
Buena Vista
Pocahontas
Humboldt
Wright
Franklin
Butler
Bremer
Fayette
Clayton
Woodbury
Ida
Sac
Calhoun
Webster
Hamilton
Hardin
Grundy
Black Hawk
Buchanan
Delaware
Dubuque
Jackson
Monona
Crawford
Carroll
Greene
Boone
Story
Marshall
Tama
Benton
Linn
Jones
Clinton
Audubon
Guthrie
Dallas
Polk
Jasper
Poweshiek
Iowa
Johnson
Cedar
Scott
Harrison
Shelby
Pottawattamie
Cass
Adair
Madison
Warren
Marion
Mahaska
Keokuk
Washington
Muscatine
Louisa
Mills
Montgomery
Adams
Union
Clarke
Lucas
Monroe
Wapello
Jefferson
Henry
Des Moines
Fremont
Page
Taylor
Ringgold
Decatur
Wayne
Appanoose
Davis
Van Buren
Lee
Sioux Falls
Mason City
Sioux City
Waterloo
Dubuque
Ames
Iowa City
Davenport
Bettendorf
Moline
Rock Island
Des Moines
Omaha
Council Bluffs
Bellevue
Galesburg
Burlington
Quincy
Statewide LDP statistics
Minimum: -25.2 ppm
Maximum: +25.7 ppm
Mean: -3.8 ppm
Std dev: ±7.5 ppm
Proportion of state that is:
within ±10 ppm = 73.9131%
within ±20 ppm = 99.6313%
within ±25 ppm = 99.9996%
Projection types:
LCC = Lambert Conformal Conic
TM = Transverse Mercator
0 10 20 30 40 50
Miles
Linear distortion (parts per million)
-20 to -25 ppm
-10 to -20 ppm
±10 ppm
+10 to +20 ppm
+20 to +25 ppm
96°30'W
96°W
95°30'W
95°W
94°30'W
94°W
93°30'W
93°W
92°30'W
92°W
91°30'W
91°W
90°30'W
90°W
43°30'N
43°N
42°30'N
42°N
41°30'N
41°N
40°30'N
40°N


Oregon Coordinate Reference System (OCRS)
Representative zone extents
0 25 50 75
Miles
125°W
124°W
123°W
122°W
121°W
120°W
119°W
118°W
117°W
116°W
46°N
45°N
44°N
43°N
42°N
Columbia River West
Coast Range North
Portland
Columbia River East
North Central
Pendleton
Wallowa
Pilot Rock-Ukiah
La Grande
Pendleton-La Grande
Gresham-Warm Springs
Dufur-Madras
Ukiah-Fox
Baker
Halfway
Salem
Bend-Redmond-Prineville
Mitchell
Dayville-Prairie City
Prairie City-Brogan
Santiam Pass
Ochoco Summit
Oregon Coast
Eugene
Canyon City-Burns
Ontario
Bend-Burns
Burns-Harper
Cottage Grove-Canyonville
Willamette Pass
Medford-Diamond Lake
Canyonville-Grants Pass
Bend-Klamath Falls
Riley-Lakeview
Denio-Burns
Owyhee
Grants Pass-Ashland
Siskiyou Pass
Warner Highway

The Pima County Coordinate System



Pima County Coordinate System (PCCS)

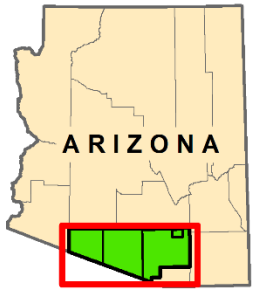
North American Datum of 1983

Linear unit: international foot (ift)
1 ift = 0.3048 meter (exact)

Scale 1:800,000
when printed on 11" x 17" sheet

0 10 20 30
Miles

Grid North



Zone 1: East

Oblique Mercator projection
(local grid origin)
Local grid origin latitude: 32° 15' 00" N
Local grid origin longitude: 111° 24' 00" W
Local false northing: 800,000.000 ift
Local false easting: 160,000.000 ift
Skew axis scale at origin: 1.000 110 (exact)
Skew axis azimuth at origin: +45° 00' 00"

Zone 2: Central

Transverse Mercator projection

Grid origin latitude: 31° 15' 00" N
Central meridian: 112° 10' 00" W
False northing: 1,000,000.000 ift
False easting: 1,800,000.000 ift
Central merid scale: 1.000 090 (exact)

Zone 3: West

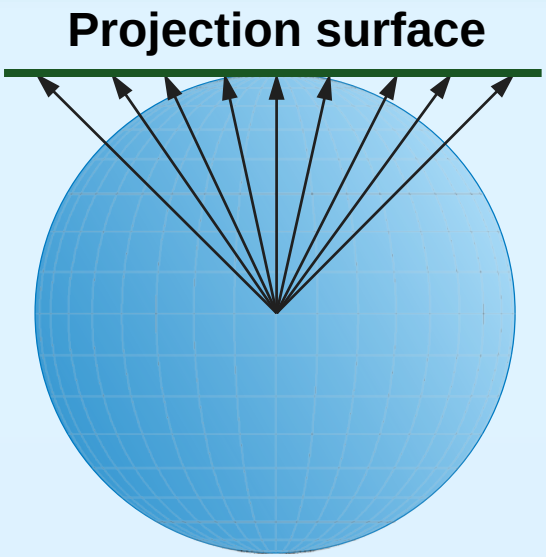
Transverse Mercator projection

Grid origin latitude: 31° 30' 00" N
Central meridian: 113° 10' 00" W
False northing: 0.000 ift
False easting: 600,000.000 ift
Central merid scale: 1.000 055 (exact)

Zone 4: Mount Lemmon

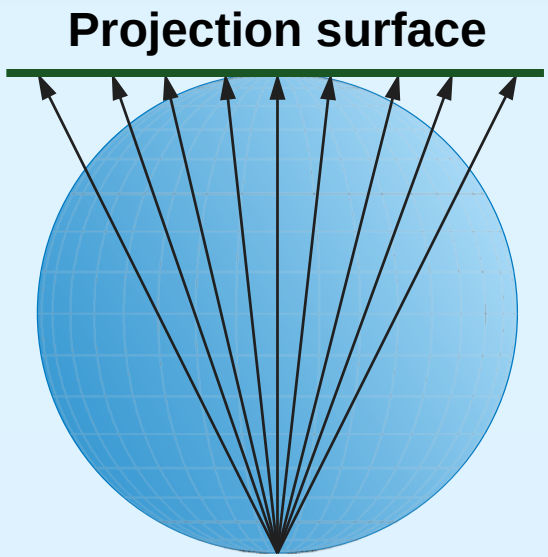
Lambert conformal conic projection
(single parallel)
Standard parallel & grid origin: 30° 30' 00" N
Central meridian: 110° 45' 00" W
False northing: -620,000.000 ift
False easting: 30,000.000 ift
Scale on standard parallel: 0.999 800 (exact)

Can think of projection as “light rays” projecting onto surface



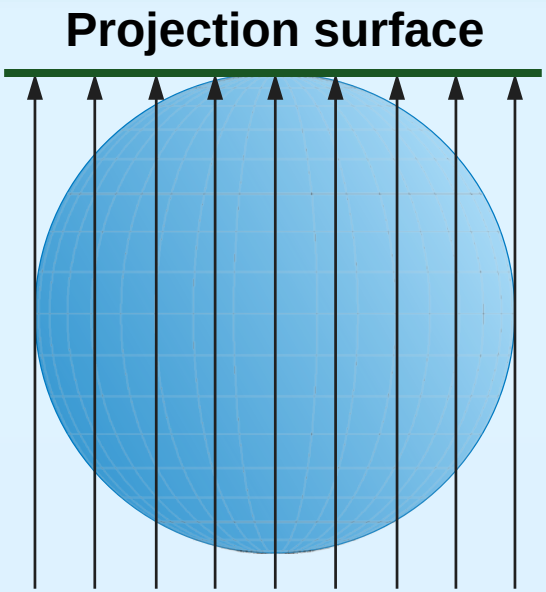
Ray source at center of Earth

Gnomonic projection *(non-conformal)*



Ray source at opposite side of Earth

Stereographic projection *(conformal)*



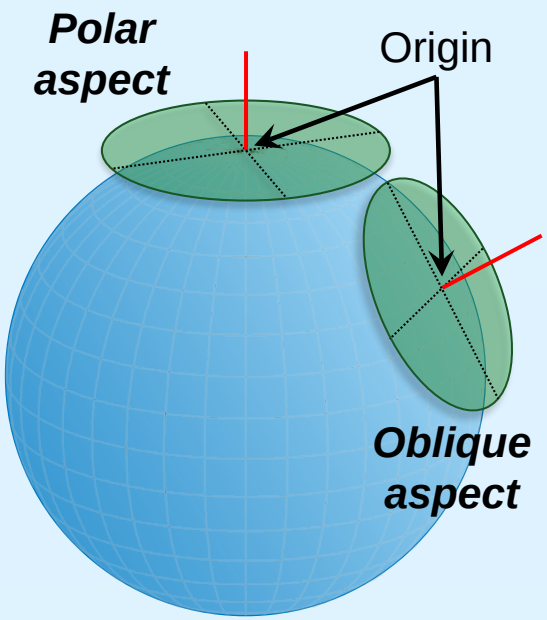
Ray source at infinity

Orthographic projection *(non-conformal)*

However, this only works for a few sphere-based projections

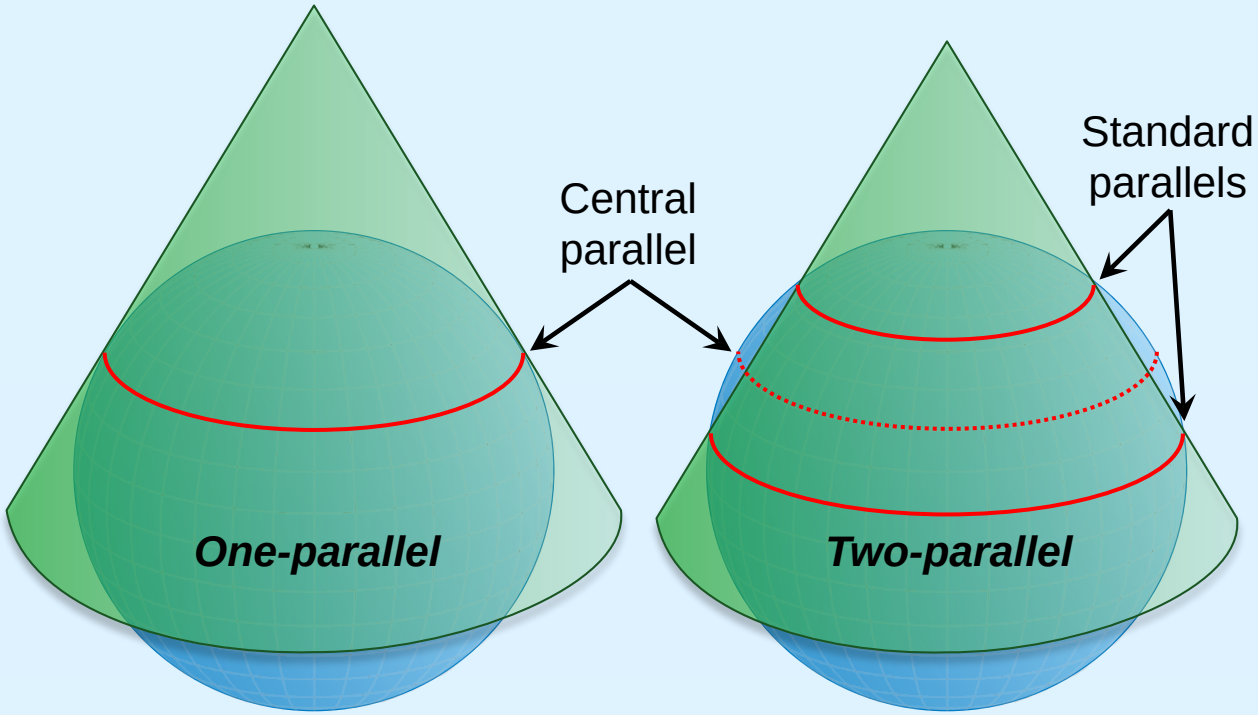
Developable surfaces: Planes and cones

Planar (azimuthal) projections



e.g., stereographic

Conic projections



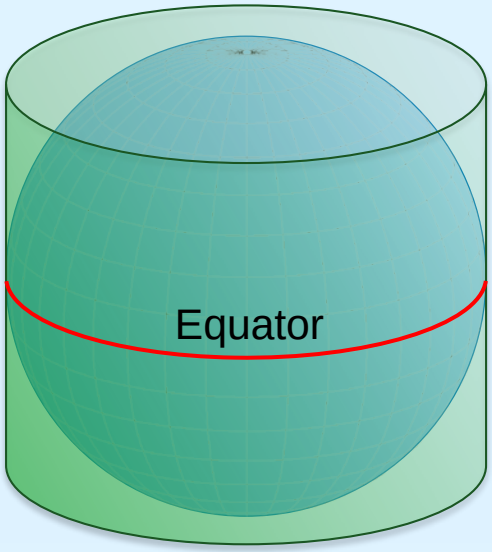
e.g., Lambert conformal conic

Examples given are CONFORMAL projections

Developable surfaces: Cylinders

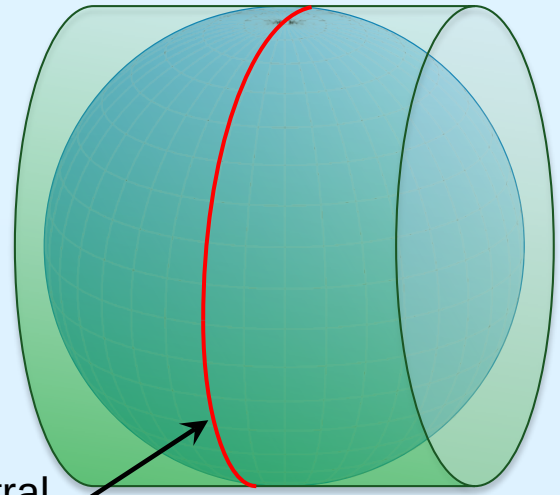
Cylindrical projections

"Regular" aspect



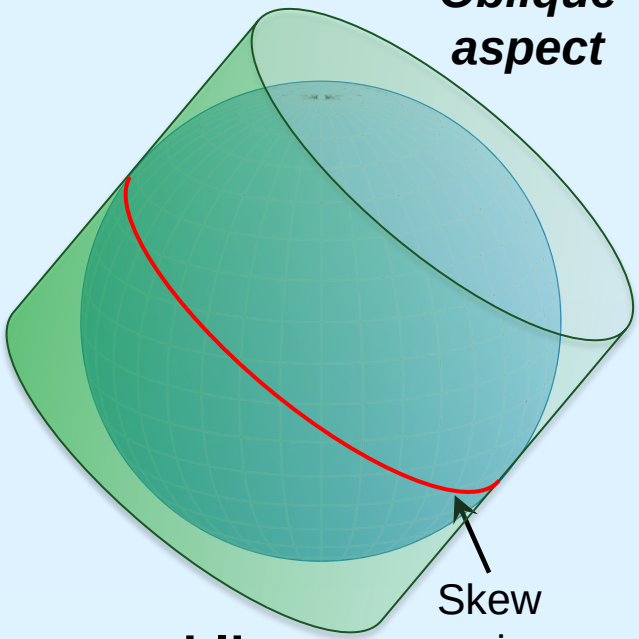
e.g., Mercator

Transverse aspect



e.g., transverse Mercator

Oblique aspect



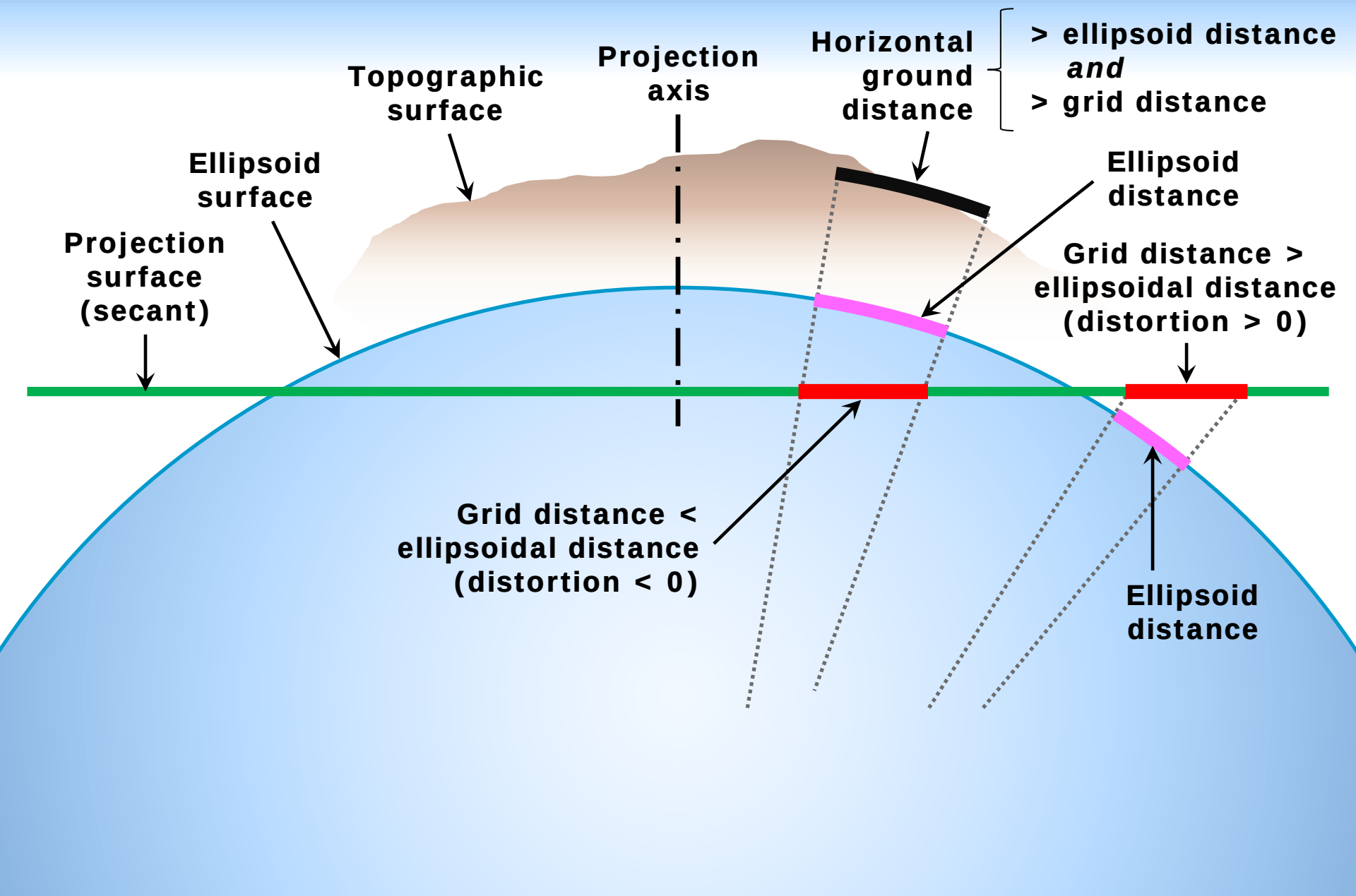
e.g., oblique Mercator

Examples given are CONFORMAL projections

Types of Map Projection Distortion

- **Angular distortion.** Equals *convergence (mapping) angle* for *conformal* projections (e.g., Transverse Mercator)
- **Linear distortion.** Difference in distance between a pair of grid (map) coordinates when compared to the "true" horizontal ("ground") distance
  - Can express as ratio of distorted length to "true" length
    - E.g., feet of distortion per mile, or as mm/km (= ppm)
  - Distortion can be **negative** or **positive**
    - **NEGATIVE:** Grid distance less than true distance
    - **POSITIVE:** Grid distance greater than true distance

Linear distortion with respect to ellipsoid and ground



Horizontal distortion due to Earth curvature

Maximum projection zone width	**Maximum linear horizontal distortion**		
	Parts per million	Feet per mile	Ratio (absolute value)
16 miles	±1 ppm	±0.005 ft/mi	1 : 1,000,000
50 miles	±10 ppm	±0.053 ft/mi	1 : 100,000
71 miles	**±20 ppm**	**±0.11 ft/mi**	**1 : 50,000**

Horizontal distortion due to Earth curvature

Maximum projection zone width	**Maximum linear horizontal distortion**		
	Parts per million	Feet per mile	Ratio (absolute value)
16 miles	±1 ppm	±0.005 ft/mi	1 : 1,000,000
50 miles	±10 ppm	±0.053 ft/mi	1 : 100,000
71 miles	**±20 ppm**	**±0.11 ft/mi**	**1 : 50,000**
112 miles	±50 ppm	±0.26 ft/mi	1 : 20,000
158 miles*	±100 ppm	±0.53 ft/mi	1 : 10,000
317 miles**	±400 ppm	±2.11 ft/mi	1 : 2,500

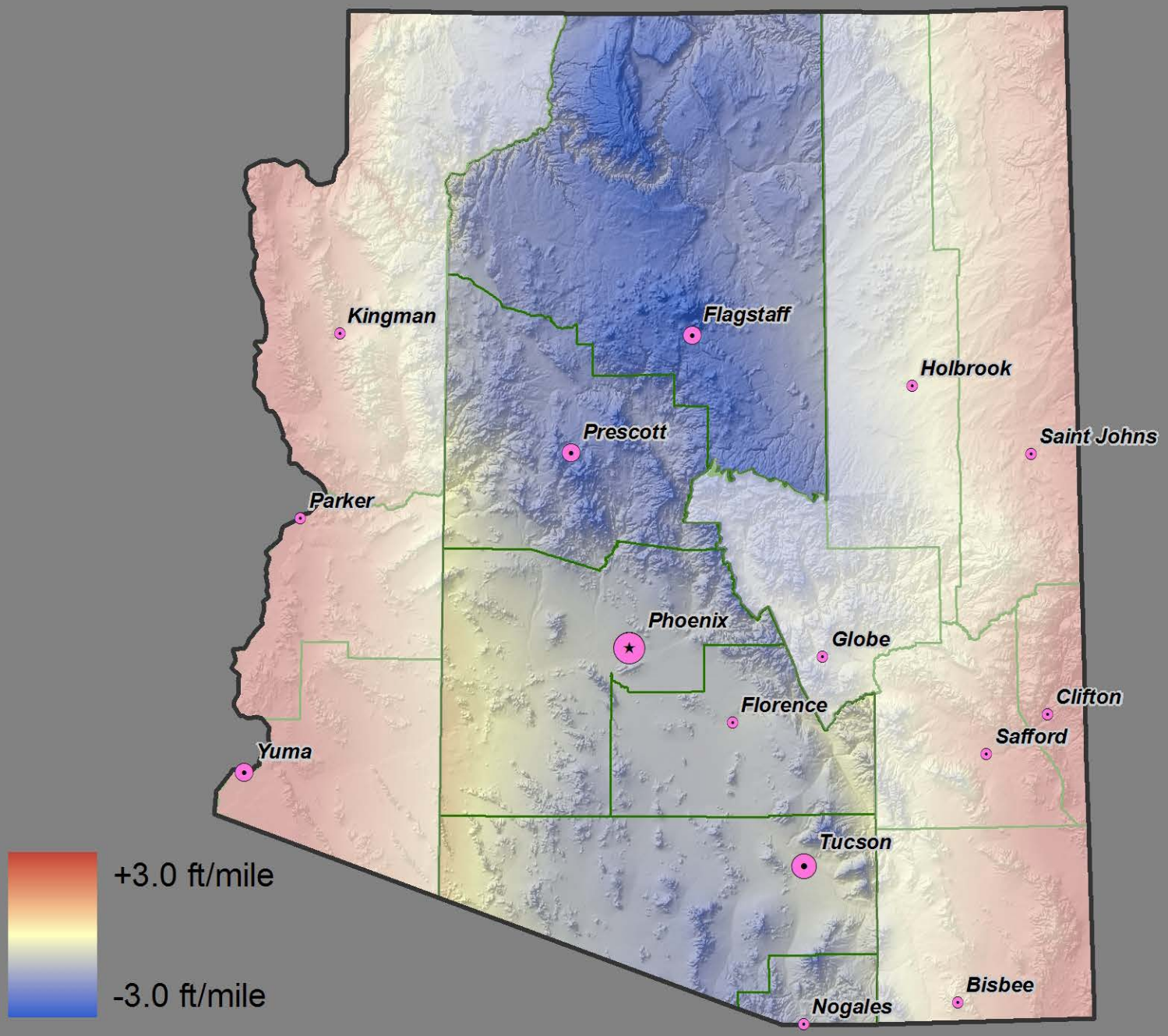
Horizontal distortion due to height above ellipsoid

Height below (–) and above (+) projection surface	Maximum linear horizontal distortion		
	Parts per million	Feet per mile	Ratio (absolute value)
±100 ft	±4.8 ppm	±0.025 ft/mi	~1 : 209,000
±400 ft	**±19 ppm**	**±0.10 ft/mi**	**~1 : 52,000**
±1000 ft	±48 ppm	±0.25 ft/mi	~1 : 21,000

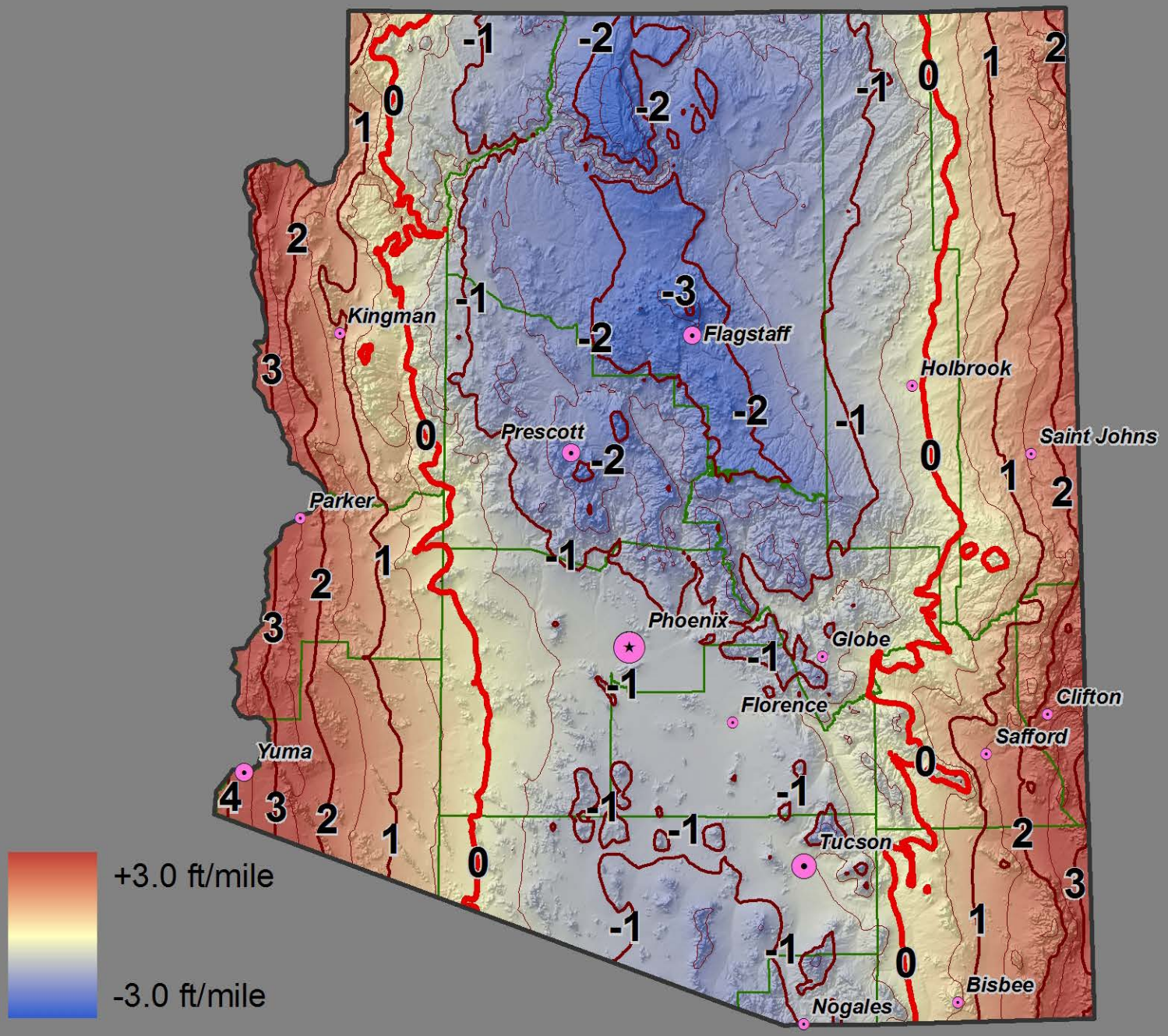
Horizontal distortion due to height above ellipsoid

Height below (–) and above (+) projection surface	Maximum linear horizontal distortion		
	Parts per million	Feet per mile	Ratio (absolute value)
±100 ft	±4.8 ppm	±0.025 ft/mi	~1 : 209,000
±400 ft	**±19 ppm**	**±0.10 ft/mi**	**~1 : 52,000**
±1000 ft	±48 ppm	±0.25 ft/mi	~1 : 21,000
+2000 ft	–96 ppm	–0.51 ft/mi	~1 : 10,500
+3300 ft*	–158 ppm	–0.83 ft/mi	~1 : 6300
+14,400 ft**	–690 ppm	–3.6 ft/mi	~1 : 1450

State Plane (AZ zone C) “linear distortion”



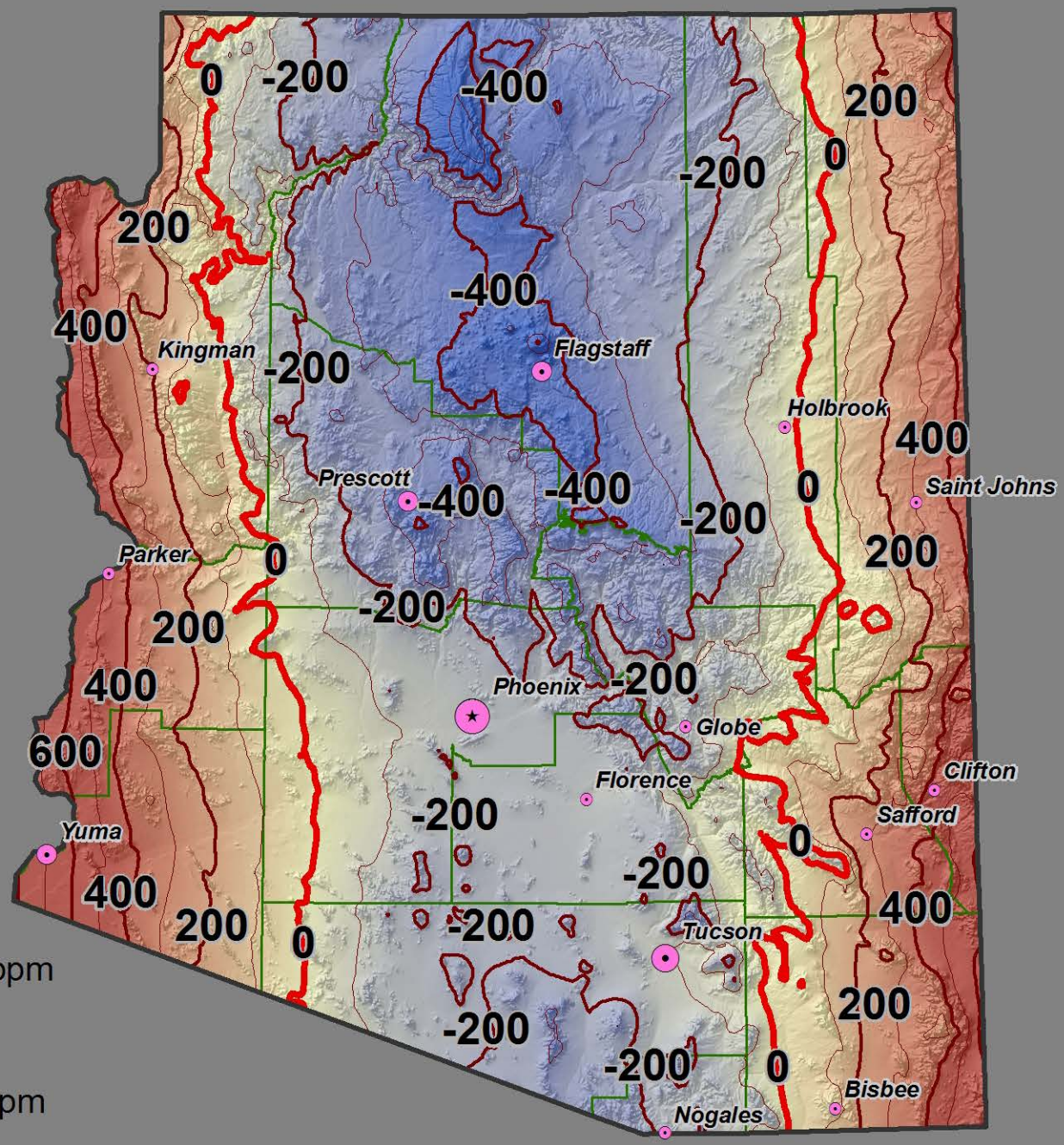
State Plane (AZ Zone C) linear distortion (feet/mile)



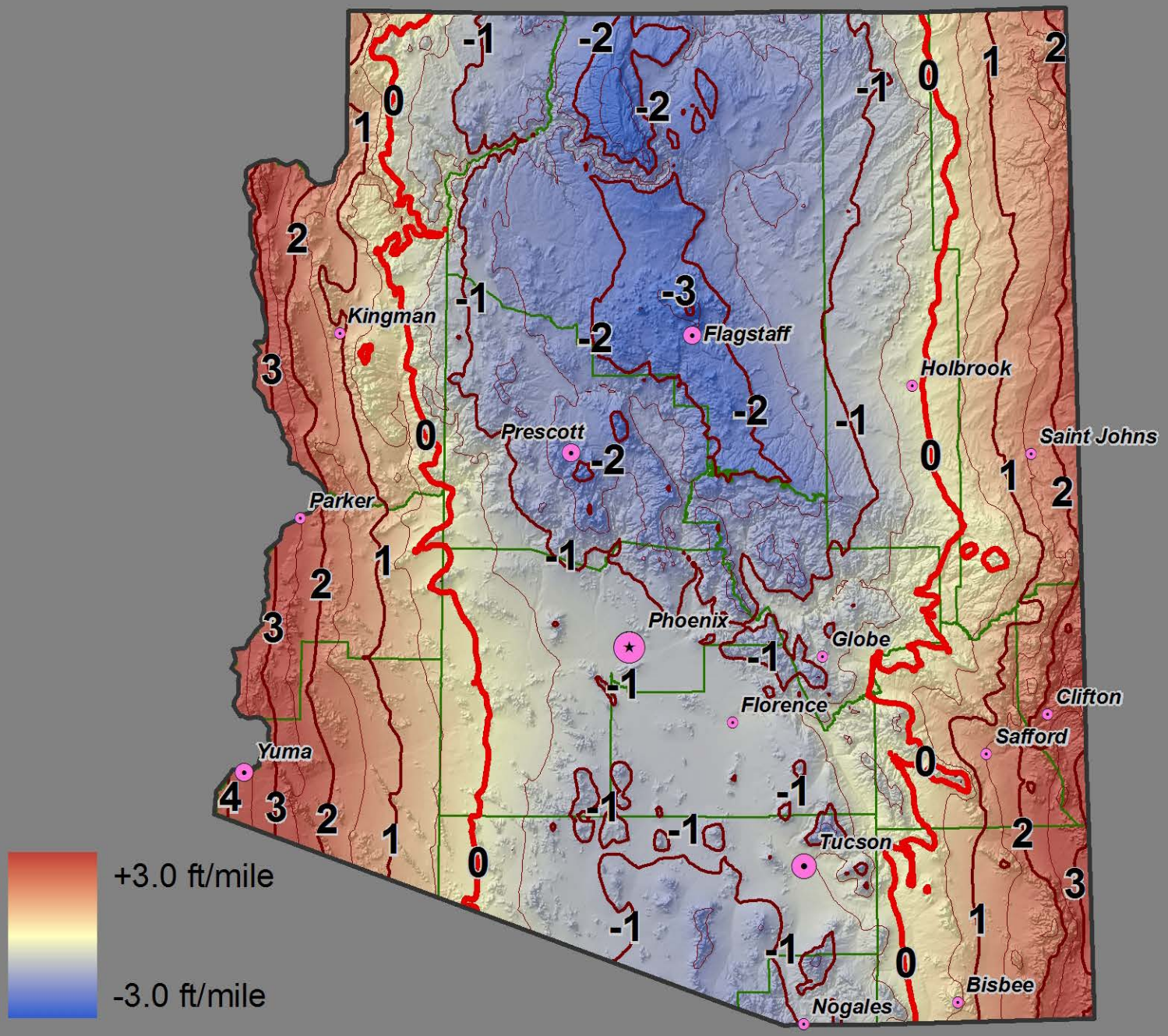
State Plane (AZ Zone C) linear distortion (parts per million)

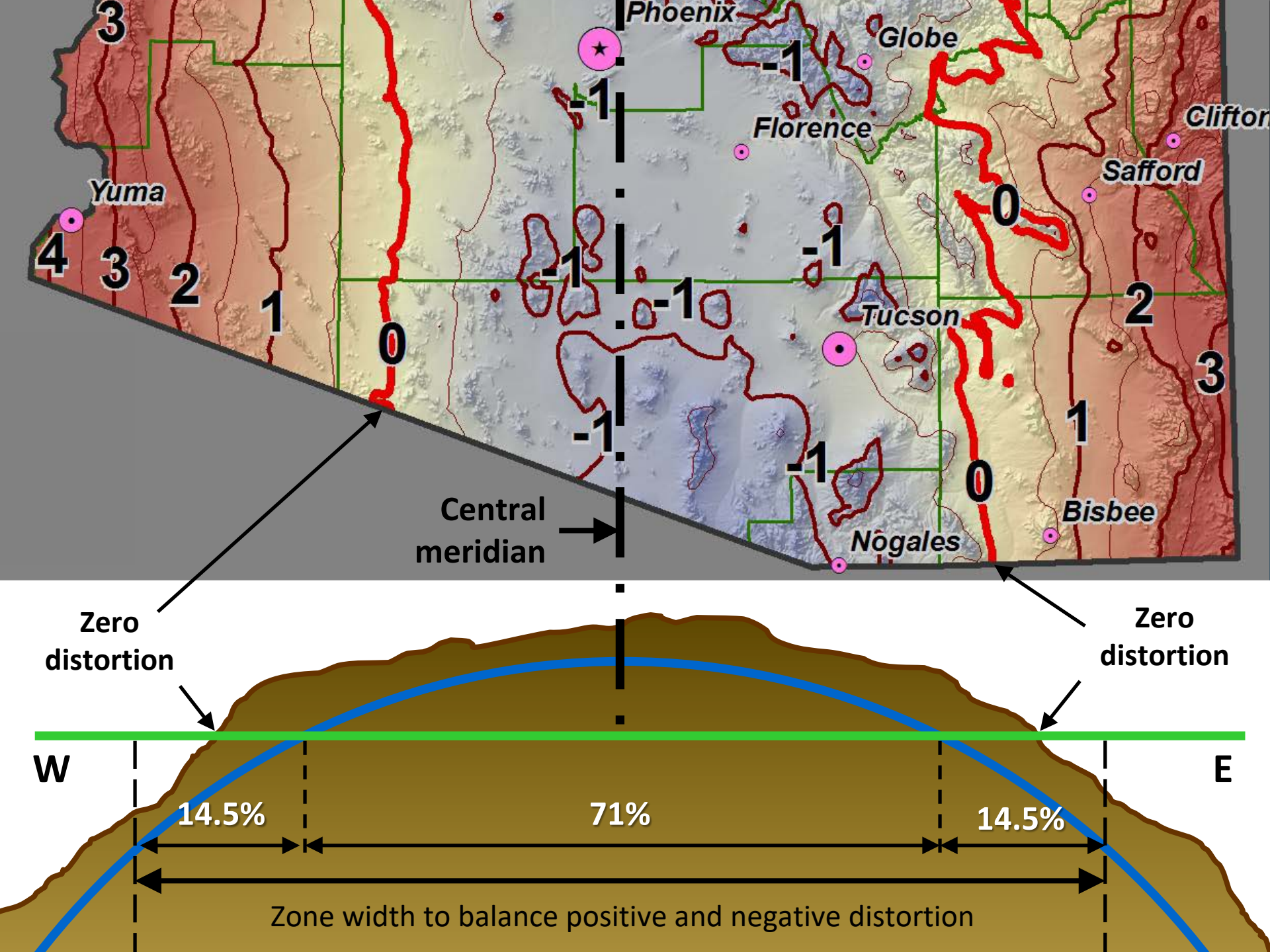
1 ft/mile
≈ 189 ppm

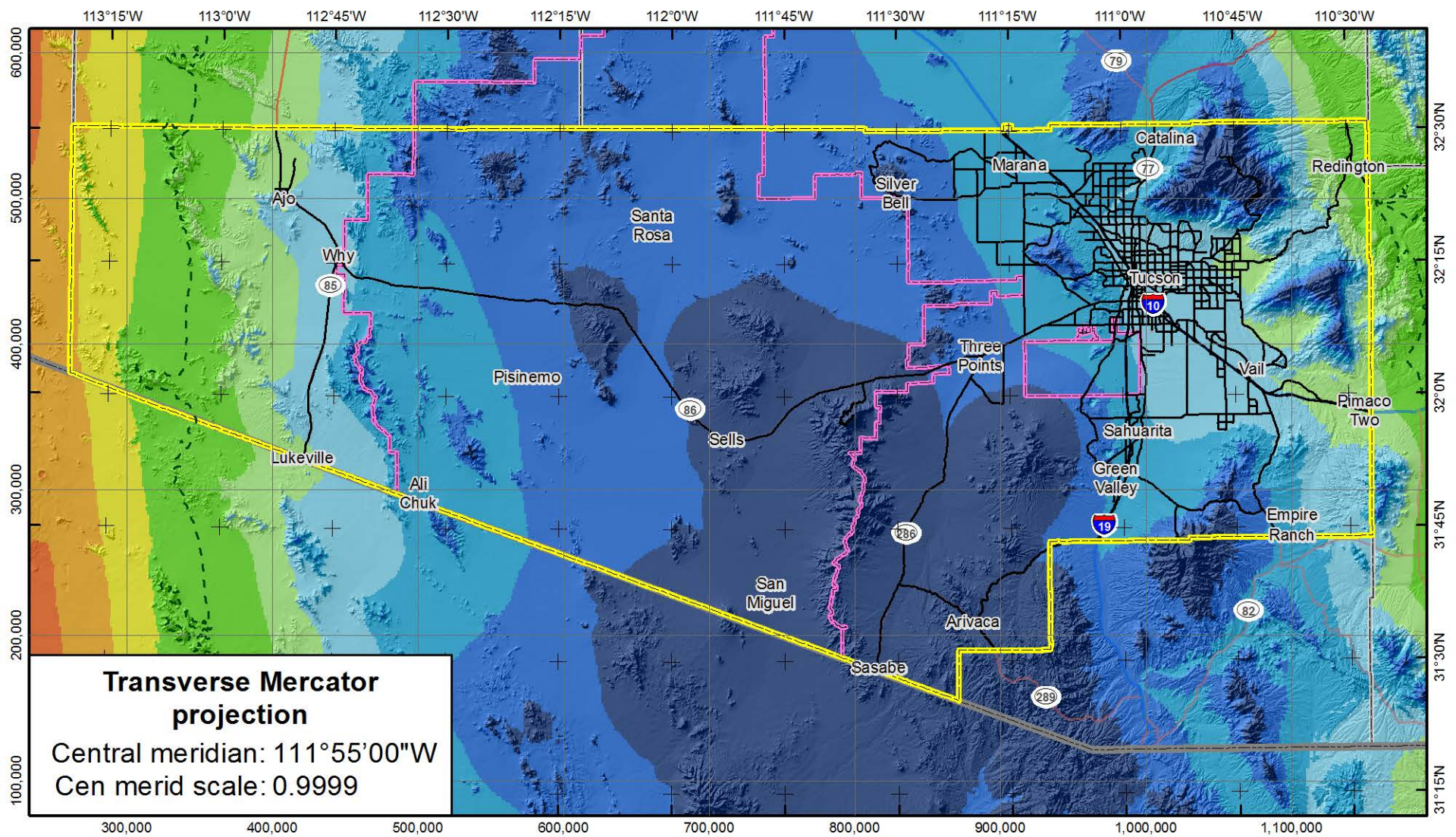
1 ppm
≈ 0.005 ft/mi
= 1 mm/km



State Plane (AZ Zone C) linear distortion (feet/mile)




Phoenix
Globe
Florence
Clifton
Safford
Yuma
Tucson
Bisbee
Nogales
Central meridian
Zero distortion
Zero distortion
W
E
14.5%
71%
14.5%
Zone width to balance positive and negative distortion



State Plane Coordinate System of 1983, Arizona Central Zone

Pima County

40 parts per million (ppm) distortion interval

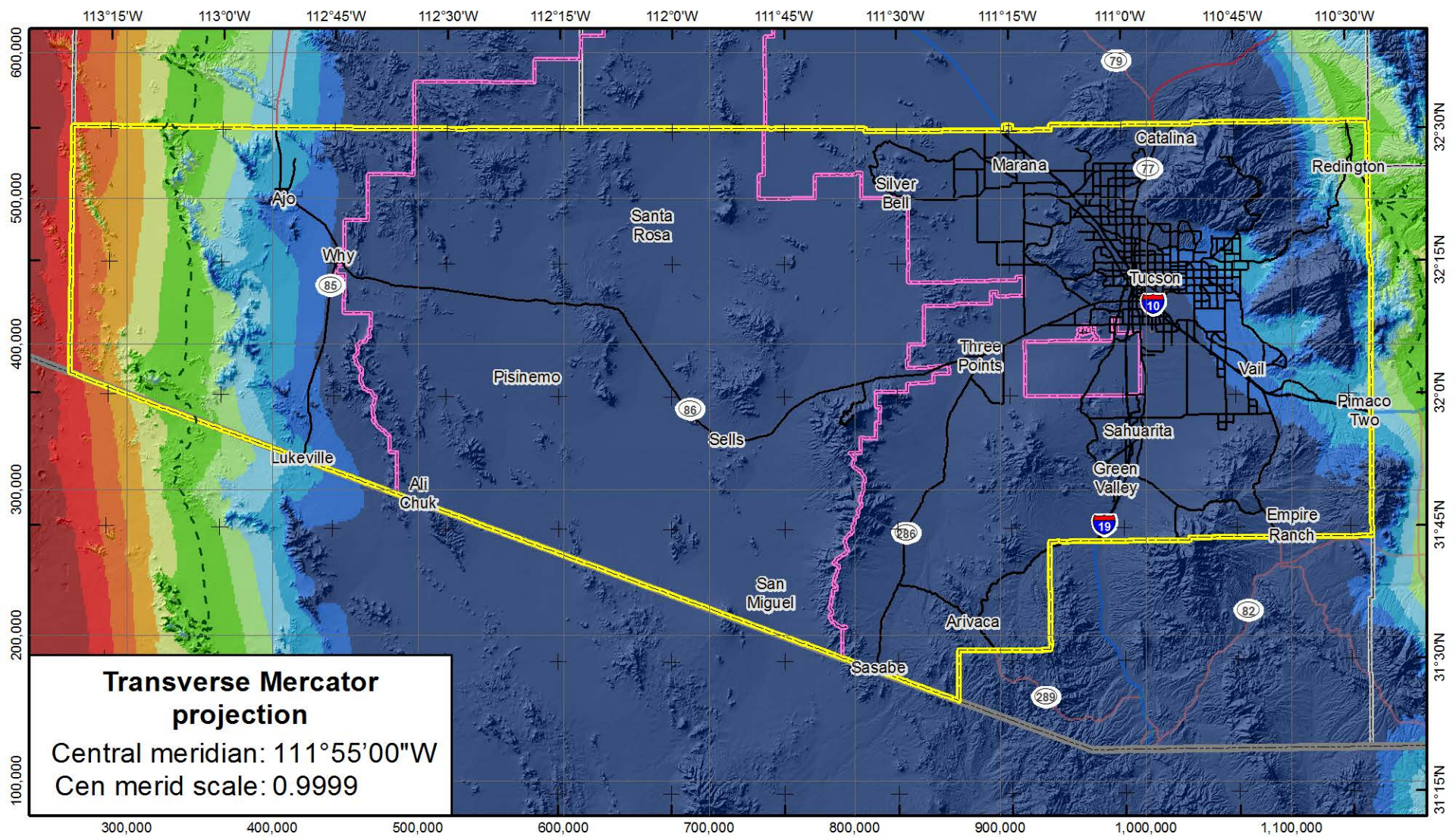
Linear distortion (parts per million)

- <-200 ppm (<-1.1 ft/mile)
- -160 to -200 ppm
- -120 to -160 ppm
- -80 to -120 ppm
- -40 to -80 ppm
- ±40 ppm (±0.2 ft/mile)
- +40 to +80 ppm
- +80 to +120 ppm
- +120 to +160 ppm
- +160 to +200 ppm
- >+200 ppm (>+1.1 ft/mile)
- Zero distortion

0 10 20 30 Miles

Grid North

Projected grid labels are SPCS 83 AZ C, international feet



State Plane Coordinate System of 1983, Arizona Central Zone

Pima County

20 parts per million (ppm) distortion interval

Linear distortion (parts per million)

- <-100 ppm (<-0.5 ft/mile)
- -80 to -100 ppm
- -60 to -80 ppm
- -40 to -60 ppm
- -20 to -40 ppm
- ±20 ppm (±0.1 ft/mile)
- +20 to +40 ppm
- +40 to +60 ppm
- +60 to +80 ppm
- +80 to +100 ppm
- >+100 ppm (>+0.5 ft/mile)
- Zero distortion

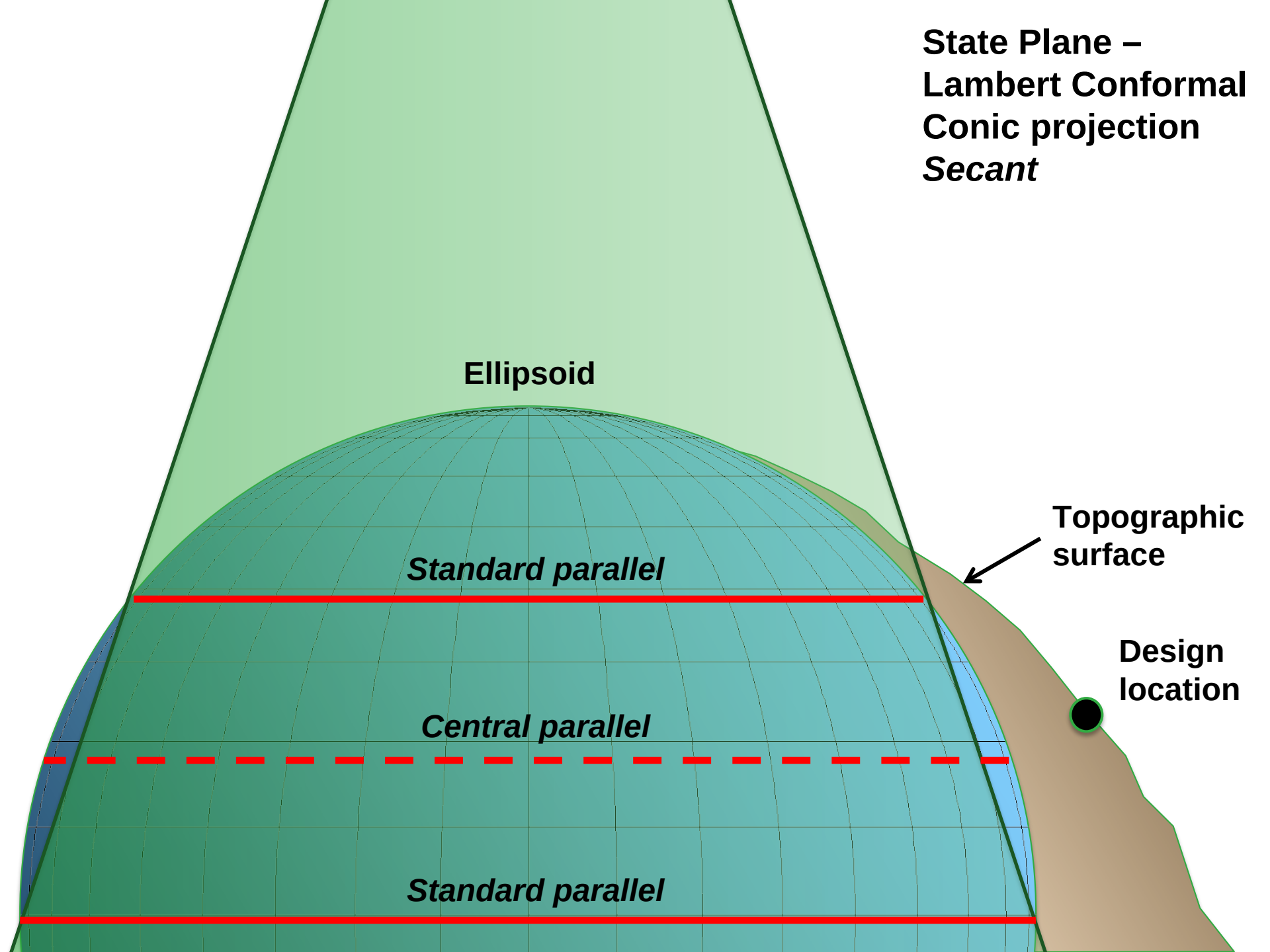
0 10 20 30 Miles

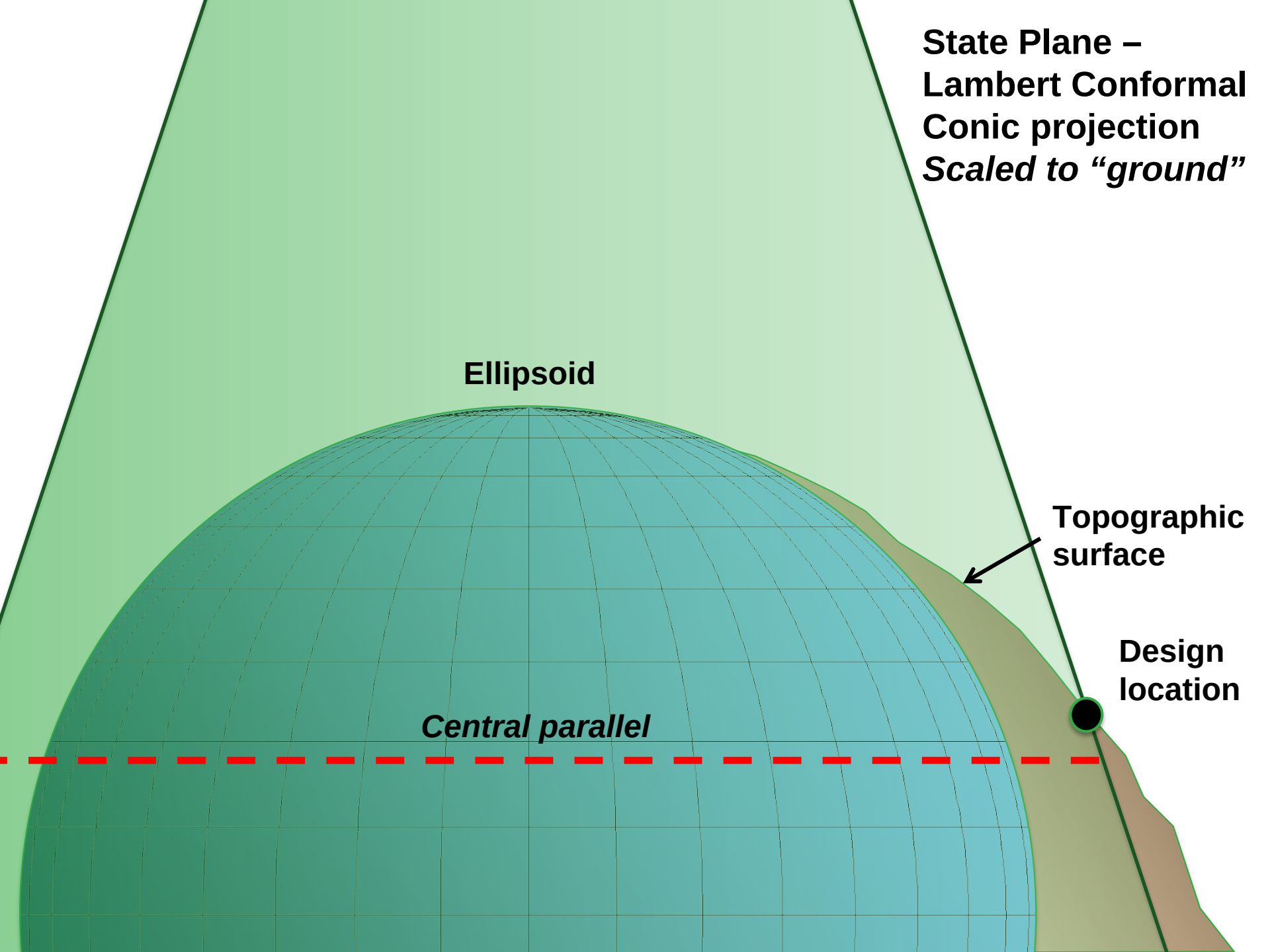
Grid North

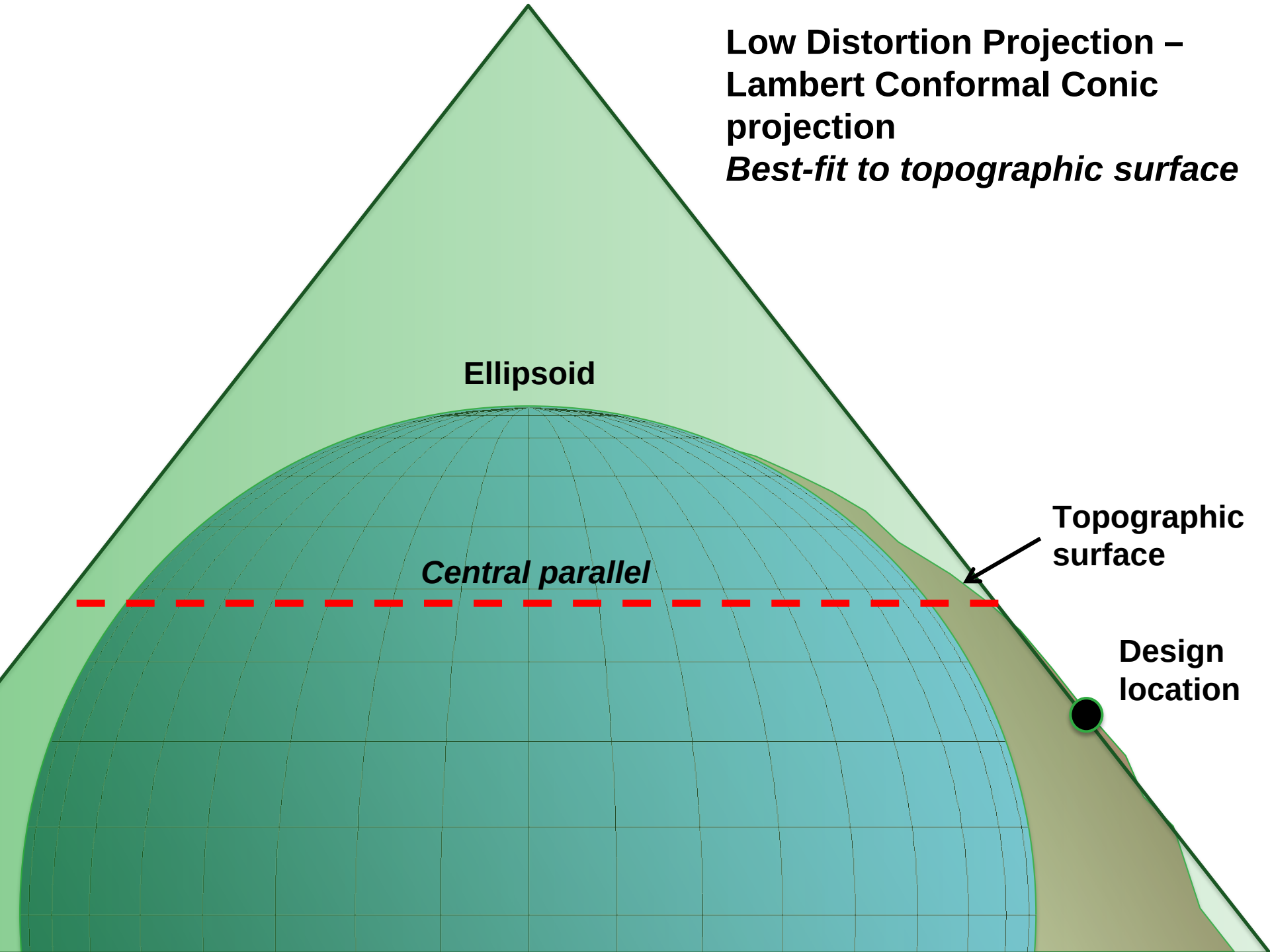
Projected grid labels are SPCS 83 AZ C, international feet

Minimizing linear distortion

- Methods for reducing linear distortion:
  - Scale existing projection (e.g., State Plane) “to ground”
  - Scale ellipsoid “to ground” and use for custom projection
  - Design custom projection “at ground” (LDP)
- All do same thing:
  - *Projection developable surface “at” topographic surface*
- But not all perform the same:
  - *Certain methods better at minimizing distortion*


State Plane –
Lambert Conformal
Conic projection
Secant
Ellipsoid
Topographic
surface
Standard parallel
Design
location
Central parallel
Standard parallel


State Plane –
Lambert Conformal
Conic projection
Scaled to "ground"
Ellipsoid
Topographic
surface
Design
location
Central parallel


Low Distortion Projection – Lambert Conformal Conic projection
Best-fit to topographic surface
Ellipsoid
Central parallel
Topographic surface
Design location

General LDP design approach for sloping topography

- Choose several/many design points
  - Distributed throughout project area
  - Projection axis through centroid
  - Scale projection using mean ***ellipsoid height***
  - These steps are to ***START*** the process…

General LDP design approach for sloping topography

- Choose ***existing*** projection type
  - Slope east-west → **Transverse Mercator (TM)**
  - Slope north-south → **Lambert Conformal Conic (LCC)**
  - Slope oblique direction → **Oblique Mercator (OM)**
    (or Oblique Stereographic, but not recommended)
- "Flat" areas with long dimension > ~30 miles (~50 km)
  - Choose projection based on long dimension
  - TM if long N-S, LCC if long E-W, OM if long oblique direction
  - Offsetting projection axis may further reduce distortion

General LDP design approach for sloping topography

- Change projection type or axis location/orientation
  - To minimize distortion ***variation***
  - e.g., ***range*** and ***standard deviation***
  - Require mathematical analysis and/or iteration
- Change projection scale
  - Distortion changes by same amount everywhere
    - Make average distortion = zero
    - ***OR*** balance positive and negative distortion

General LDP design approach for sloping topography

Be aware:

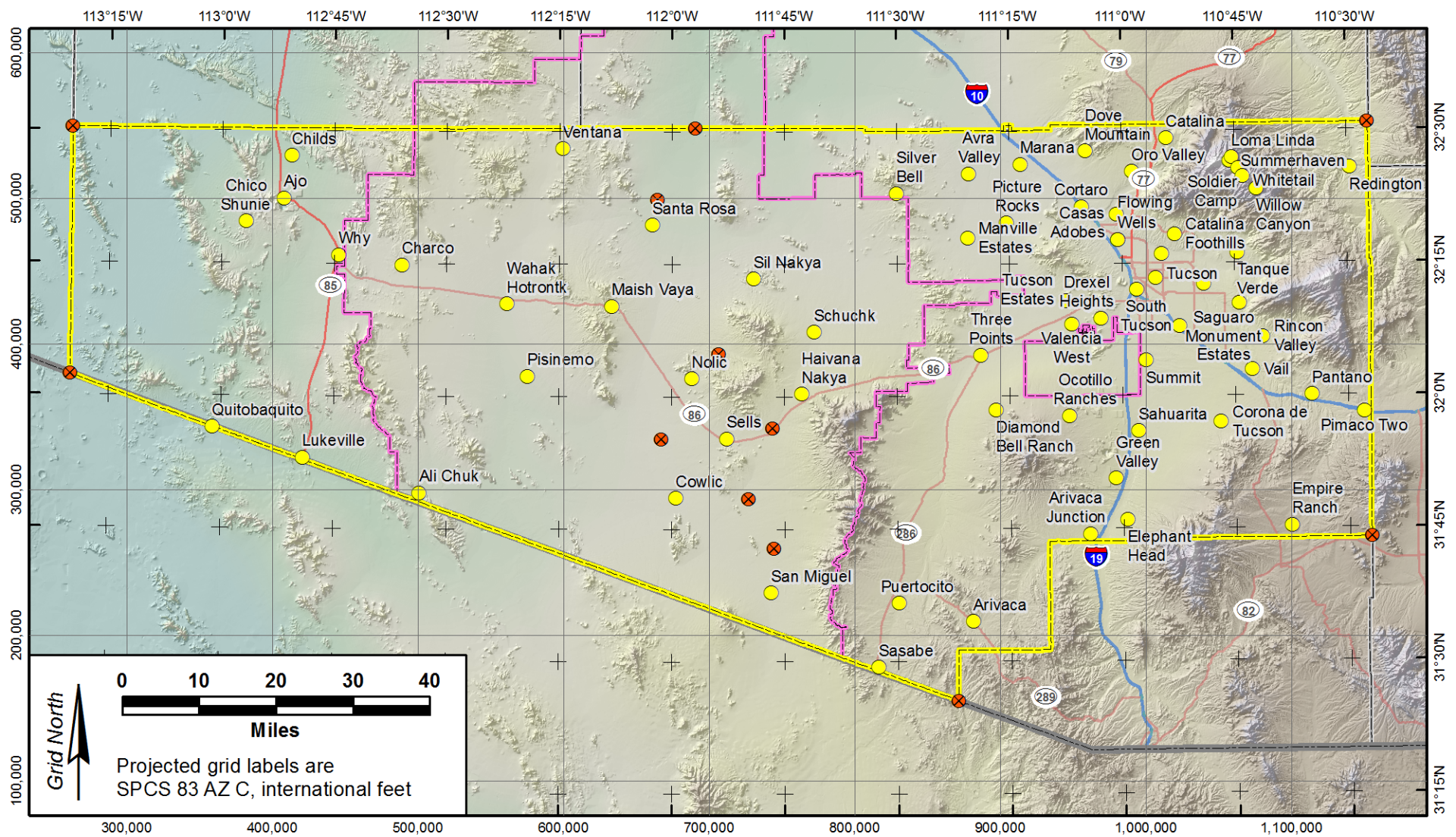
- Designing an LDP is an **OPTIMIZATION** problem
- Often want **LEAST** distortion over **LARGEST** area
  - These goals are at odds with one another
  - So design may not be a simple process

Design criteria for PCCS

- Distortion criterion. ±20 parts per million (±0.1 ft/mi or 1:50,000)
  - Applies to populated or non-mountainous parts of county
- Number of zones. 4 zones, with one for Mount Lemmon
- Projection types. Limited to following 3 conformal projections:
  - Transverse Mercator, Lambert Conformal Conic, Oblique Mercator
- Uniqueness of coordinates. Values differ substantially from:
  - State Plane Arizona Central 1983 and 1927, and UTM Zone 12 North
- Projected coordinate values.
  - Different from other zones; northing not same as eastings within zone
- Linear unit. International foot for defining parameters
- Geodetic reference system. NAD 83 (all realizations)

Design approach for PCCS

- Preliminary work indicated 4 zones
  - 3 zones for overall county, 1 for Mt Lemmon
  - Other alternatives for zones considered but not used:
    - Combining west and central into a single zone
    - Splitting east zone into two zones
- Zone extents determined by distortion
  - Final boundaries correspond to township lines
  - Allow for 1 township overlap into adjacent zone
- Used topographic slope to determine projection type
  - Performance criterion of ±20 ppm in populated areas
  - Initially based on towns/populated places as design points
- ***NOTE:*** Not all design alternatives shown in this presentation



Pima County Low Distortion Projection Coordinate System

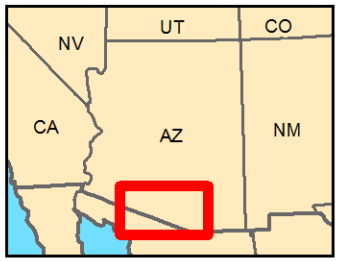
Preliminary design points

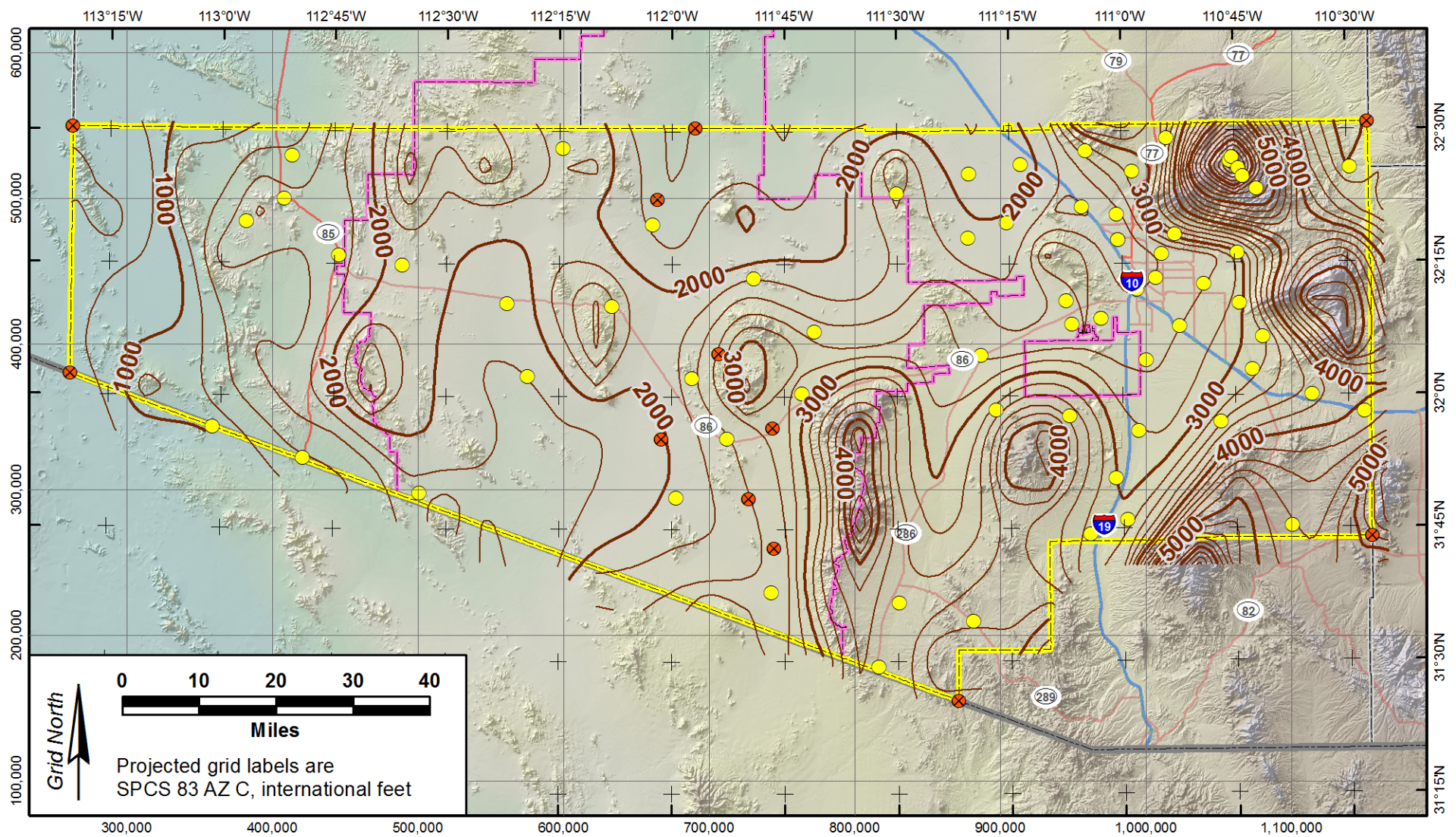
Consist mainly of populated locations based on County and Census data

Design points

- Used (labeled)
- Not used

Vicinity map





Pima County Low Distortion Projection Coordinate System

Topographic ellipsoid height

Generalized to 5 arc-minute grid to show overall trends. Contours are labeled in feet.

Generalized topographic ellipsoid height

- Index contour (1000 ft)
- Intermediate contour (200 ft)

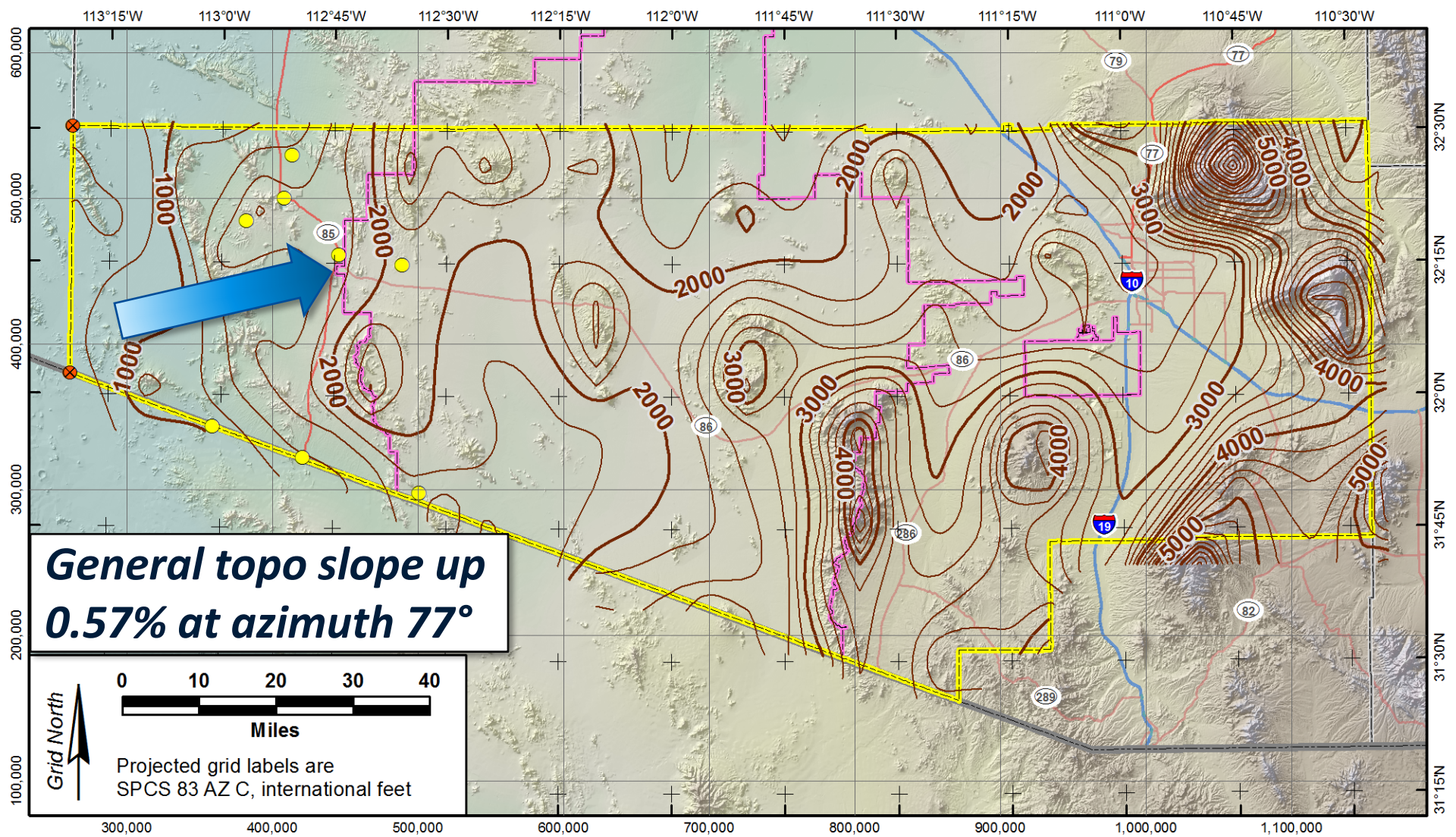
Design points

- Used
- Not used

Vicinity map

Pima County LDP Design Alternatives
West Zone

- 8-10 design points
  - Topo height 550-1990 ft (range = 1440 ft)
  - Zone width ~50 miles (E-W)
- Implied distortion
  - 69 ppm range due to height
  - ±10 ppm due to curvature
- 4 design alternatives
  - All are Transverse Mercator projections
  - Two best ones shown here
  - Final selected is ***alternative 3***
    - Less distortion in western-most areas
    - Selection best matches choice for Central Zone (alternative 4)



Pima County Low Distortion Projection Coordinate System

Topographic ellipsoid height

Generalized to 5 arc-minute grid to show overall trends. Contours are labeled in feet.

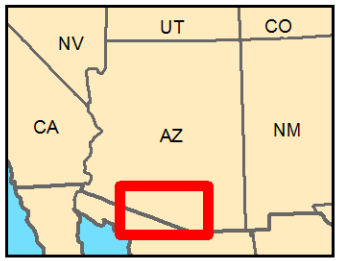
Generalized topographic ellipsoid height

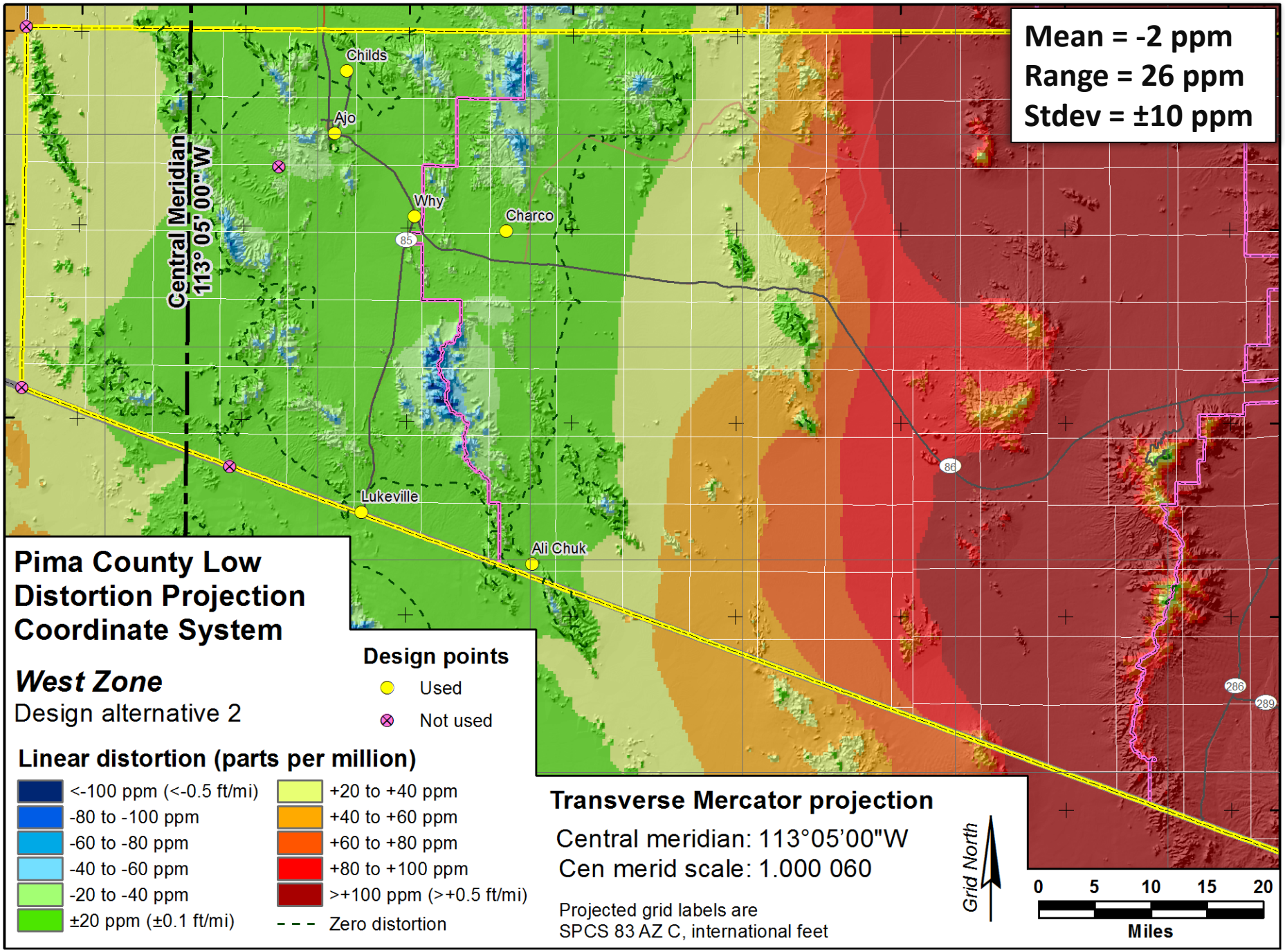
- Index contour (1000 ft)
- Intermediate contour (200 ft)

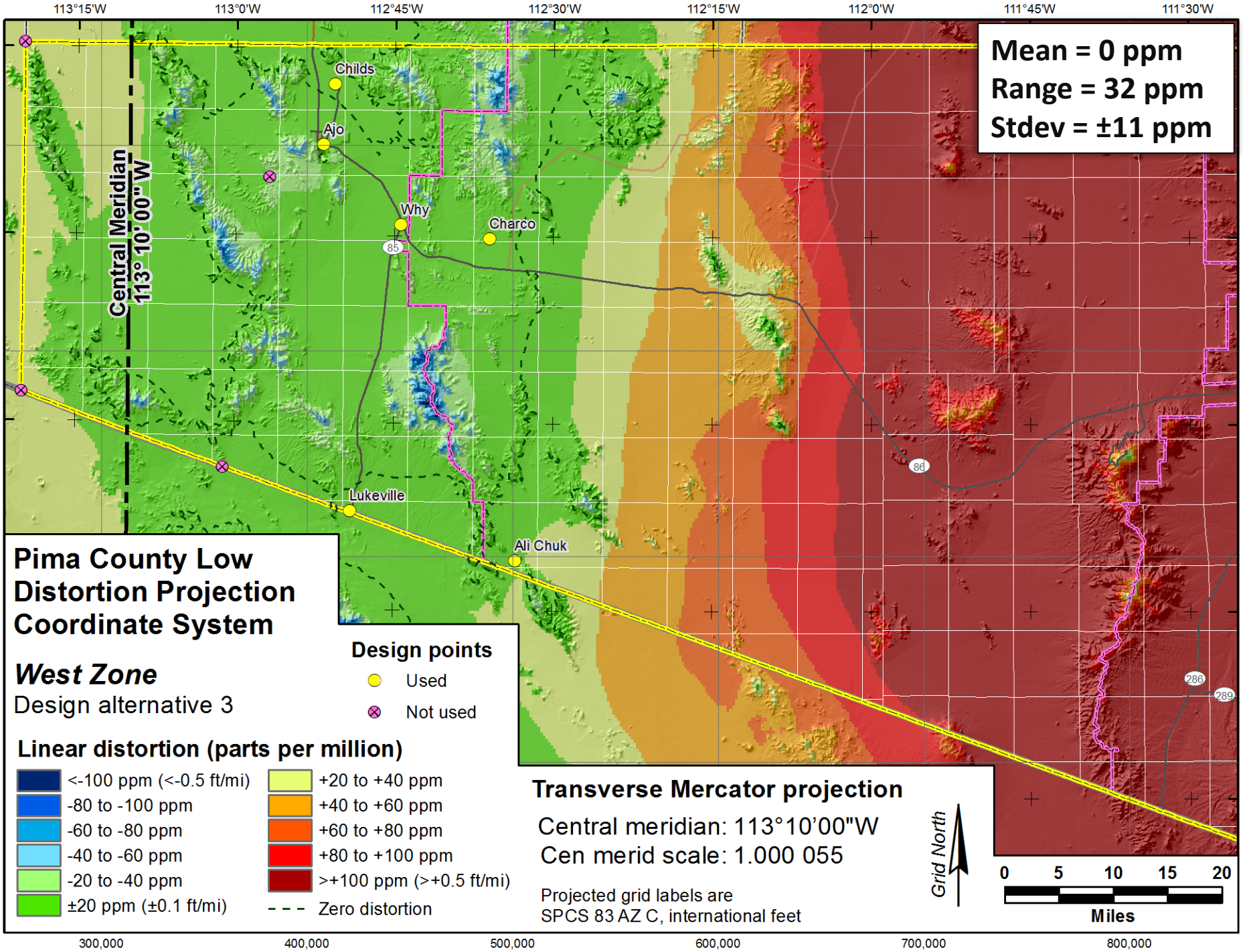
Design points

- Used
- Not used

Vicinity map

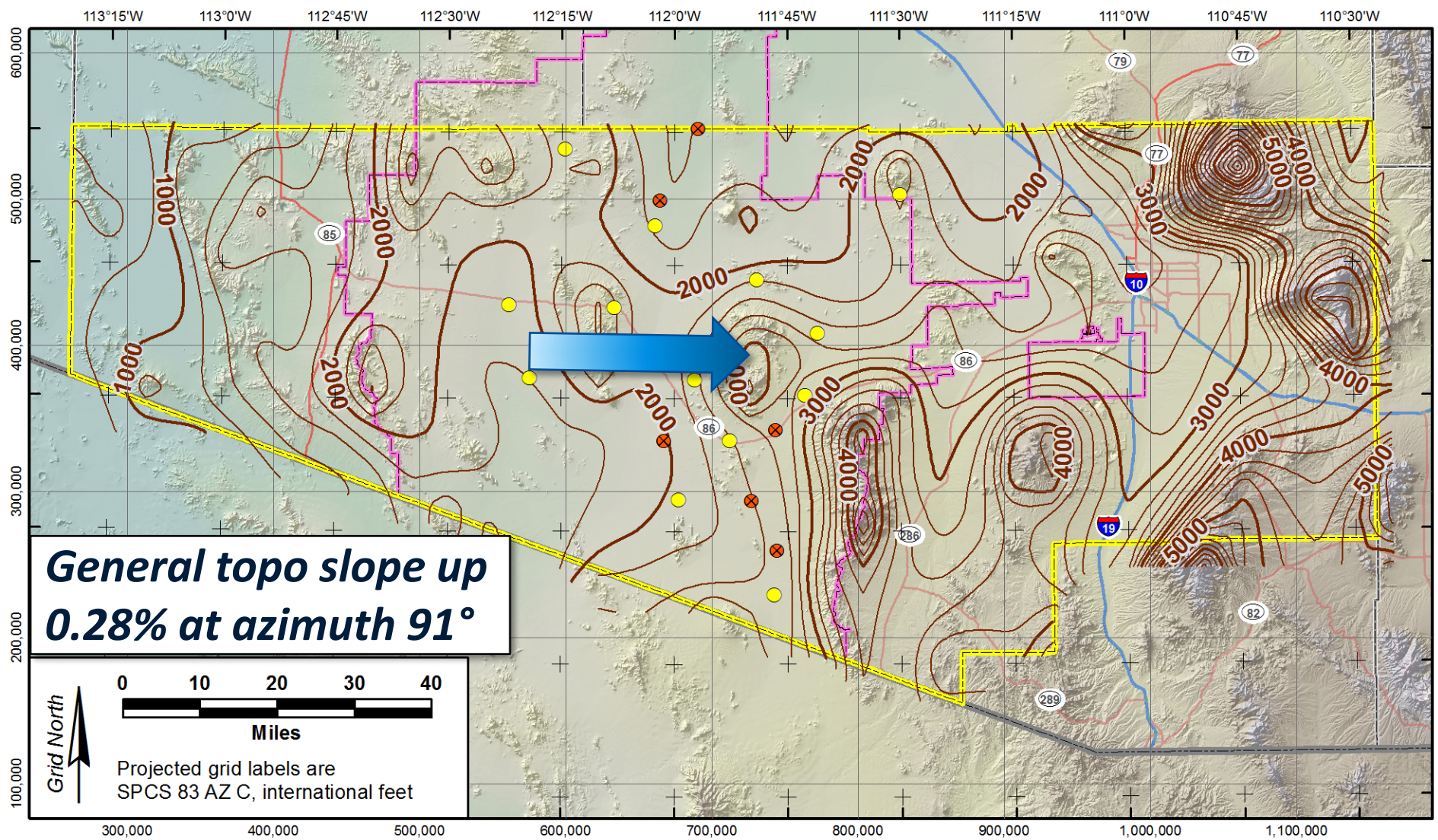



Mean = -2 ppm
Range = 26 ppm
Stdev = ±10 ppm
Pima County Low Distortion Projection Coordinate System
West Zone
Design alternative 2
Design points
Used
Not used
Linear distortion (parts per million)
<-100 ppm (<-0.5 ft/mi)
-80 to -100 ppm
-60 to -80 ppm
-40 to -60 ppm
-20 to -40 ppm
±20 ppm (±0.1 ft/mi)
+20 to +40 ppm
+40 to +60 ppm
+60 to +80 ppm
+80 to +100 ppm
>+100 ppm (>+0.5 ft/mi)
Zero distortion
Transverse Mercator projection
Central meridian: 113°05'00"W
Cen merid scale: 1.000 060
Projected grid labels are
SPCS 83 AZ C, international feet
Grid North
0 5 10 15 20
Miles
Central Meridian 113° 05' 00" W
Childs
Ajo
Why
Charco
Lukeville
Ali Chuk
85
86
286
289
113°15'W
113°0'W
112°45'W
112°30'W
112°15'W
112°0'W
111°45'W
111°30'W
32°30'N
32°15'N
32°0'N
31°45'N
31°30'N
500,000
400,000
300,000
200,000
300,000
400,000
500,000
600,000
700,000
800,000


Mean = 0 ppm
Range = 32 ppm
Stdev = ±11 ppm
Pima County Low Distortion Projection Coordinate System
West Zone
Design alternative 3
Design points
Used
Not used
Linear distortion (parts per million)
<-100 ppm (<-0.5 ft/mi)
-80 to -100 ppm
-60 to -80 ppm
-40 to -60 ppm
-20 to -40 ppm
±20 ppm (±0.1 ft/mi)
+20 to +40 ppm
+40 to +60 ppm
+60 to +80 ppm
+80 to +100 ppm
>+100 ppm (>+0.5 ft/mi)
Zero distortion
Transverse Mercator projection
Central meridian: 113°10'00"W
Cen merid scale: 1.000 055
Projected grid labels are
SPCS 83 AZ C, international feet
Grid North
0 5 10 15 20
Miles
Central Meridian
113° 10' 00" W
Childs
Ajo
Why
Charco
Lukeville
Ali Chuk
85
86
286
289
113°15'W
113°0'W
112°45'W
112°30'W
112°15'W
112°0'W
111°45'W
111°30'W
32°30'N
32°15'N
32°0'N
31°45'N
31°30'N
500,000
400,000
300,000
200,000
300,000
400,000
500,000
600,000
700,000
800,000

Pima County LDP Design Alternatives
Central Zone

- 13 design points
  - Topo height 1710-2750 ft (range = 1040 ft)
  - Zone width ~60 miles (E-W)
- Implied distortion
  - 50 ppm range due to height
  - ±7 ppm due to curvature
- 4 design alternatives
  - All are Transverse Mercator projections
  - Two best ones shown here
  - Final selected is ***alternative 4***
    - Lower distortion especially in southwest area
    - Larger area of overall zone within 20 ppm distortion
    - Selection best matches choice for East Zone (alternative 3)



Pima County Low Distortion Projection Coordinate System

Topographic ellipsoid height

Generalized to 5 arc-minute grid to show overall trends. Contours are labeled in feet.

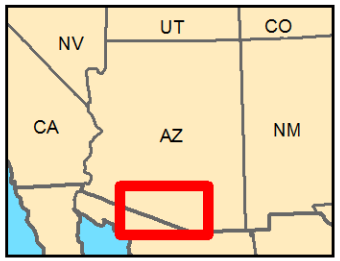
Generalized topographic ellipsoid height

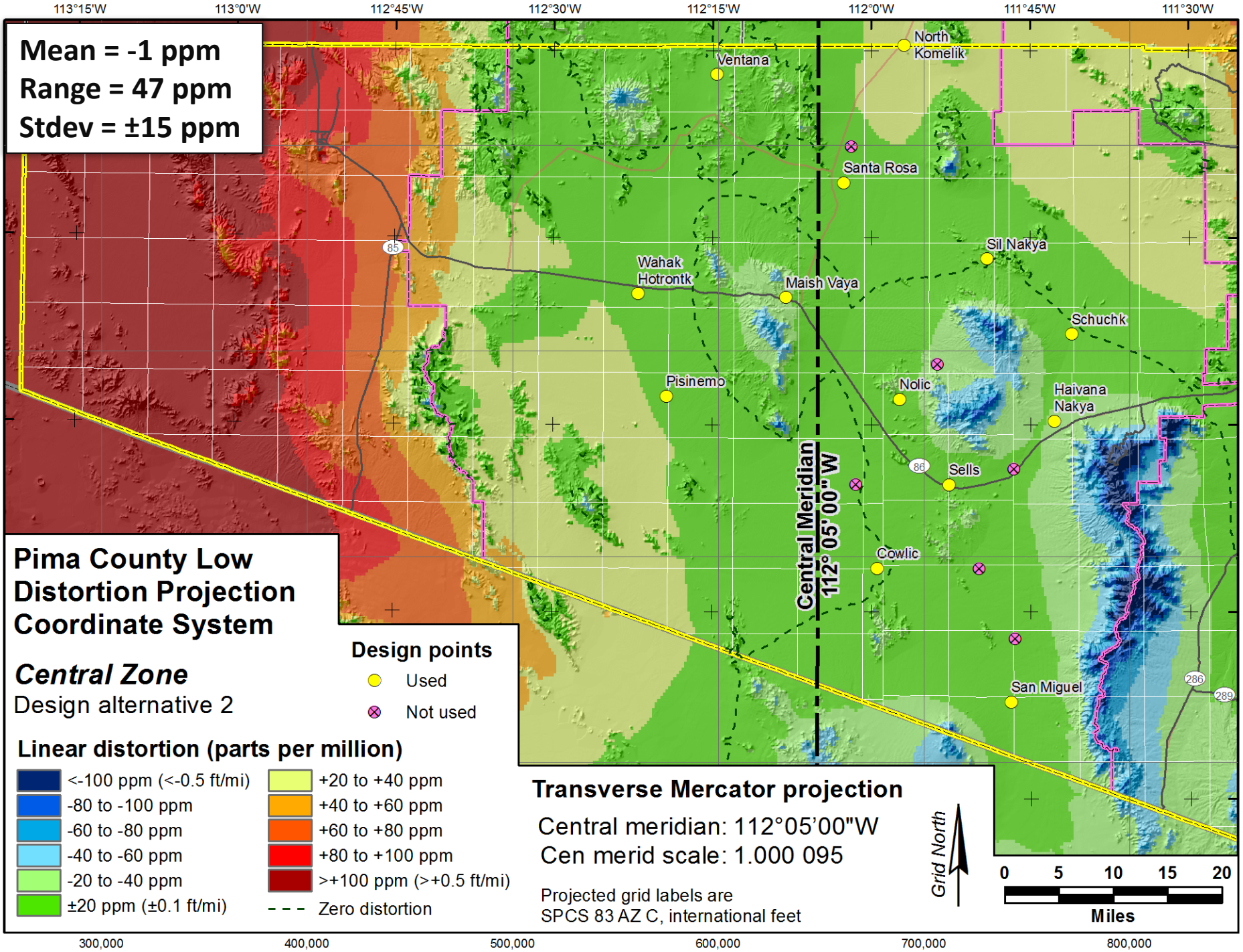
- Index contour (1000 ft)
- Intermediate contour (200 ft)

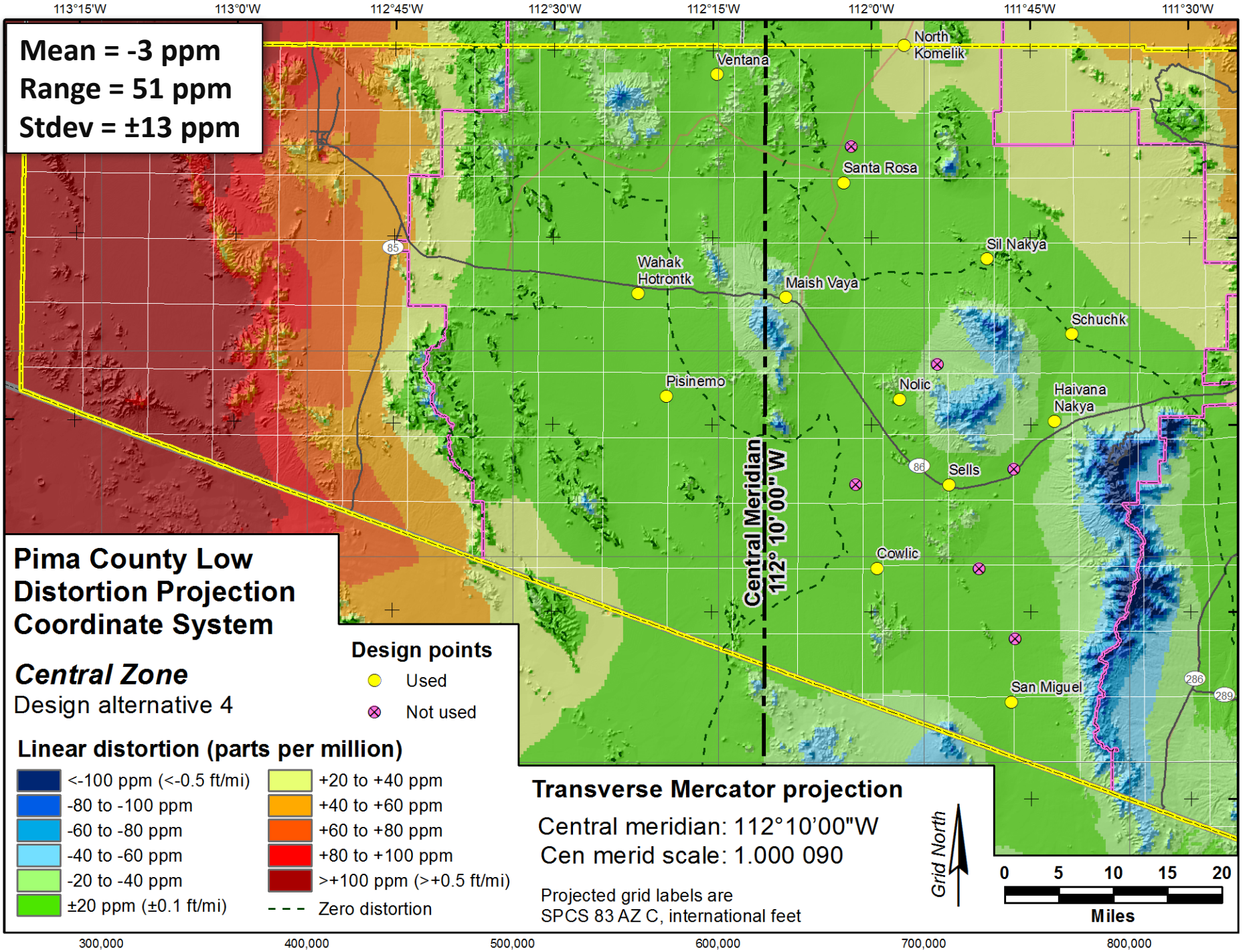
Design points

- Used
- Not used

Vicinity map

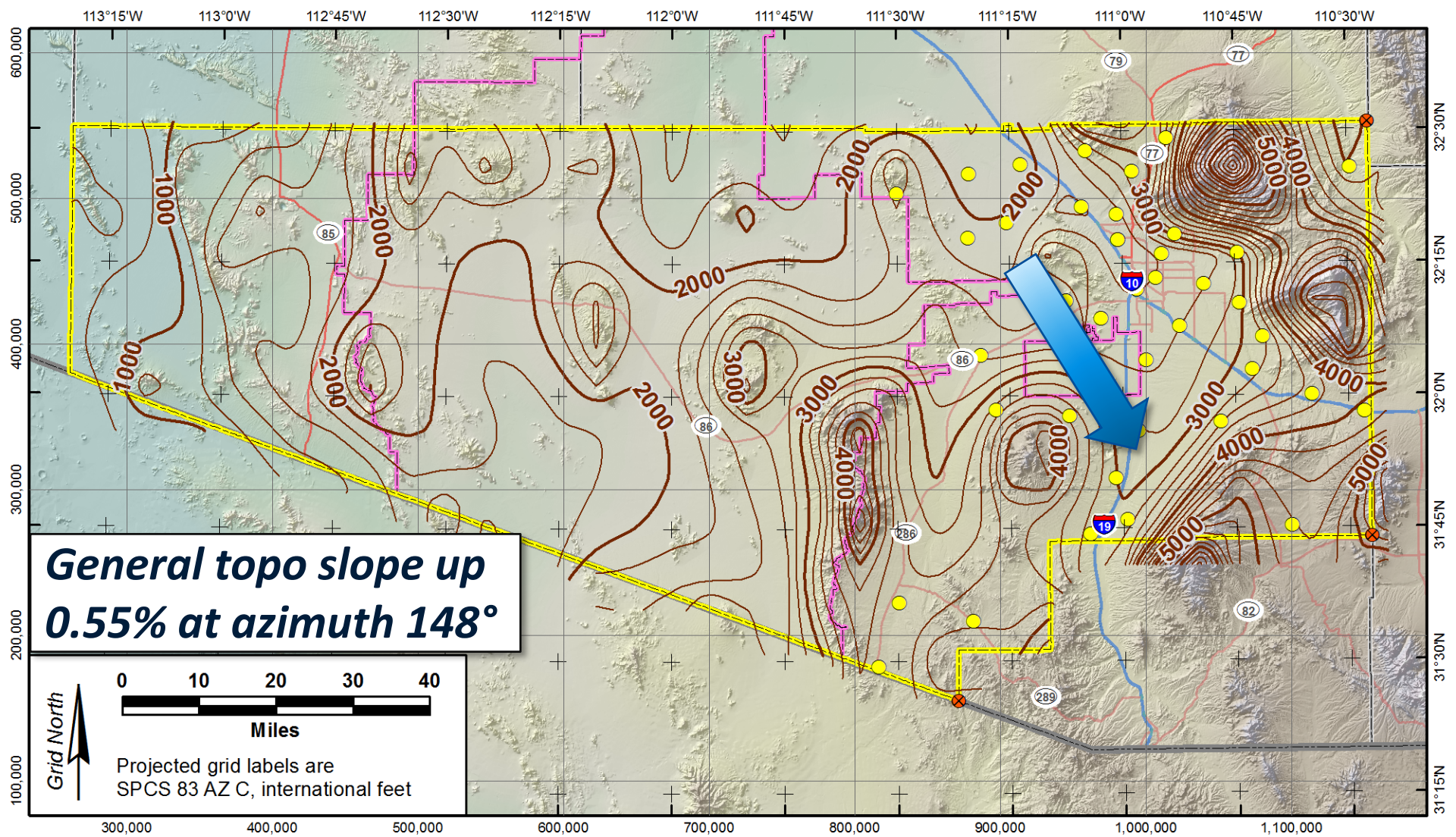



Mean = -1 ppm
Range = 47 ppm
Stdev = ±15 ppm
Pima County Low Distortion Projection Coordinate System
Central Zone
Design alternative 2
Design points
Used
Not used
Linear distortion (parts per million)
<-100 ppm (<-0.5 ft/mi)
-80 to -100 ppm
-60 to -80 ppm
-40 to -60 ppm
-20 to -40 ppm
±20 ppm (±0.1 ft/mi)
+20 to +40 ppm
+40 to +60 ppm
+60 to +80 ppm
+80 to +100 ppm
>+100 ppm (>+0.5 ft/mi)
Zero distortion
Transverse Mercator projection
Central meridian: 112°05'00"W
Cen merid scale: 1.000 095
Projected grid labels are
SPCS 83 AZ C, international feet
Grid North
0 5 10 15 20
Miles
Central Meridian
112° 05' 00" W
North Komelik
Ventana
Santa Rosa
Sil Nakya
Wahak Hotrontk
Maish Vaya
Schuchk
Pisinemo
Nolic
Haivana Nakya
Sells
Cowlic
San Miguel
85
86
286
289
113°15'W
113°0'W
112°45'W
112°30'W
112°15'W
112°0'W
111°45'W
111°30'W
32°30'N
32°15'N
32°0'N
31°45'N
31°30'N
500,000
400,000
300,000
200,000
300,000
400,000
500,000
600,000
700,000
800,000


Mean = -3 ppm
Range = 51 ppm
Stdev = ±13 ppm
Pima County Low Distortion Projection Coordinate System
Central Zone
Design alternative 4
Design points
Used
Not used
Linear distortion (parts per million)
<-100 ppm (<-0.5 ft/mi)
-80 to -100 ppm
-60 to -80 ppm
-40 to -60 ppm
-20 to -40 ppm
±20 ppm (±0.1 ft/mi)
+20 to +40 ppm
+40 to +60 ppm
+60 to +80 ppm
+80 to +100 ppm
>+100 ppm (>+0.5 ft/mi)
Zero distortion
Transverse Mercator projection
Central meridian: 112°10'00"W
Cen merid scale: 1.000 090
Projected grid labels are
SPCS 83 AZ C, international feet
Grid North
0 5 10 15 20
Miles
Central Meridian
112° 10' 00" W
Ventana
North Komelik
Santa Rosa
Sil Nakya
Wahak Hotrontk
Maish Vaya
Schuchk
Pisinemo
Nolic
Haivana Nakya
Sells
Cowlic
San Miguel
85
86
286
289
113°15'W
113°0'W
112°45'W
112°30'W
112°15'W
112°0'W
111°45'W
111°30'W
32°30'N
32°15'N
32°0'N
31°45'N
31°30'N
500,000
400,000
300,000
200,000
300,000
400,000
500,000
600,000
700,000
800,000

Pima County LDP Design Alternatives
East Zone

- 41 design points
  - Topo height 1840-4500 ft (range = 2660 ft)
  - Zone width ~70 miles (NW-SE)
- Implied distortion
  - 128 ppm range due to height
  - ±20 ppm due to curvature
- 7 design alternatives
  - 2 preliminary TM designs, 5 new OM designs
  - Two best ones shown here
  - Final selected is ***alternative 7***
    - Lower distortion in areas with higher population and development
    - Larger area of overall zone within 20 ppm distortion



Pima County Low Distortion Projection Coordinate System

Topographic ellipsoid height

Generalized to 5 arc-minute grid to show overall trends. Contours are labeled in feet.

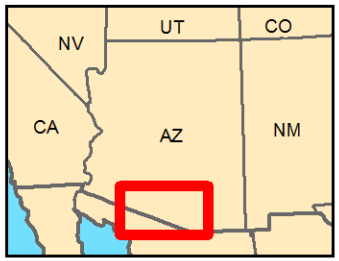
Generalized topographic ellipsoid height

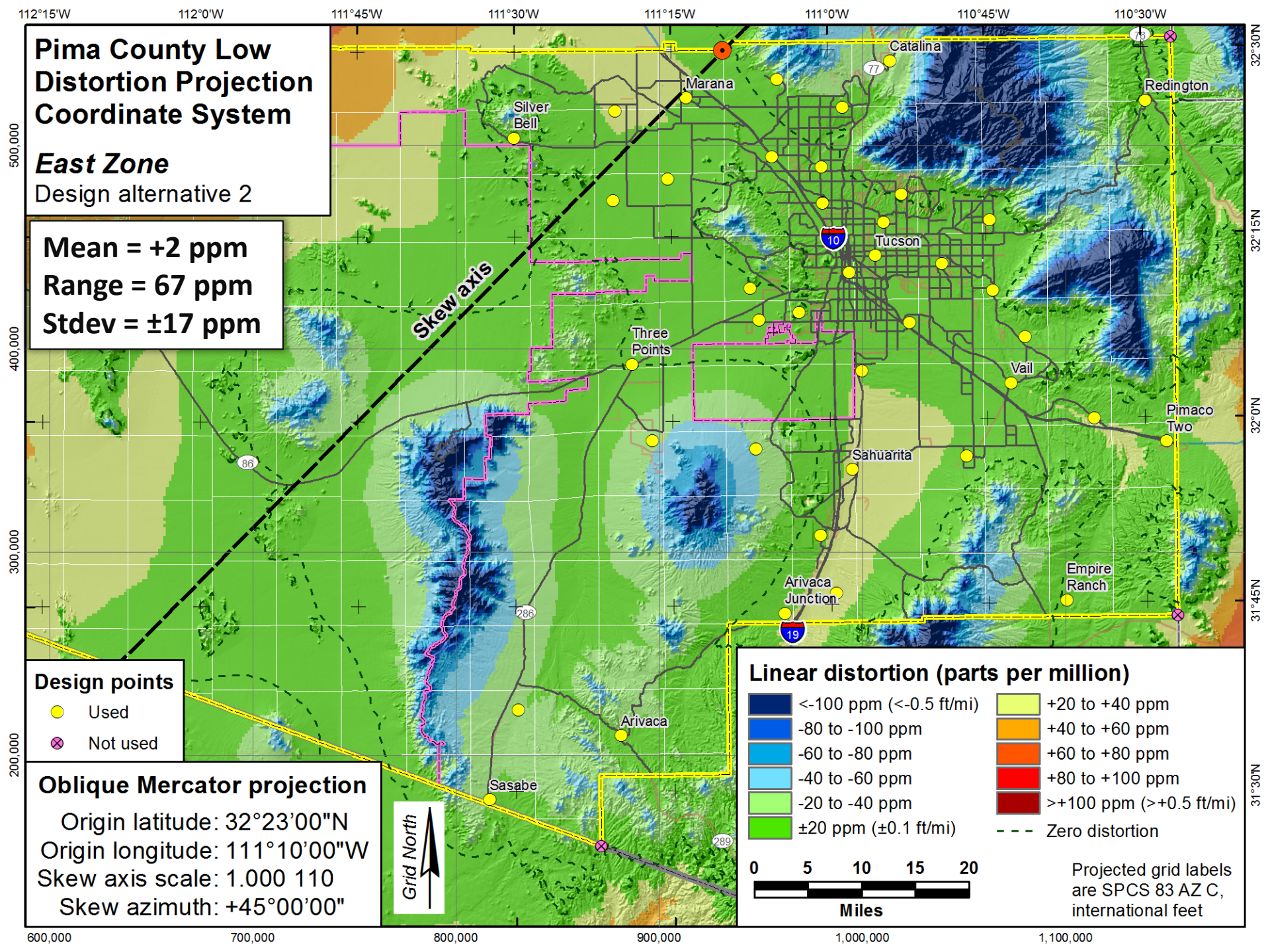
- Index contour (1000 ft)
- Intermediate contour (200 ft)

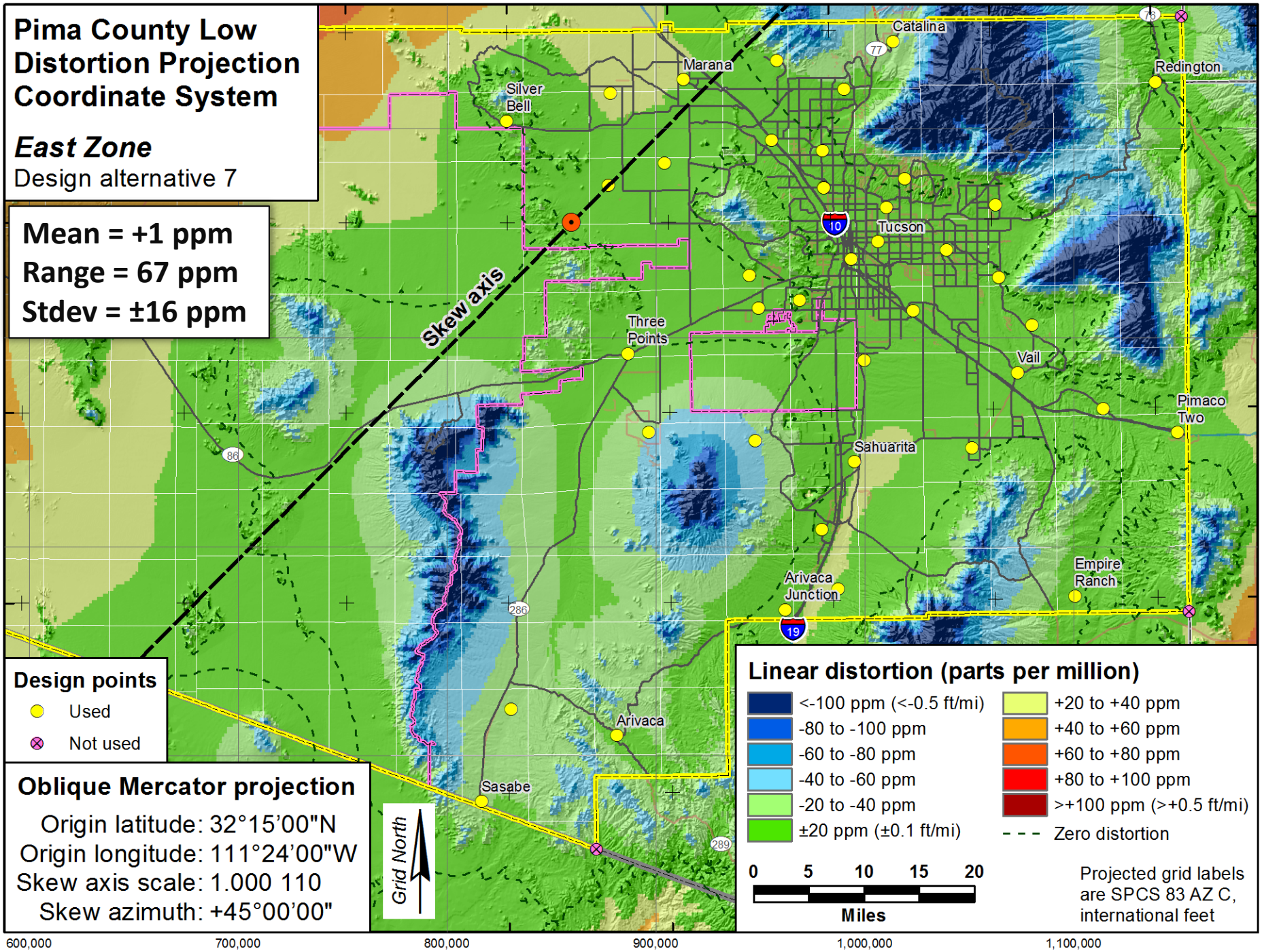
Design points

- Used
- Not used

Vicinity map

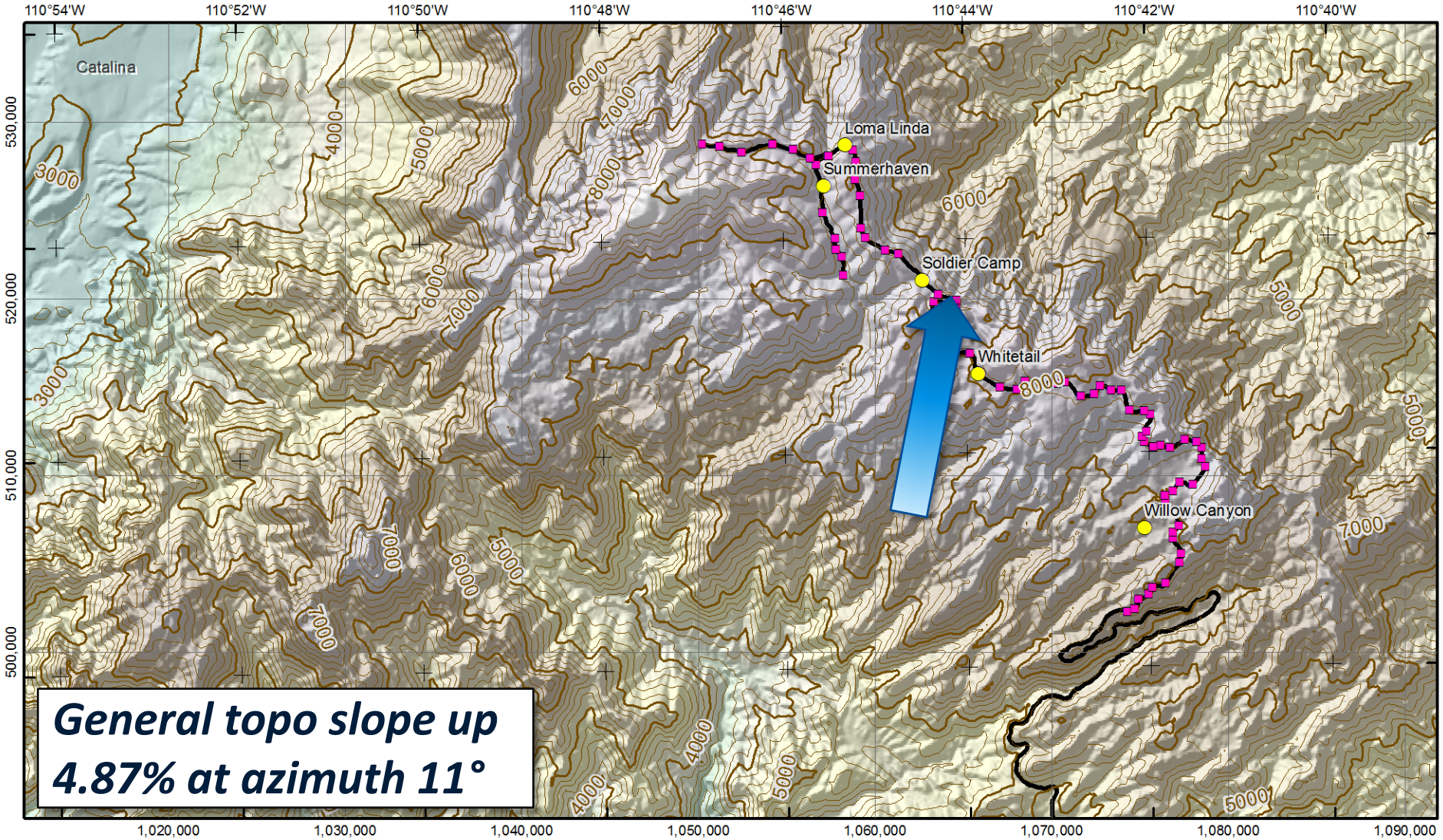



Pima County Low Distortion Projection Coordinate System
East Zone
Design alternative 2
Mean = +2 ppm
Range = 67 ppm
Stdev = ±17 ppm
Skew axis
Design points
Used
Not used
Oblique Mercator projection
Origin latitude: 32°23'00"N
Origin longitude: 111°10'00"W
Skew axis scale: 1.000 110
Skew azimuth: +45°00'00"
Grid North
Linear distortion (parts per million)
<-100 ppm (<-0.5 ft/mi)
-80 to -100 ppm
-60 to -80 ppm
-40 to -60 ppm
-20 to -40 ppm
±20 ppm (±0.1 ft/mi)
+20 to +40 ppm
+40 to +60 ppm
+60 to +80 ppm
+80 to +100 ppm
>+100 ppm (>+0.5 ft/mi)
Zero distortion
0 5 10 15 20
Miles
Projected grid labels are SPCS 83 AZ C, international feet
Catalina
Marana
Redington
Silver Bell
Tucson
Three Points
Vail
Pimaco Two
Sahuarita
Empire Ranch
Arivaca Junction
Arivaca
Sasabe
112°15'W
112°0'W
111°45'W
111°30'W
111°15'W
111°0'W
110°45'W
110°30'W
32°30'N
32°15'N
32°0'N
31°45'N
31°30'N
500,000
400,000
300,000
200,000
600,000
700,000
800,000
900,000
1,000,000
1,100,000


Pima County Low Distortion Projection Coordinate System
East Zone
Design alternative 7
Mean = +1 ppm
Range = 67 ppm
Stdev = ±16 ppm
Skew axis
Catalina
Marana
Redington
Silver Bell
Tucson
Three Points
Vail
Pimaco Two
Sahuarita
Empire Ranch
Arivaca Junction
Arivaca
Sasabe
Design points
Used
Not used
Oblique Mercator projection
Origin latitude: 32°15'00"N
Origin longitude: 111°24'00"W
Skew axis scale: 1.000 110
Skew azimuth: +45°00'00"
Grid North
Linear distortion (parts per million)
<-100 ppm (<-0.5 ft/mi)
-80 to -100 ppm
-60 to -80 ppm
-40 to -60 ppm
-20 to -40 ppm
±20 ppm (±0.1 ft/mi)
+20 to +40 ppm
+40 to +60 ppm
+60 to +80 ppm
+80 to +100 ppm
>+100 ppm (>+0.5 ft/mi)
Zero distortion
0 5 10 15 20
Miles
Projected grid labels are SPCS 83 AZ C, international feet
112°15'W
112°0'W
111°45'W
111°30'W
111°15'W
111°0'W
110°45'W
110°30'W
32°30'N
32°15'N
32°0'N
31°45'N
31°30'N
500,000
400,000
300,000
200,000
600,000
700,000
800,000
900,000
1,000,000
1,100,000

Pima County LDP Design Alternatives
Mount Lemon Zone

- 81 design points
  - 5 points of interest + 76 on road
  - Topo height 6710-8270 ft (range = 1560 ft)
  - Zone width ~5 miles (N-S)
- Implied distortion
  - 75 ppm range due to height
  - 0 ppm due to curvature (negligible)
- 2 design alternatives (both shown)
  - Both Lambert Conformal Conic projection
  - Identical except alternative 2 scale decreased by 5 ppm
  - Final selected is ***alternative 2***
    - Reduces distortion in Willow Canyon to < 20 ppm
    - Cleaner definition (scale = 0.999805 for alt 1 versus 0.9998 for alt 2)



Pima County Low Distortion Projection Coordinate System

Mount Lemmon Zone

Ellipsoid height of topography

Topographic ellipsoid height

- Index contour (1000 ft)
- Intermediate contour (200 ft)

Design points

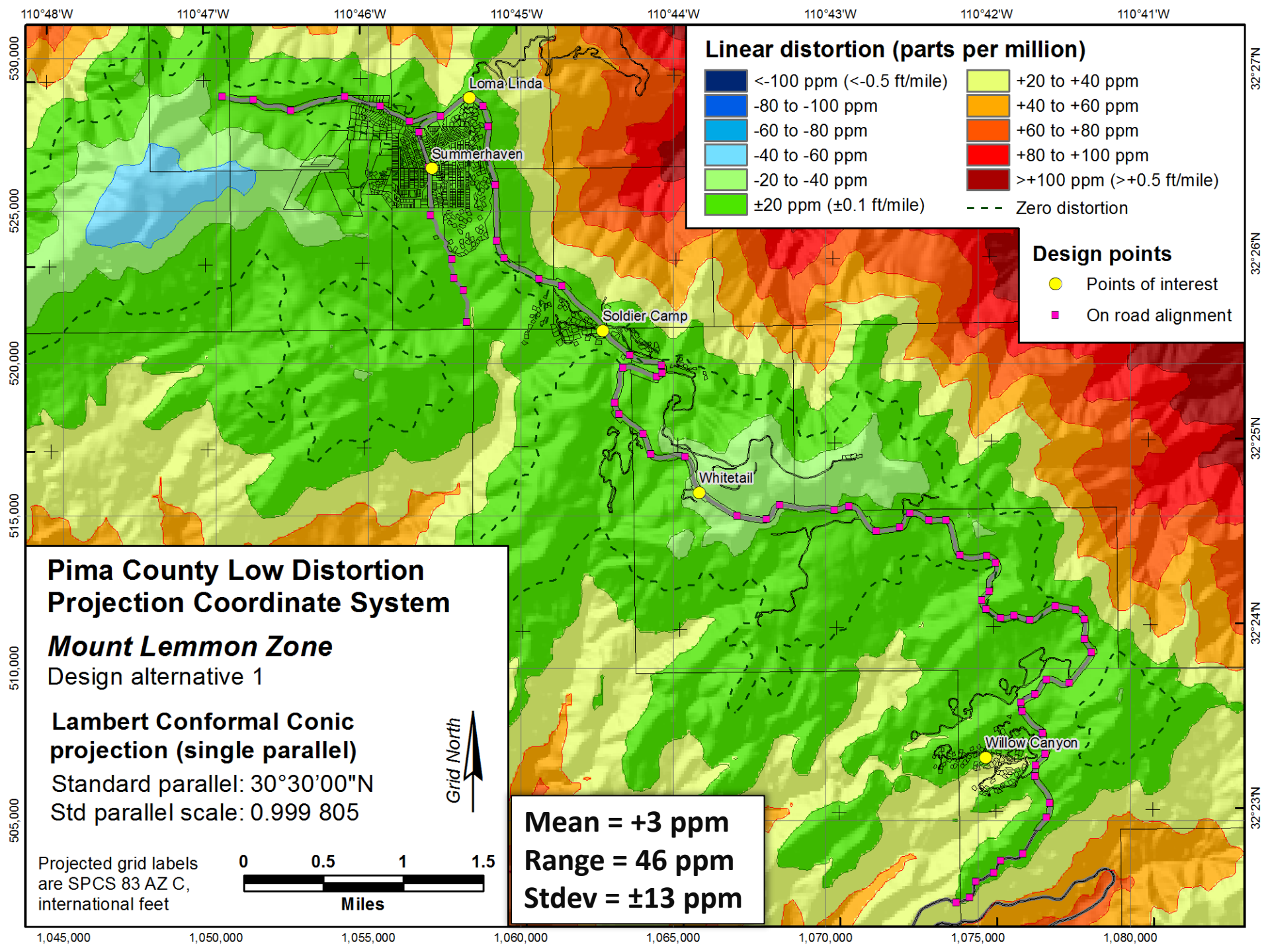
- Points of interest
- On road alignment

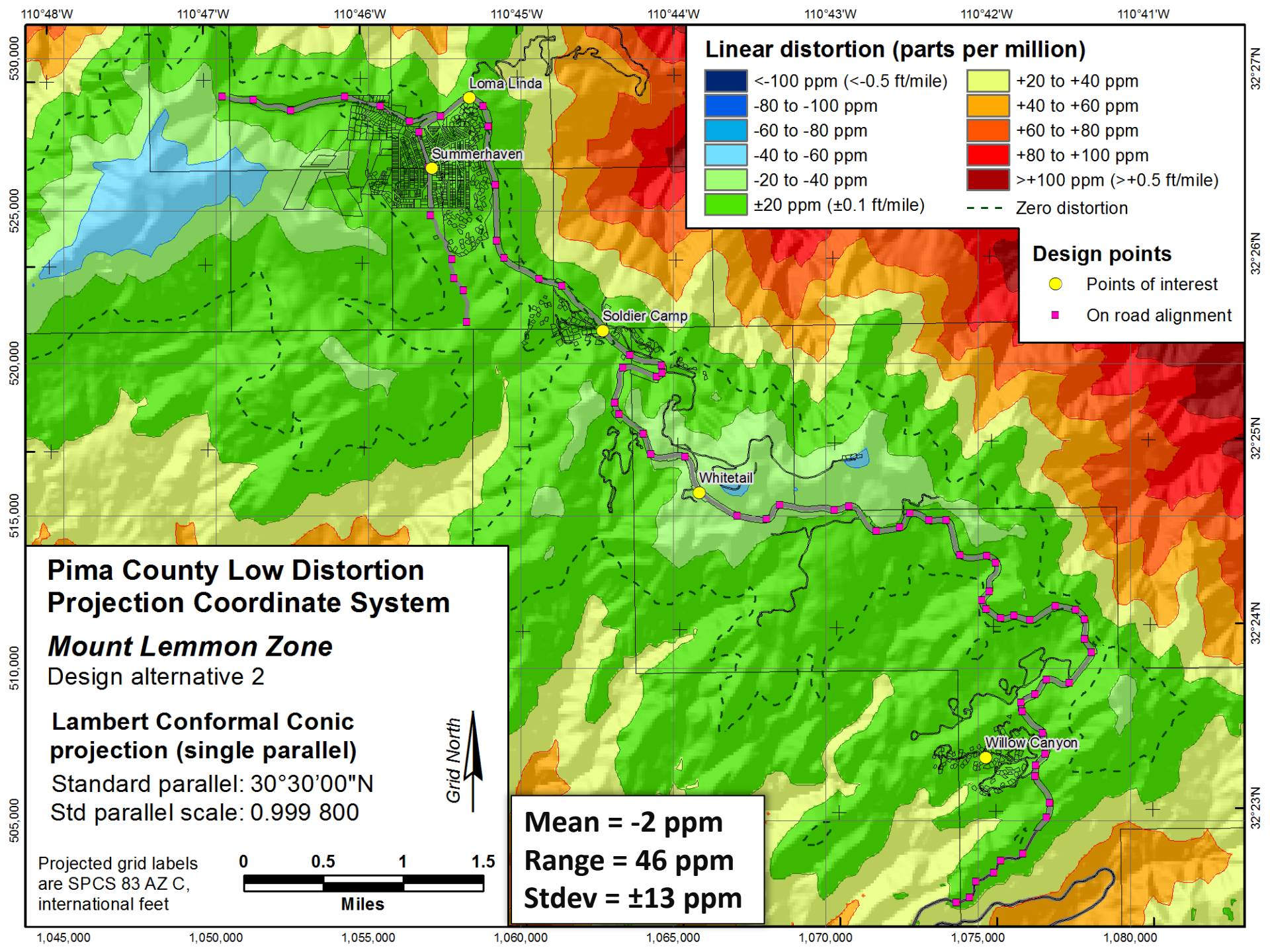
0 1 2 3

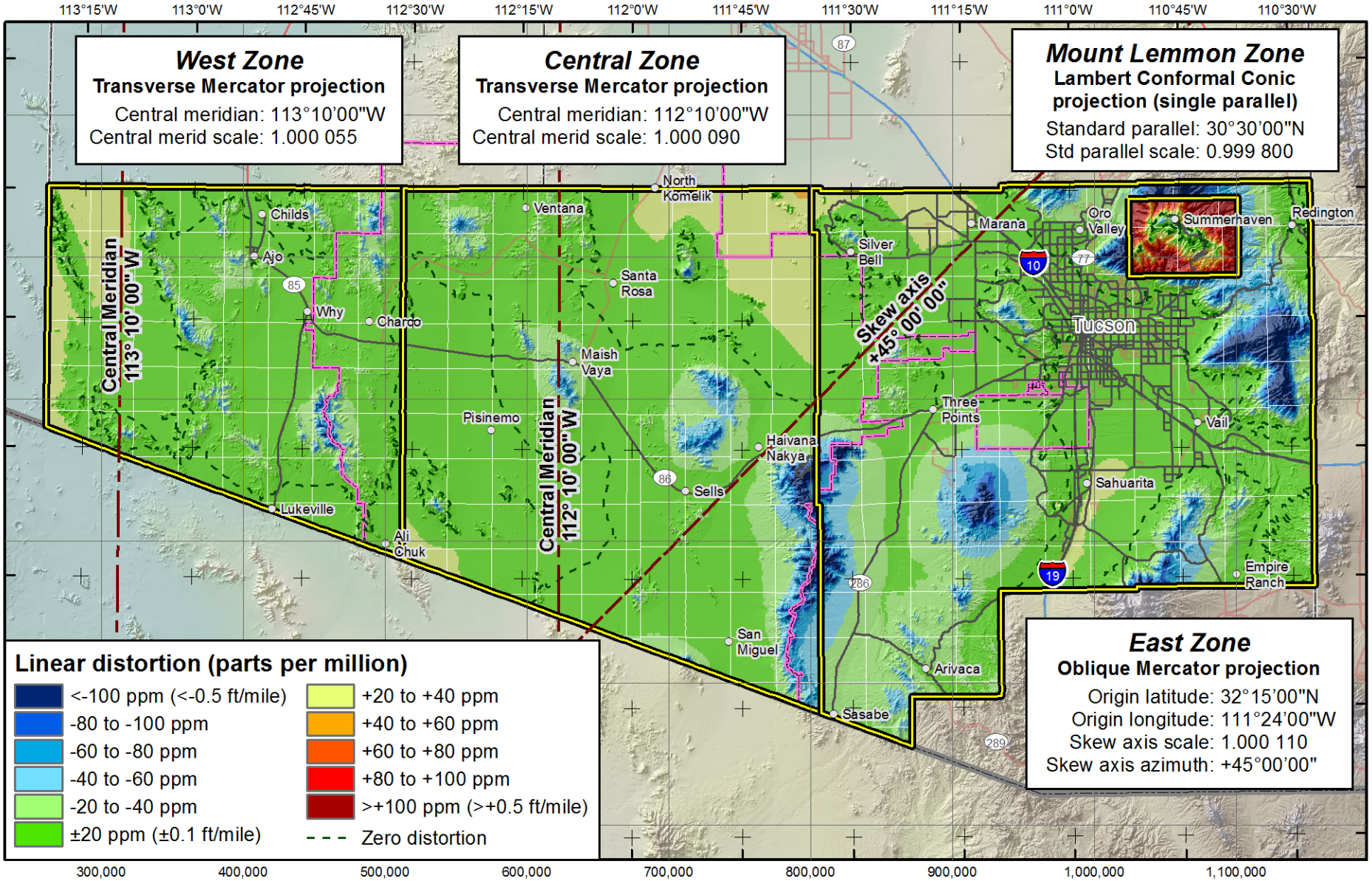
Miles

Grid North

Projected grid labels are SPCS 83 AZ C, international feet


Linear distortion (parts per million)
<-100 ppm (<-0.5 ft/mile)
-80 to -100 ppm
-60 to -80 ppm
-40 to -60 ppm
-20 to -40 ppm
±20 ppm (±0.1 ft/mile)
+20 to +40 ppm
+40 to +60 ppm
+60 to +80 ppm
+80 to +100 ppm
>+100 ppm (>+0.5 ft/mile)
Zero distortion
Design points
Points of interest
On road alignment
Loma Linda
Summerhaven
Soldier Camp
Whitetail
Willow Canyon
Pima County Low Distortion Projection Coordinate System
Mount Lemmon Zone
Design alternative 1
Lambert Conformal Conic projection (single parallel)
Standard parallel: 30°30'00"N
Std parallel scale: 0.999 805
Grid North
Projected grid labels are SPCS 83 AZ C, international feet
0 0.5 1 1.5
Miles
Mean = +3 ppm
Range = 46 ppm
Stdev = ±13 ppm
110°48'W
110°47'W
110°46'W
110°45'W
110°44'W
110°43'W
110°42'W
110°41'W
32°27'N
32°26'N
32°25'N
32°24'N
32°23'N
530,000
525,000
520,000
515,000
510,000
505,000
1,045,000
1,050,000
1,055,000
1,060,000
1,065,000
1,070,000
1,075,000
1,080,000


Linear distortion (parts per million)
<-100 ppm (<-0.5 ft/mile)
-80 to -100 ppm
-60 to -80 ppm
-40 to -60 ppm
-20 to -40 ppm
±20 ppm (±0.1 ft/mile)
+20 to +40 ppm
+40 to +60 ppm
+60 to +80 ppm
+80 to +100 ppm
>+100 ppm (>+0.5 ft/mile)
Zero distortion
Design points
Points of interest
On road alignment
Loma Linda
Summerhaven
Soldier Camp
Whitetail
Willow Canyon
Pima County Low Distortion Projection Coordinate System
Mount Lemmon Zone
Design alternative 2
Lambert Conformal Conic projection (single parallel)
Standard parallel: 30°30'00"N
Std parallel scale: 0.999 800
Grid North
Projected grid labels are SPCS 83 AZ C, international feet
0 0.5 1 1.5
Miles
Mean = -2 ppm
Range = 46 ppm
Stdev = ±13 ppm
110°48'W
110°47'W
110°46'W
110°45'W
110°44'W
110°43'W
110°42'W
110°41'W
530,000
525,000
520,000
515,000
510,000
505,000
32°27'N
32°26'N
32°25'N
32°24'N
32°23'N
1,045,000
1,050,000
1,055,000
1,060,000
1,065,000
1,070,000
1,075,000
1,080,000



Pima County Low Distortion Projection Coordinate System

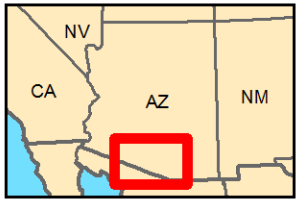
All zones (large zones clipped to townships)

Combined design alternative 1

0 10 20 30
Miles

Grid North

Projected grid labels are SPCS 83 AZ C, international feet



Pima County Coordinate System

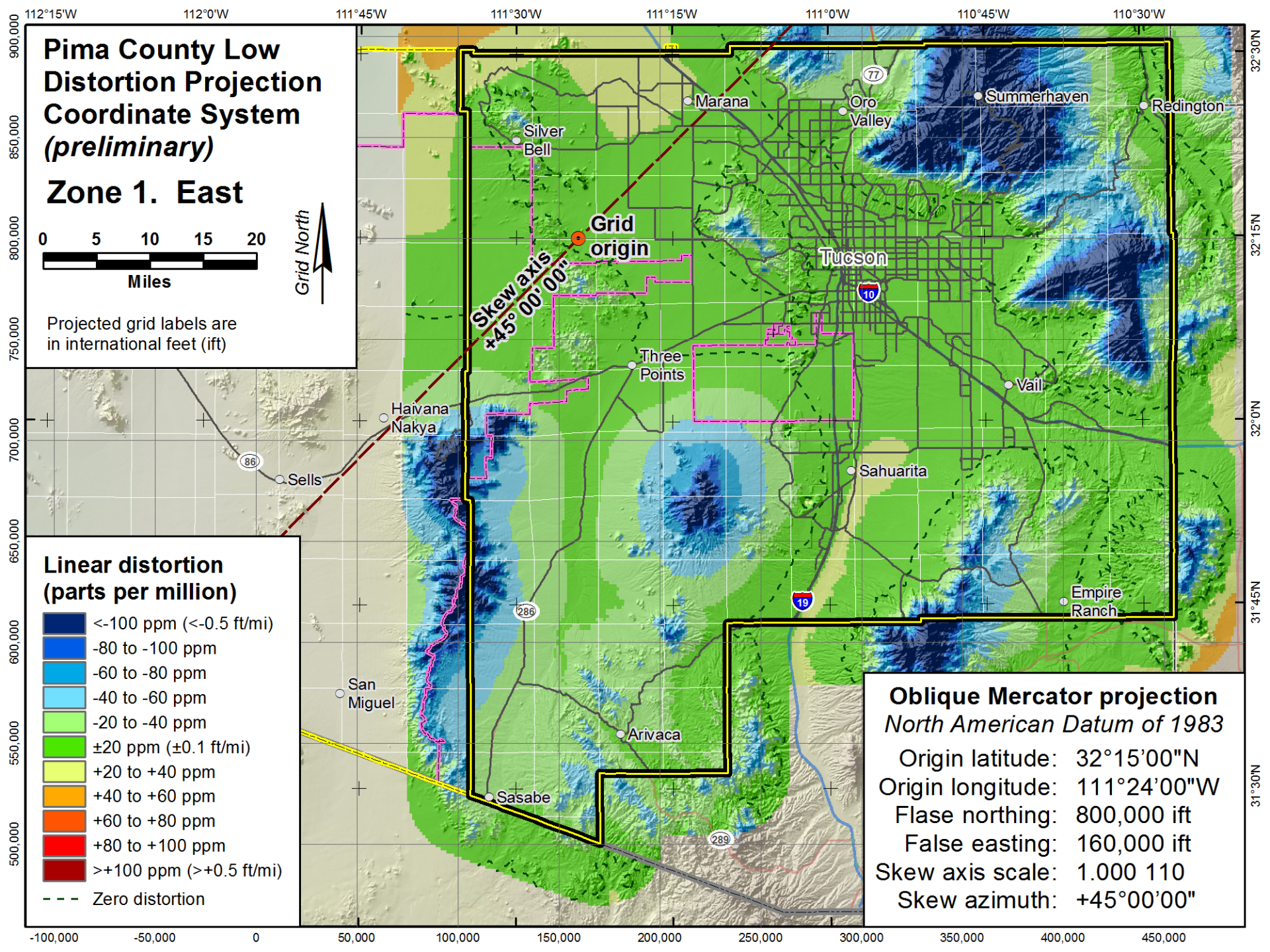
Approximate coordinate ranges in each zone (intern'l feet)

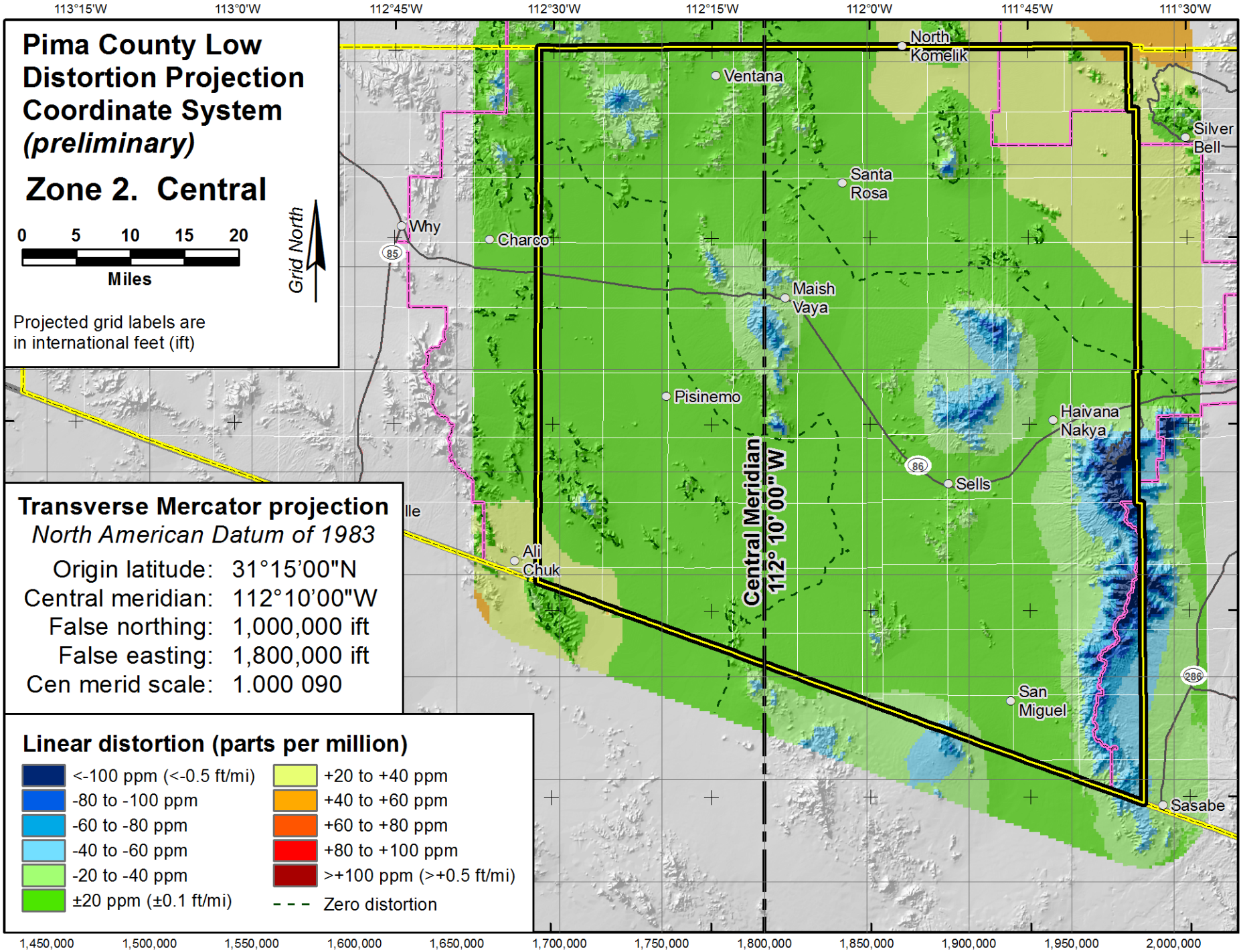
- Zone 1 (East)
  - Range N-S: 500,000 to 900,000
  - Range E-W: 100,000 to 500,000
- Zone 2 (Central)
  - Range N-S: 1,000,000 to 1,500,000
  - Range E-W: 1,700,000 to 2,000,000
- Zone 3 (West)
  - Range N-S: 100,000 to 400,000
  - Range E-W: 500,000 to 800,000
- Zone 4 (Mount Lemmon)
  - Range N-S: 60,000 to 90,000
  - Range E-W: 10,000 to 50,000

Pima County Coordinate System

Magnitude of coordinate differences with other systems

- State Plane 1983, AZ C (international feet)
  - Range N-S: 180,000 to 910,000
  - Range E-W: 290,000 to 1,180,000
- State Plane 1927, AZ C (US survey feet)
  - Range N-S: 180,000 to 910,000
  - Range E-W: 490,000 to 1,380,000
- UTM 83, Zone 12N (international feet)
  - Range N-S: 10,340,000 to 11,690,000
  - Range E-W: 370,000 to 1,690,000
- UTM 83, Zone 12N (meters)
  - Range N-S: 2,250,000 to 3,510,000
  - Range E-W: 230,000 to 1,440,000


Pima County Low Distortion Projection Coordinate System (preliminary)
Zone 1. East
0 5 10 15 20
Miles
Grid North
Projected grid labels are in international feet (ift)
Grid origin
Skew axis +45° 00' 00"
Linear distortion (parts per million)
<-100 ppm (<-0.5 ft/mi)
-80 to -100 ppm
-60 to -80 ppm
-40 to -60 ppm
-20 to -40 ppm
±20 ppm (±0.1 ft/mi)
+20 to +40 ppm
+40 to +60 ppm
+60 to +80 ppm
+80 to +100 ppm
>+100 ppm (>+0.5 ft/mi)
Zero distortion
Oblique Mercator projection
North American Datum of 1983
Origin latitude: 32°15'00"N
Origin longitude: 111°24'00"W
Flase northing: 800,000 ift
False easting: 160,000 ift
Skew axis scale: 1.000 110
Skew azimuth: +45°00'00"
Marana
Oro Valley
Summerhaven
Redington
Silver Bell
Tucson
Three Points
Vail
Haivana Nakya
Sells
Sahuarita
Empire Ranch
San Miguel
Arivaca
Sasabe
112°15'W
112°0'W
111°45'W
111°30'W
111°15'W
111°0'W
110°45'W
110°30'W
32°30'N
32°15'N
32°0'N
31°45'N
31°30'N
900,000
850,000
800,000
750,000
700,000
650,000
600,000
550,000
500,000
-100,000
-50,000
0
50,000
100,000
150,000
200,000
250,000
300,000
350,000
400,000
450,000


Pima County Low Distortion Projection Coordinate System (preliminary)
Zone 2. Central
0 5 10 15 20
Miles
Grid North
Projected grid labels are in international feet (ift)
Transverse Mercator projection
North American Datum of 1983
Origin latitude: 31°15'00"N
Central meridian: 112°10'00"W
False northing: 1,000,000 ift
False easting: 1,800,000 ift
Cen merid scale: 1.000 090
Linear distortion (parts per million)
<-100 ppm (<-0.5 ft/mi)
-80 to -100 ppm
-60 to -80 ppm
-40 to -60 ppm
-20 to -40 ppm
±20 ppm (±0.1 ft/mi)
+20 to +40 ppm
+40 to +60 ppm
+60 to +80 ppm
+80 to +100 ppm
>+100 ppm (>+0.5 ft/mi)
Zero distortion
Central Meridian 112° 10' 00" W
North Komelik
Ventana
Silver Bell
Santa Rosa
Why
Charco
Maish Vaya
Pisinemo
Haivana Nakya
Sells
Ali Chuk
San Miguel
Sasabe
113°15'W
113°0'W
112°45'W
112°30'W
112°15'W
112°0'W
111°45'W
111°30'W
32°30'N
32°15'N
32°0'N
31°45'N
31°30'N
1,450,000
1,400,000
1,350,000
1,300,000
1,250,000
1,200,000
1,150,000
1,100,000
1,050,000
1,500,000
1,550,000
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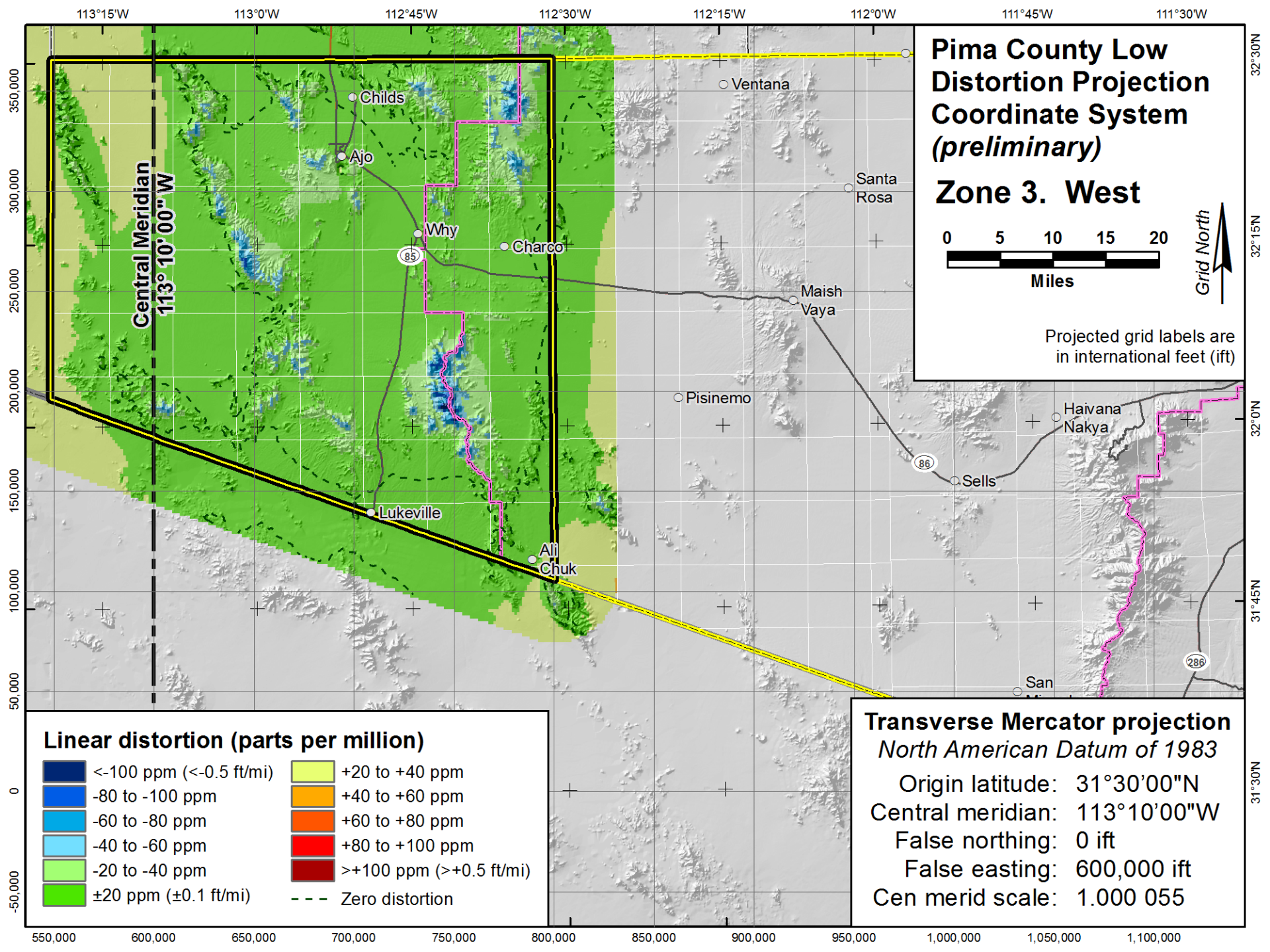
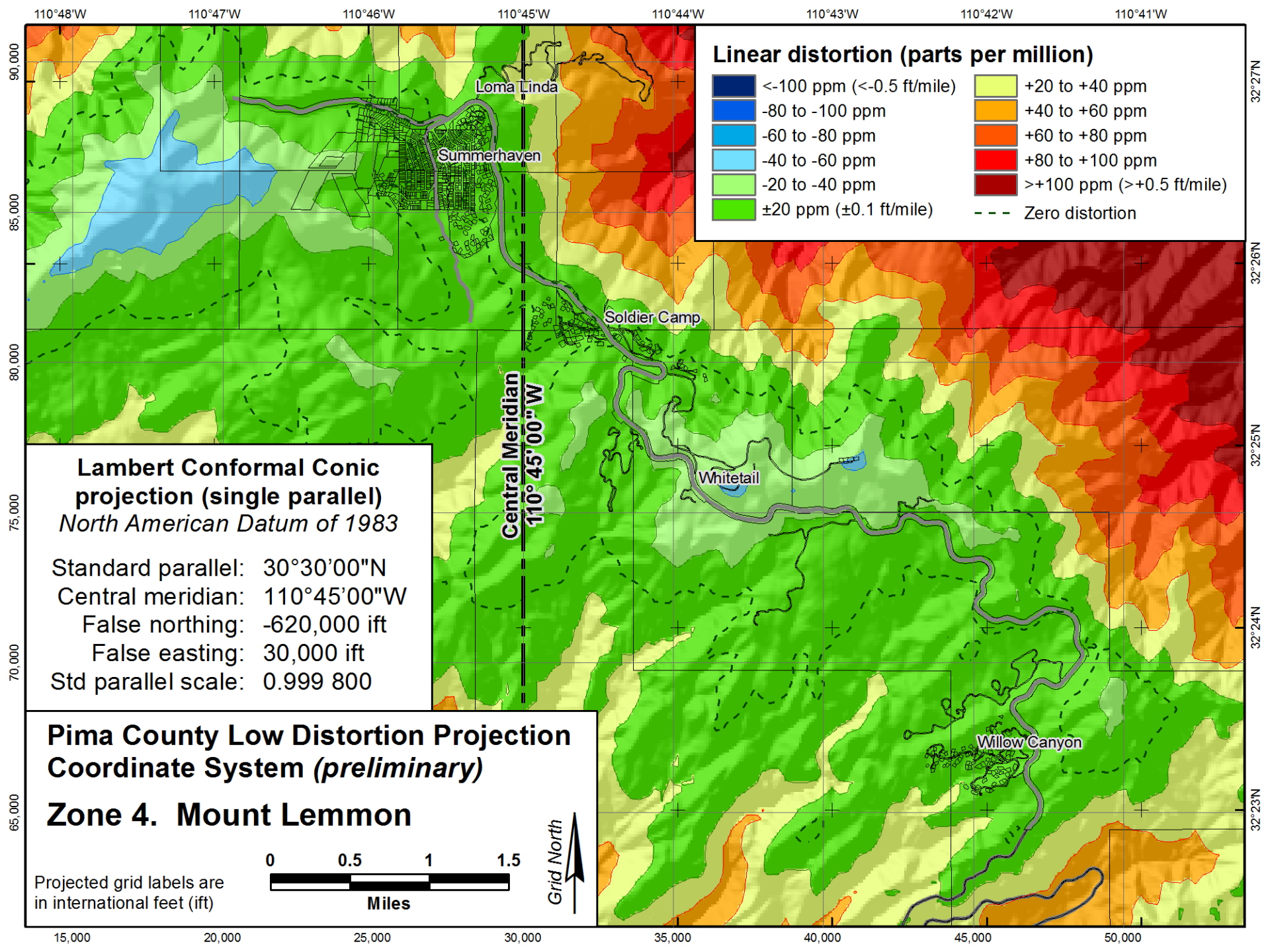
1,900,000
1,950,000
2,000,000


Pima County Low Distortion Projection Coordinate System (preliminary)
Zone 3. West
0 5 10 15 20
Miles
Grid North
Projected grid labels are in international feet (ift)
Central Meridian 113° 10' 00" W
Childs
Ajo
Why
Charco
Ventana
Santa Rosa
Maish Vaya
Pisinemo
Haivana Nakya
Sells
Lukeville
Ali Chuk
San
Linear distortion (parts per million)
<-100 ppm (<-0.5 ft/mi)
-80 to -100 ppm
-60 to -80 ppm
-40 to -60 ppm
-20 to -40 ppm
±20 ppm (±0.1 ft/mi)
+20 to +40 ppm
+40 to +60 ppm
+60 to +80 ppm
+80 to +100 ppm
>+100 ppm (>+0.5 ft/mi)
Zero distortion
Transverse Mercator projection
North American Datum of 1983
Origin latitude: 31°30'00"N
Central meridian: 113°10'00"W
False northing: 0 ift
False easting: 600,000 ift
Cen merid scale: 1.000 055
113°15'W
113°0'W
112°45'W
112°30'W
112°15'W
112°0'W
111°45'W
111°30'W
32°30'N
32°15'N
32°0'N
31°45'N
31°30'N
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
-50,000
550,000
600,000
650,000
700,000
750,000
800,000
850,000
900,000
950,000
1,000,000
1,050,000
1,100,000


Linear distortion (parts per million)
<-100 ppm (<-0.5 ft/mile)
-80 to -100 ppm
-60 to -80 ppm
-40 to -60 ppm
-20 to -40 ppm
±20 ppm (±0.1 ft/mile)
+20 to +40 ppm
+40 to +60 ppm
+60 to +80 ppm
+80 to +100 ppm
>+100 ppm (>+0.5 ft/mile)
Zero distortion
Lambert Conformal Conic projection (single parallel)
North American Datum of 1983
Standard parallel: 30°30'00"N
Central meridian: 110°45'00"W
False northing: -620,000 ift
False easting: 30,000 ift
Std parallel scale: 0.999 800
Pima County Low Distortion Projection Coordinate System (preliminary)
Zone 4. Mount Lemmon
Projected grid labels are in international feet (ift)
0 0.5 1 1.5
Miles
Grid North
Central Meridian 110° 45' 00" W
Loma Linda
Summerhaven
Soldier Camp
Whitetail
Willow Canyon
110°48'W
110°47'W
110°46'W
110°45'W
110°44'W
110°43'W
110°42'W
110°41'W
32°27'N
32°26'N
32°25'N
32°24'N
32°23'N
90,000
85,000
80,000
75,000
70,000
65,000
15,000
20,000
25,000
30,000
35,000
40,000
45,000
50,000

PCCS design summary

Map projection linear distortion

- Minimized when developable surface at topo surface
- No single design height for large areas
- For areas of sloping topography:
  - *Offset projection axis from area centroid*
  - *Specialized methods needed for optimized designs*
- Use existing projections types!
  - *No special projection types required*
- Reference generic datum, not specific realization
  - “NAD 83” not “NAD 83 (2011)”

Questions?

Understanding and Using the Pima County Coordinate System

Putting "Grid"

at "Ground"

Arizona Professional Land Surveyors Conference

Tucson, Arizona ● May 19, 2017

Michael L. Dennis, RLS, PE

Geodetic Analysis, LLC

The Plan

- Projected coordinate systems
  - Required defining parameters
  - Availability in software
- The vertical ("elevation") component
- Checking PCCS coordinate computations
- What if PCCS cannot be defined in your software?
- The hard part: ***Datums***
  - Handling multiple NAD 83 realizations
  - Relationship between NAD 83 and WGS 84
  - Impact of the new 2022 geometric datum
- ***Discussion!***

The Goal

- Make working at "ground" simple as possible
- Guiding ideas for PCCS:
  - Once in software it works ***automatically***
  - Uses ***standard*** projection definitions
  - ***Single system*** covers large area
  - ***No special processes*** required (e.g., no "calibration" or "localization")
- ***Important to ask questions, give comments!***
  - Concepts here are fundamental for geospatial professionals
  - Guidance also in PCCS Project Report

Defining the PCCS in software

- Best situation: Already defined in software
  - Esri PRJ files available from PCCS website
  - Definitions available from EPSG (soon)
  - PCCS included on your software
- If not in software, need to enter it yourself
  - Make sure values (and units) are
  - Datum definitions can be tricky
- ***IMPORTANT:*** Check to ensure it works!

Speaking the same language

- Coordinate system MUST have a "datum"
- Coordinate system MAY have a "map projection"
- "Datum" = "Geographic coordinate system"
  - Also = "Geometric reference frame"
- Modern datums 4-dimensional (3-D position PLUS time)
  - Epoch = date of coordinates (e.g., 2010.00 = Jan 1, 2010)
  - Coordinates different at different epochs
- "Map projection"
  - Curved geographic → planar projected (*x, y* or *east, north*)
  - Horizontal ONLY
- Vertical datums (coordinate systems)
  - A more complex topic for another time…

Projected coordinate systems

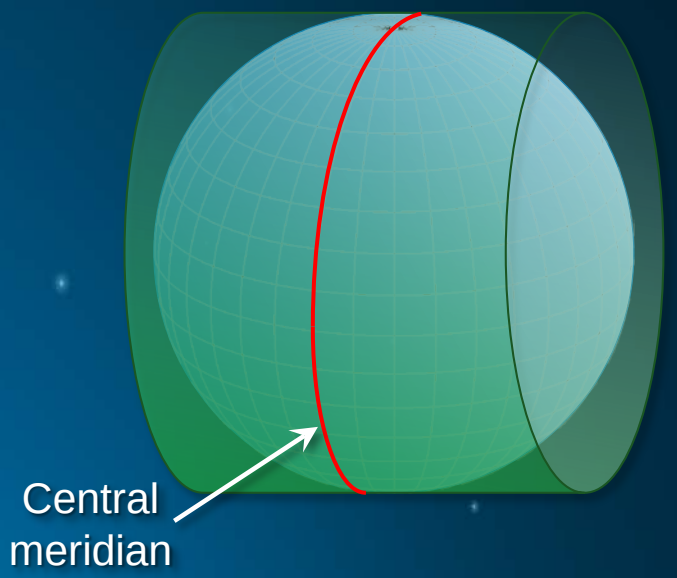
- Has 3 ***required*** components:
  - Map projection
  - Reference ellipsoid
    - Connects the projection to the Earth
    - Associated with a specific “datum” (a.k.a. “geometric reference frame”, “geographic coordinate system”)
  - Linear unit

Map projections

- Three types in PCCS (all conformal)
  - Transverse Mercator (TM)
  - Lambert Conformal Conic (LCC)
  - Oblique Mercator (OM)
- All have (nearly) same "ingredients"
  - Geodetic origin (latitude and longitude)
  - Grid origin (false northing and easting)
    - Grid coordinate values at geodetic origin
  - Scale (its "size" compared to Earth ellipsoid)
  - *OM only:* Skew azimuth
    - Rotation of cylindrical developable surface

Transverse Mercator projection

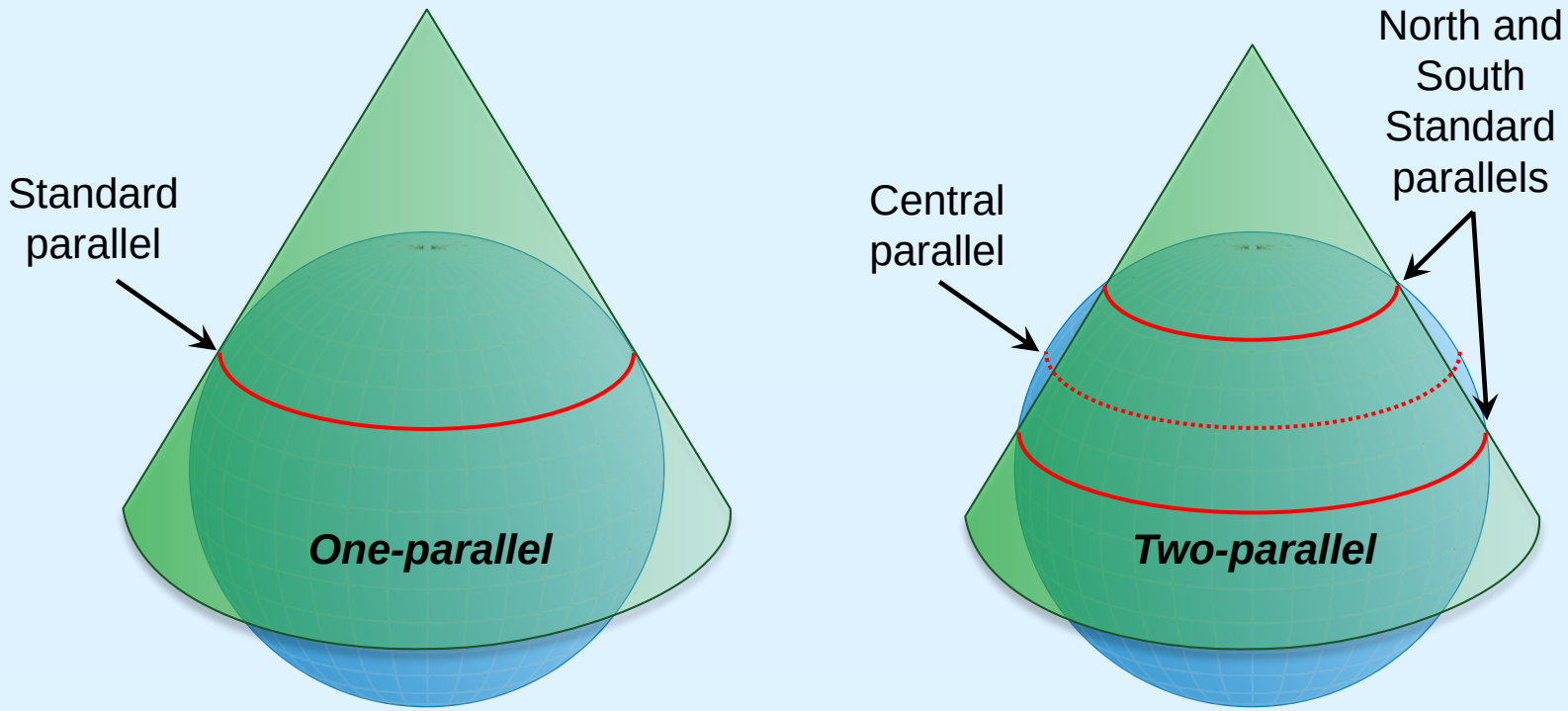
- Cylindrical developable surface
- Used in Zone 2 (Central) and Zone 3 (West)
- Simple and common projection type
- 5 defining parameters:
  1. Latitude of grid origin
  2. Central meridian
  3. False northing
  4. False easting
  5. Central meridian scale



Lambert Conformal Conic projection

- Conical developable surface, Zone 4 (Mt Lemmon)
- Two implementations: 1- and 2-parallel
  - PCCS uses 1 parallel with 5 defining parameters
- Defining parameters for single parallel LCC in PCCS
  1. Latitude of grid origin = Standard parallel (latitude)
     - ***NOTE:*** Generally, origin latitude ***NOT*** = Central parallel
     - Done here because of commercial software limitations
  2. Central meridian
  3. False northing
  4. False easting
  5. Standard parallel scale
     - ***NOTE:*** If scale < 1, can use 2 standard parallels instead
     - Central standard parallel and its scale are ***computed***

Lambert Conformal Conic Projection



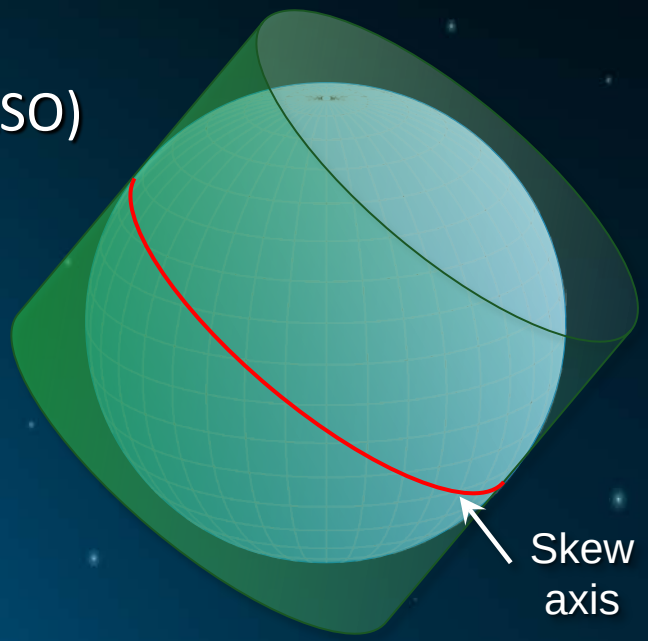
1- and 2-parallel versions are mathematically identical

Additional LCC considerations

- 1-parallel LCC available in most software
  - May be limited to 2-parallel with no separate scale
  - Since PCCS LCC scale < 1, can define as 2-parallel
  - 2-parallel LCC definition is in PCCS Project Report
- General LCC implementations
  - Not specified as 1- or 2-parallel
  - If 2 standard parallels equal, becomes 1-parallel
  - Allows use of scale even if standard parallels not equal
    - However this is NOT recommended
    - Defeats purpose of using 2 standard parallels
  - This is used in some software (e.g., Esri)

Oblique Mercator projection

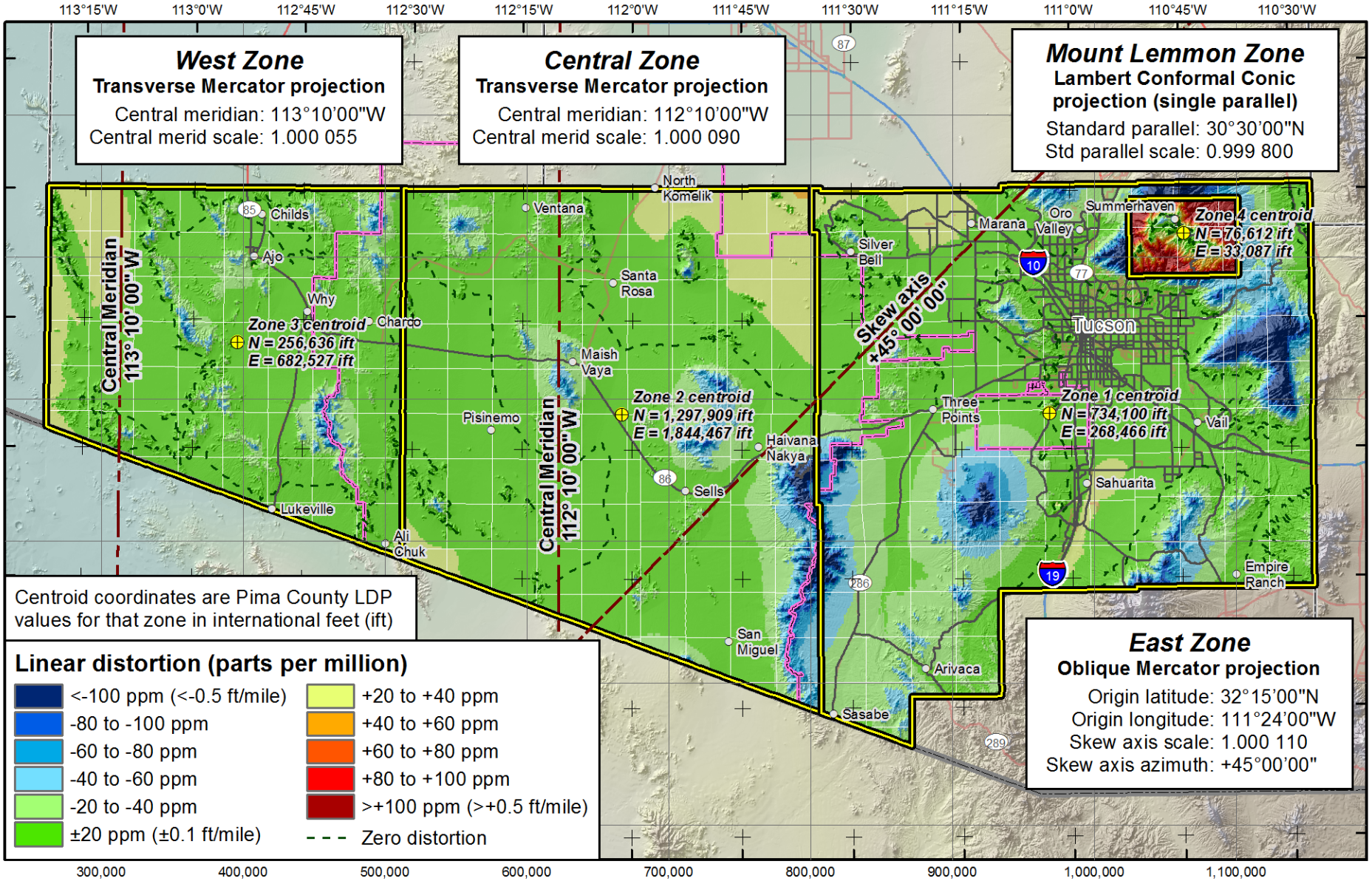
- Cylindrical developable surface, used in Zone 1 (East)
- PCCS uses "Hotine" implementation
  - a.k.a. "rectified skew orthomorphic" (RSO)
- 5 defining parameters for PCCS:
  1. Latitude of local grid origin
  2. Longitude of local grid origin
  3. False northing at local origin
  4. False easting at local origin
  5. Skew axis scale at local origin
  6. Skew axis azimuth at local origin



- ***NOTE:*** Implementation defined at local ("center") origin
  - Can instead define at "true" or "natural" origin (near equator)
  - See PCCS Project Report for more information on implementing
- ***NOTE:*** In all cases coordinates must be "rectified"
  - i.e., coordinates rotated so that north is "up"

Computation checks

- Important to check computations
  - Do this whether PCCS hand-entered or included with software
  - Can be affected by datum transformation (more on this later…)
- Check coordinates in PCCS Project Report
  - Centroid coordinates for each zone (Table 2)
  - Coordinates for 170 published NGS GNSS control stations in Pima County
    - Appendix A: PCCS coordinates
    - Appendix B: PCCS linear distortion and conv angle



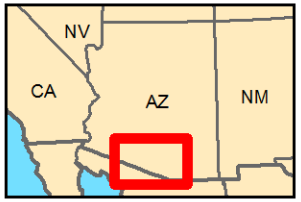
Pima County Low Distortion Projection Coordinate System *(preliminary)*

All zones (large zones clipped to townships)

Projected grid is SPCS 83 AZ C (international feet)

0 10 20 30
Miles

Grid North



Zone centroid check coordinates

- In Table 2 of PCCS Project Report
- Latitude and longitude of each zone are exact
- Northing and easting computed to 0.001 ft
- Grid coordinate units in international feet

PCCS zone of centroid point	NAD 83 geodetic coordinates (GRS-80 ellipsoid), EXACT		PCCS projected coordinates (international feet)	
	Latitude	Longitude	Northing	Easting
1. East	32°04'06"N	111°03'00"W	734,076.605	268,437.993
2. Central	32°04'08"N	112°01'23"W	1,297,953.783	1,844,492.571
3. West	32°12'18"N	112°54'00"W	256,590.784	682,491.363
4. Mt Lemmon	32°24'54"N	110°44'24"W	76,612.057	33,087.234

Worst-case scenario

What if you can't define the PCCS in your software?

- Can perform a best-fit planar transformation
  - 4-parameter similarity (conformal) transformation
  - Often called horizontal "calibration" or "localization"
  - Do ***NOT*** use an affine transformation, since PCCS is conformal
- Requirements for alignment error < 0.05 ft
  - Minimum 3 points with PCCS coordinates
  - Points should surround project area
  - Maximum extent of area should be < 3 miles
- For non-georeferenced data collection
  - e.g., total station, terrestrial scanner, structure from motion
  - Observe at least 3 points with PCCS coordinates
  - Adjust to align with PCCS coordinates

Projections are easy

Datums are hard

If you want data aligned to better than 3 m, then this stuff matters

Datum transformations are not for sissies!

The hard part: Datums

- State Plane and PCCS referenced to NAD 83
- NAD 83 has changed (4 “realizations” in AZ)
  - Original (1986)
  - “HARN” (1992)
  - 2007 (epoch 2007.0)
  - 2011 (epoch 2010.0)
- What does this mean?
  - Latitude, longitude (and ellipsoid height) changed
  - Ellipsoid (GRS-80) has NOT changed
  - State Plane and PCCS can use any NAD 83 version
  - Change in projected coordinates due ONLY to change in latitude, longitude
  - ***IMPORTANT: Document realization used for your data!***

“Datum” transformations

- No simple way to transform between NAD 83 realizations
  - *Most accurate:* Reprocess/readjust original observations
  - *Next most accurate:* Create custom transformation for your local area
  - *Least accurate:* Use a pre-defined transformation
    - Some better than others, but usually none “survey” accuracy
- New tool from NGS: NADCON 5.0
  - Will soon be released in beta
  - Transforms between all realizations of NAD 83
  - Also transforms between NAD 83, NAD 27, and USSD
  - ***BUT*** transformations not typically “survey grade” accuracy (~0.1 ft)
    - Likely falls into “least accurate” category

Example change in NAD 83

- NGS station N 419 (CZ1490) in Tucson
- Coordinate changes in Table 7 of PCC Project Report
- PCCS coordinates projected from published NAD 83 coordinates
- Gives incremental and cumulative change in coordinates

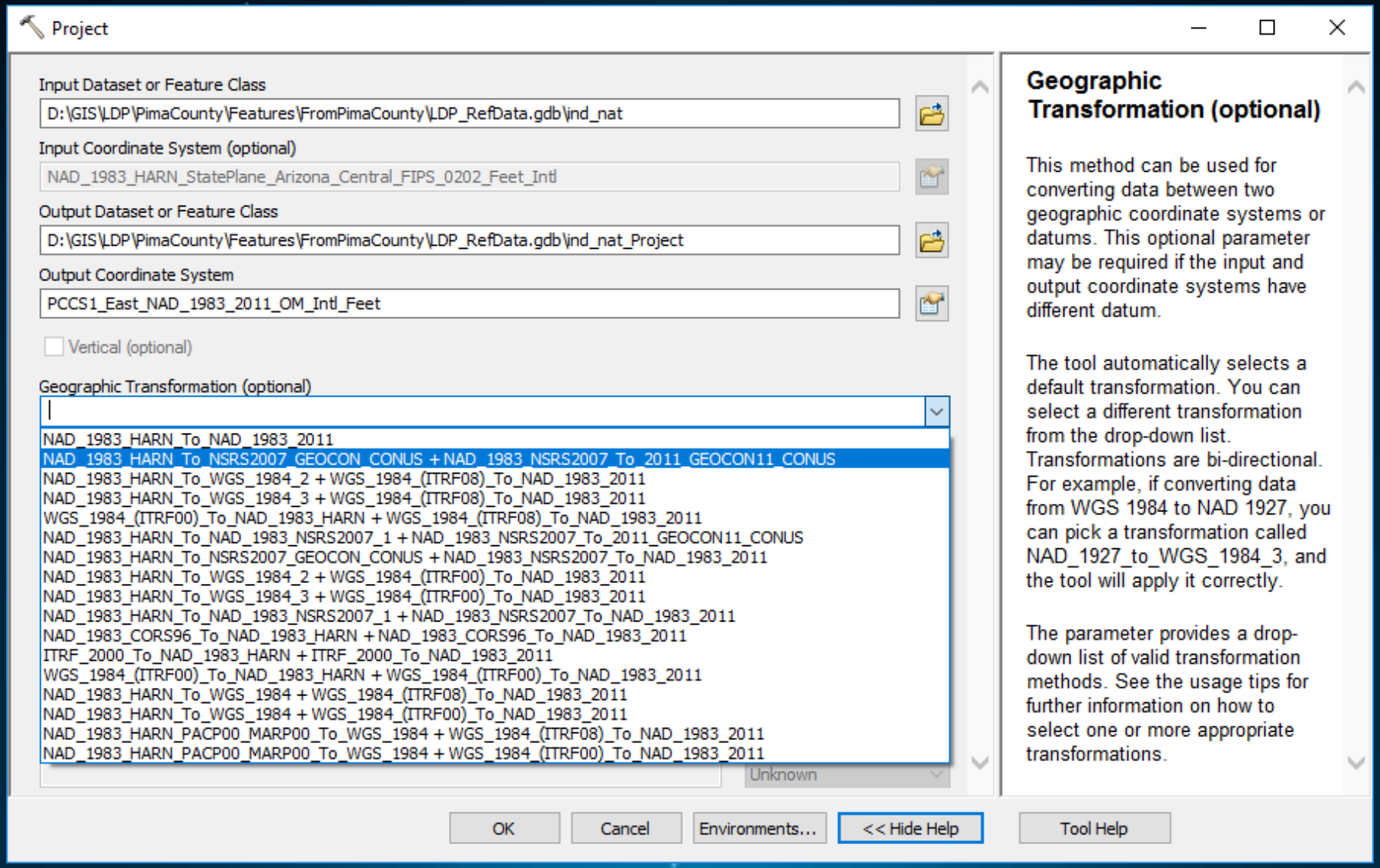
NAD 83 realization	PCCS Zone 1 (East) projected (ift)		Horizontal change in coordinates (ft)	
	Northing	Easting	Incremental	Cumulative
1986 (original)	786,953.920	287,370.132		
			0.497	0.497
1992 (HARN)	786,954.408	287,370.039		
			0.098	0.564
2007 (epoch 2007.00)	786,954.455	287,369.953		
			0.071	0.622
2011 (epoch 2010.00)	786,954.522	287,369.976		

NAD 83 transformations in software

- Can get variable and unexpected results
- Very important to ***document*** and ***verify***
- Example for Pima County in ArcGIS (10.4.1)
  - State Plane 1983 (1992) "HARN" → PCCS NAD 83 (2011)
  - Default: ""
    - Transformation does ***NOTHING*** to geodetic coordinates
    - Only change is due to change in projection
    - Underlying latitude and longitude values are ***identical***
    - There are ***17*** transformations available for this single case which one should you use? How do you know?
- ***This problem is not unique to ArcGIS***
- ***Bottom line***
  - Avoid geodetic transformations if at all possible
  - If you use them, use with caution, understand them, and document (metadata)

Geographic transformation in ArcGIS

NAD 83 (1992) “HARN” to NAD 83 (2011) in Pima County



Our good friends

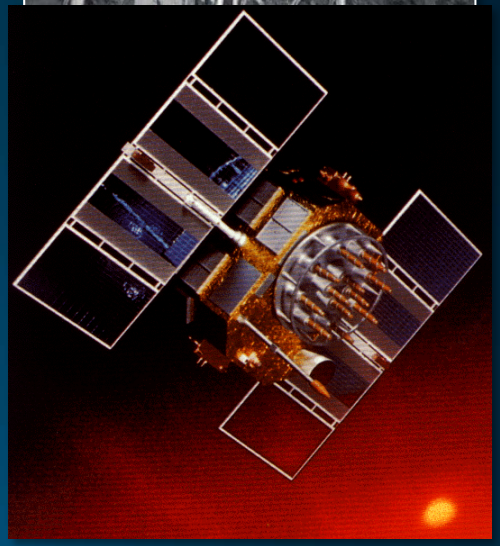
NAD 1983

and

WGS 1984

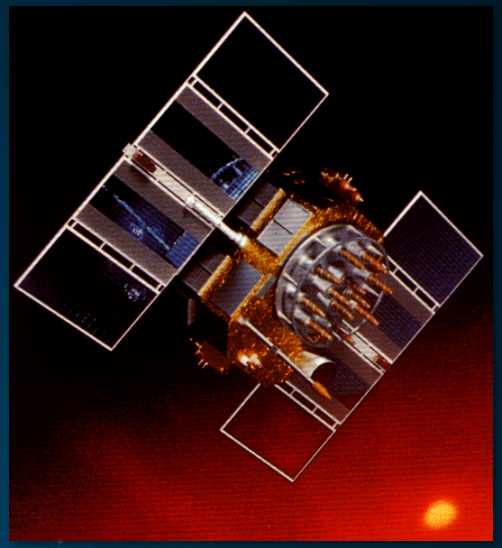
A (very) brief history of NAD 83

1. Original realization completed 1986
   - Almost entirely optical observations (no GPS)
2. "High Precision Geodetic Network" (HPGN) and "High Accuracy Reference Network" (HARN) realizations
   - Most done in 1990s, essentially state-by-state
   - Based on GPS but optical included
3. National Re-Adjustment of 2007
   - NAD 83 (CORS96) and (NSRS2007)
   - Nationwide adjustment (GPS only)
4. Latest: ***NAD 83 (2011/PA11/MA11) epoch 2010.00*** (also GPS only)



A (very) brief history of WGS 84

1. Original realization completed in 1987
   - "Same" as original NAD 83 (***to within ±2 m***)
2. WGS 84 (G730) — adopted Jan 1994
   - Aligned with ITRF91
3. WGS 84 (G873) — adopted Sep 1996
   - Aligned with ITRF94
4. WGS 84 (G1150) — adopted Jan 2002
   - Aligned with ITRF2000 (at epoch 2001.00)
5. WGS 84 (G1674) — adopted Feb 2012
   - Aligned with ITRF2008 (at epoch 2005.00)
6. Latest: ***WGS 84 (G1762) — adopted Oct 2013***
   - Also aligned with ITRF2008 (at epoch 2005.00)



How do you get **WGS 84** coordinates?

- Only true access: Broadcast orbits
  - Accuracy ~3 to 5 m (10 to 15 ft) horizontal
  - Epoch at midpoint of year (e.g., now 2016.5)
- Can assume equal to civilian global frames
  - International Terrestrial Reference Frame (ITRF)
  - International GNSS Service (IGS) frame
- Sources for ITRF/IGS coordinates:
  - Satellite Based Augmentation Systems (SBAS)
    - E.g., WAAS, OmniSTAR HP
  - Various post-processed positioning services
    - E.g., OPUS, AUSPOS, CSRS-PPP, GAPS, APPS, SCOUT, etc.

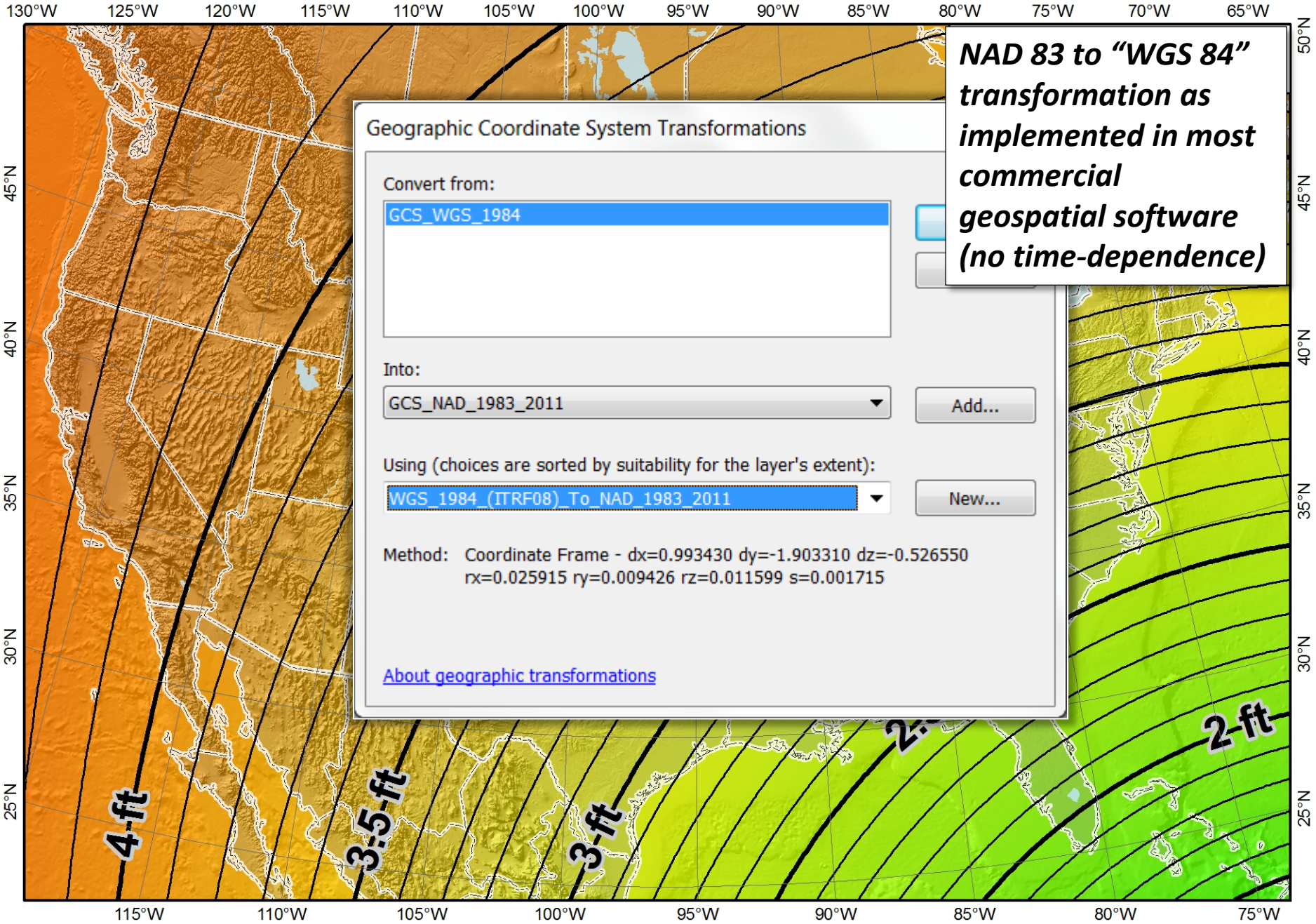
So, you think you have WGS 84 coordinates…

- ***If accuracy worse (larger) than ~3 m (10 ft)***
  - Can consider same as "generic" NAD 83
  - Don't need realization or epoch date
  - No need to transform to NAD 83
- ***If (stated) accuracy better (smaller) than ~3 m***
  - Must include realization (e.g., G1762)
  - Must include epoch date (e.g., 2017.42)
  - Otherwise can ***NOT*** be at accuracy stated
  - May not be able to accurately transform to NAD 83

NAD 83 and WGS 84

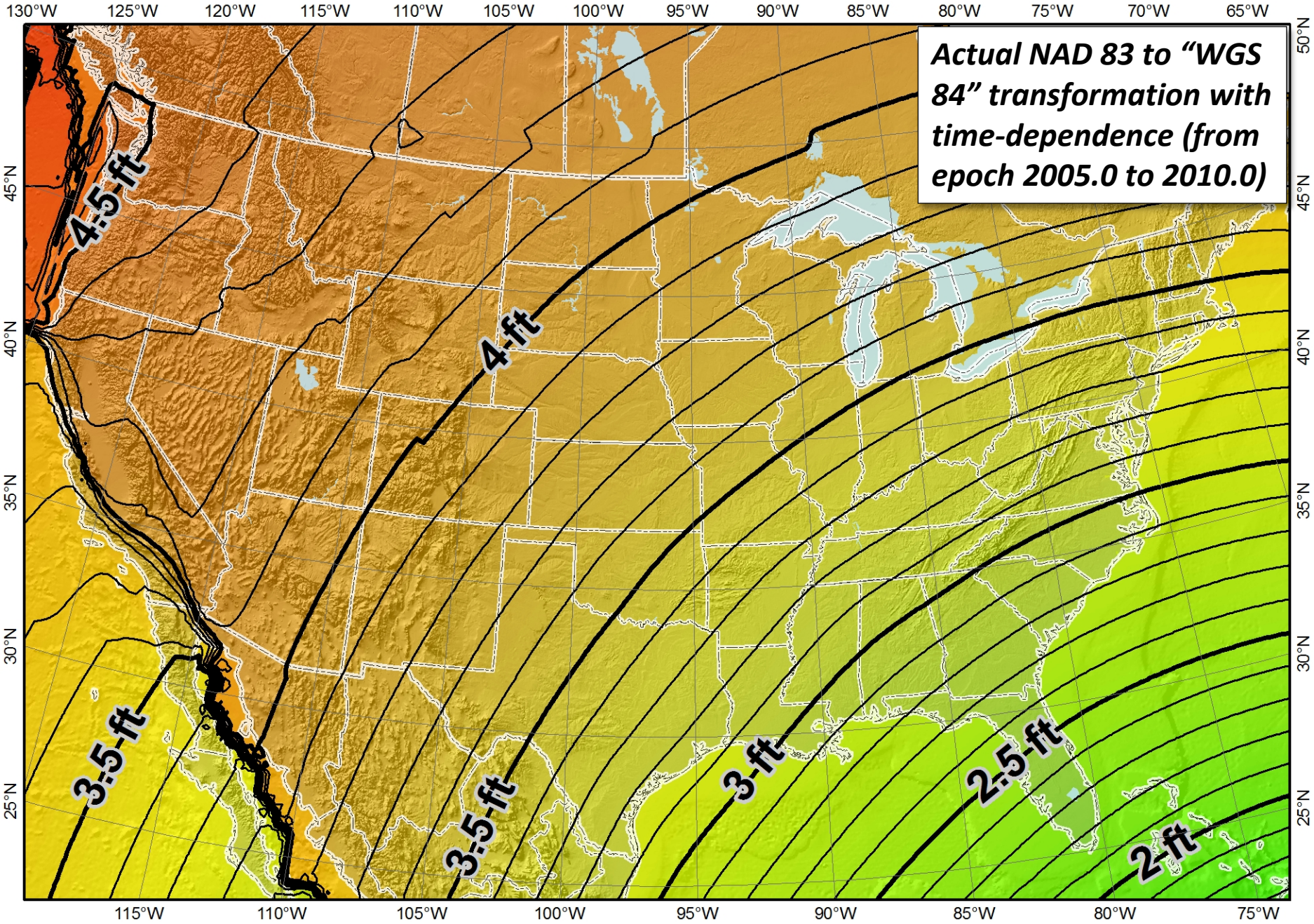
- Relationship is complex and time-dependent
  - Transformation parameters change with time
  - Also affected by differential tectonic motion
  - Differ by 1-2 m, depending on location and time
- For most commercial software:
  - Legacy applications assume NAD 83 = WGS 84
  - More recent applications do not assume same (but ignore time dependence)
- ***Bottom line***
  - If data less accurate than ~3 m, no need to transform
  - Be sure you actually have WGS 84 before doing anything
  - If you use a NAD 83 ←→ WGS 84 transformation:
    - Make sure you understand the transformation you use
    - Do some research to find best transformation available
    - Document what you did

Horizontal shift (ft) NAD83 epoch 1997.00 *to* ITRF2008 epoch 1997.00

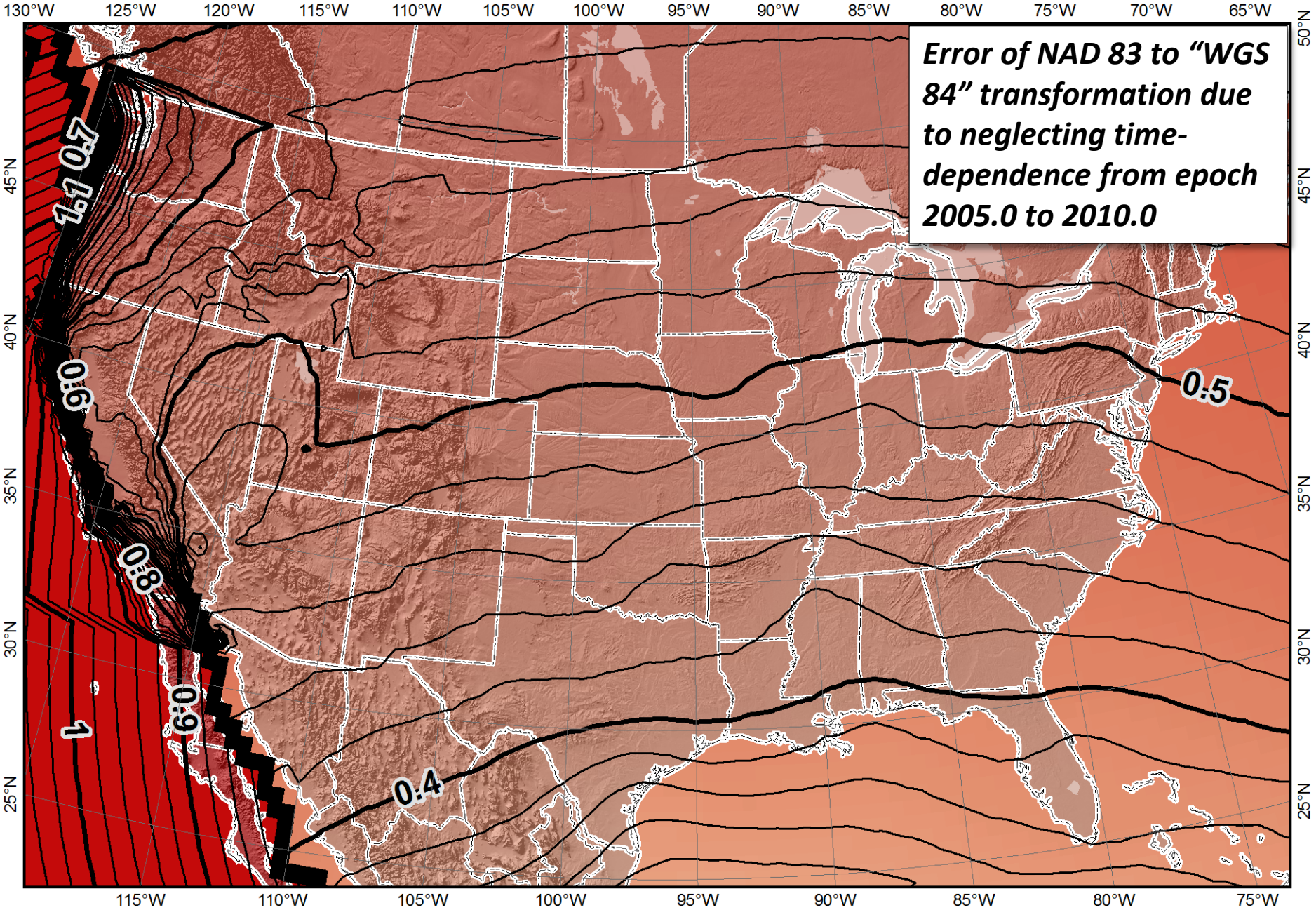


NAD 83 to "WGS 84" transformation as implemented in most commercial geospatial software (no time-dependence)

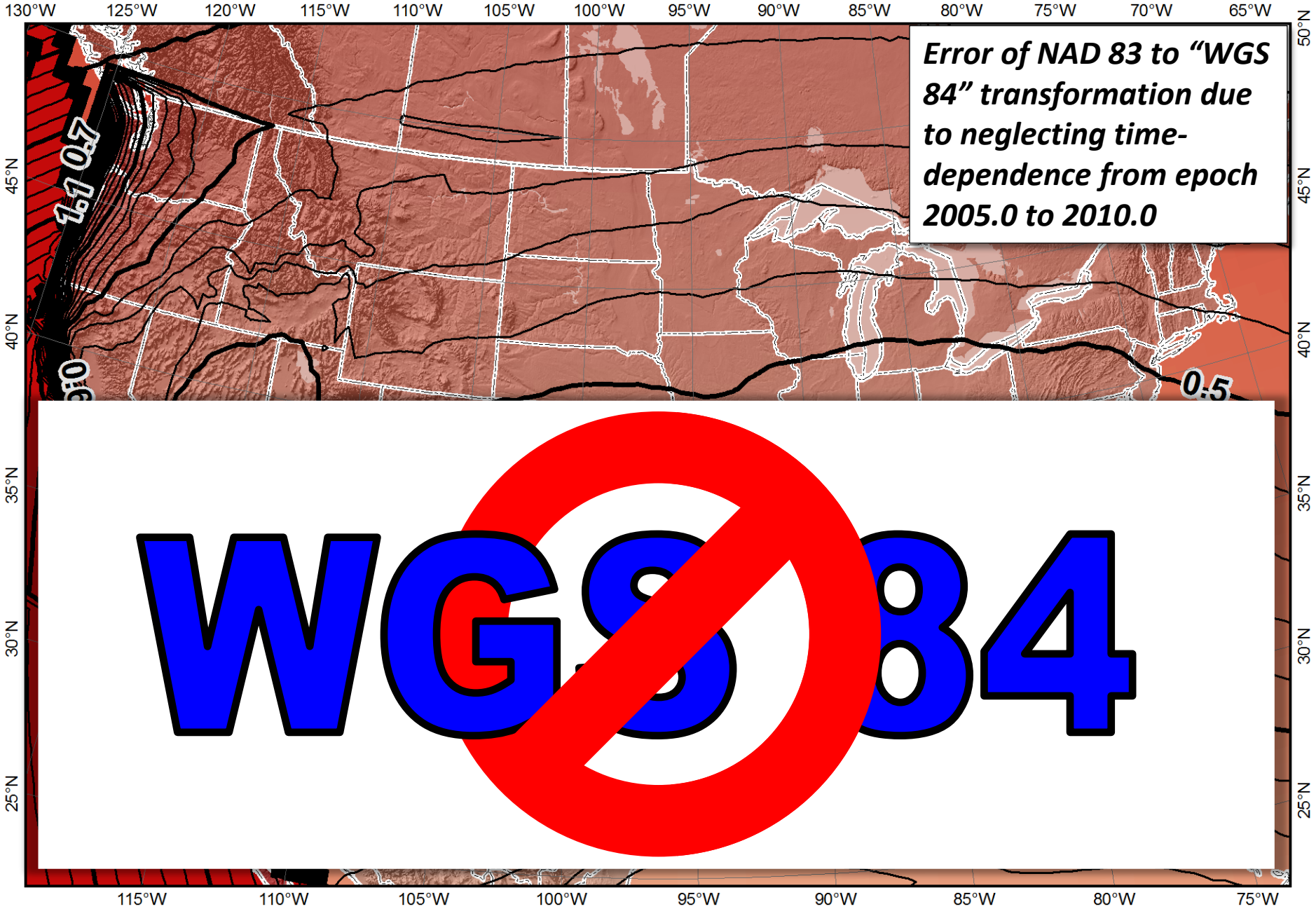
Horizontal shift (ft) NAD83 epoch 2010.00 *to* ITRF2008 epoch 2005.00



Horizontal error (ft) NAD83 *to* ITRF2008 if epoch 1997.00 used for both



Horizontal error (ft) NAD83 *to* ITRF2008 if epoch 1997.00 used for both



Your NAD 83-Based State Plane-Legislated Coordinates *Will Not* Be Maintained after 2022!

NSPS

AAGS

NOAA

What will you and your fellow professionals do?
Panic? Ignore the Issue? *or Act?*
Please let us know!

What is changing?

The North American Datum of 1983 (NAD 83) will be replaced in 2022. The new datum will have a different name.

The North American Vertical Datum of 1988 (NAVD 88) will also be replaced in 2022. Its replacement will also have a new name.

Expected horizontal shifts from NAD 83 to the new datum are in the 1-2 meter range. The National Geodetic Survey will provide a coarse, map-grade transformation tool (such as NADCON and GEOCON) to connect NAD 83 with the new datum.

Who will be affected?

All states and territories will be transitioned to the new datums.
Forty-eight states have a state-specific coordinate system law tied to NAD 83.
Your state law will not reflect the National Spatial Reference System after 2022.

Who can help?

The National Geodetic Survey (NGS), the National Society of Professional Surveyors (NSPS) and the American Association for Geodetic Surveying (AAGS) are here to help your state make these changes in legislation!

You can help by understanding your own state's laws and how these changes will impact you.

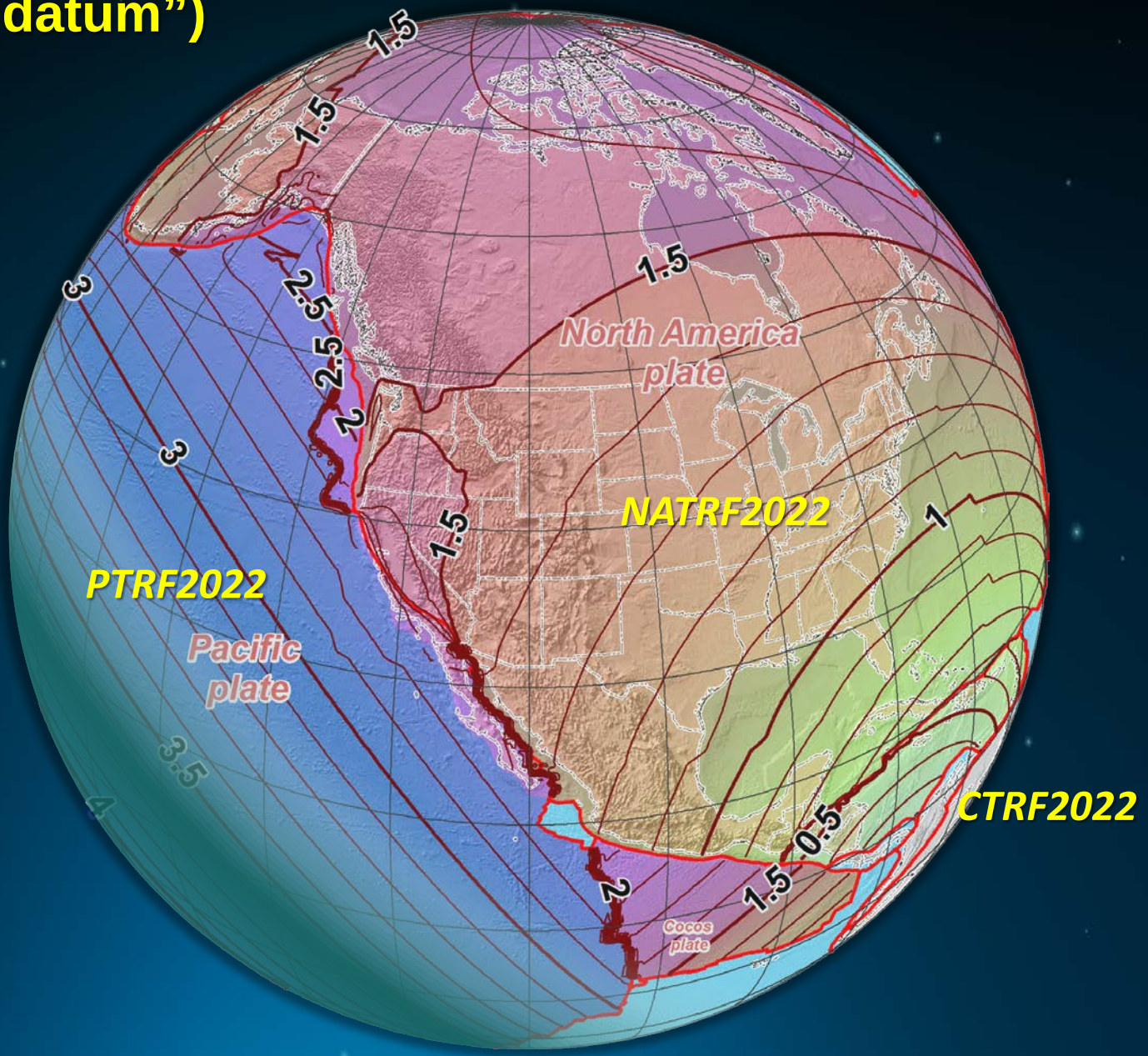
http://www.geodesy.noaa.gov/datums/newdatums/nad-83_state-plane-leg-coord_flyer.pdf

What about the new 2022 datum?

- New 2022 geometric datums
  - North America Terrestrial Reference Frame of 2022 (NATRF2022)
  - NGS will also create new 2022 State Plane system
    - May or may not include LDP systems
  - Simultaneous release of new vertical datum
    - North America-Pacific Geopotential Datum of 2022 (NAPGD2022)
    - This will have no effect at all on PCCS
- How will NATRF2022 affect the PCCS?
  - PCCS coordinates will change by ~4.6 ft horizontally
  - Ellipsoid heights will decrease by ~2.9 ft
    - Resulting change in distortion negligible (~0.14 ppm)
- Options for adapting PCCS to NATRF2022
  - Do nothing (the system will still work)
  - Modify false northings and/or easting
    - To get coordinate values that differ from PCCS NAD 83
    - Will have no effect on distortion performance

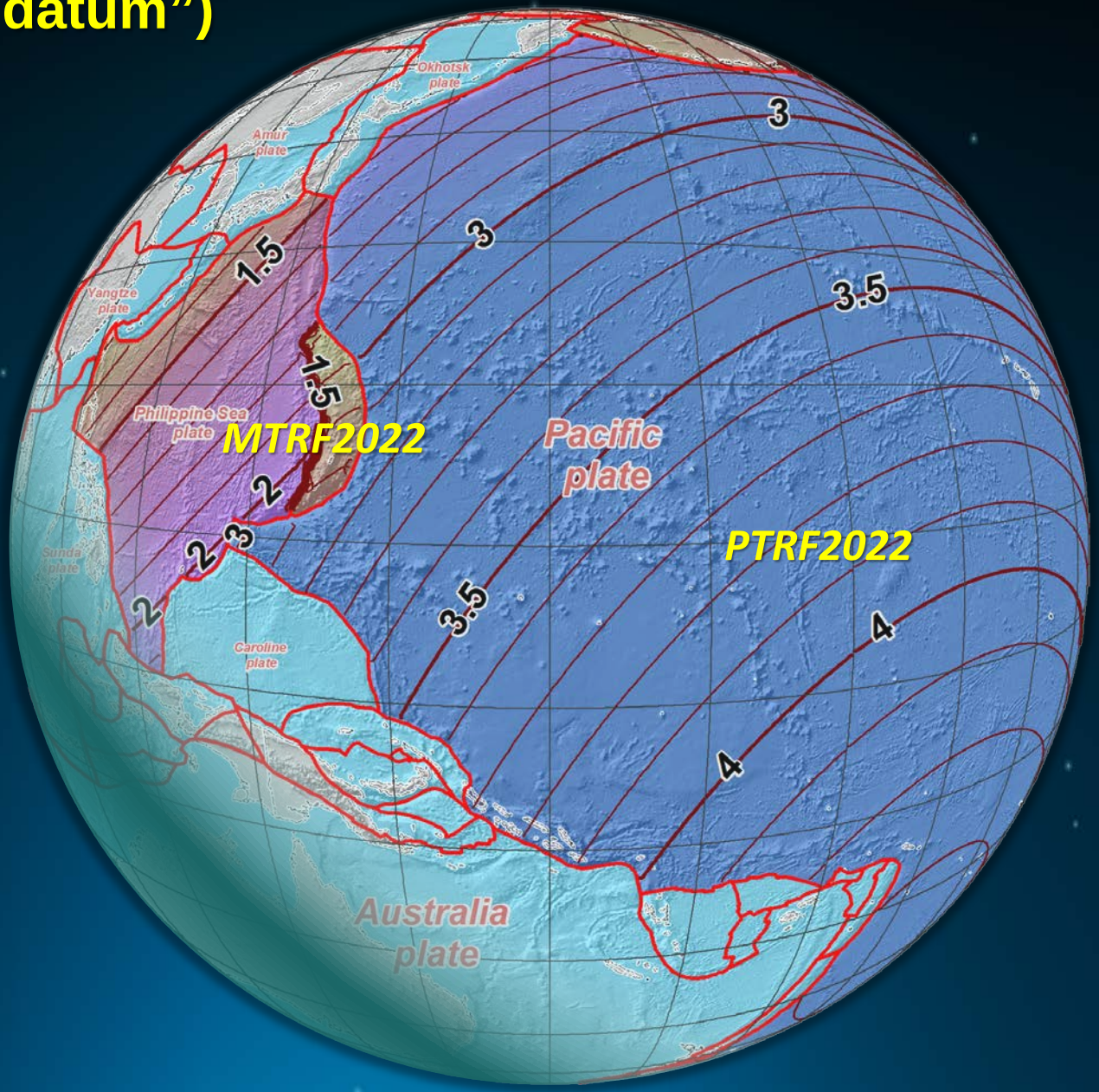
NAD 83 (2011) epoch 2010.00 → IGS08 ("new datum") epoch 2022.00

(contours in meters)



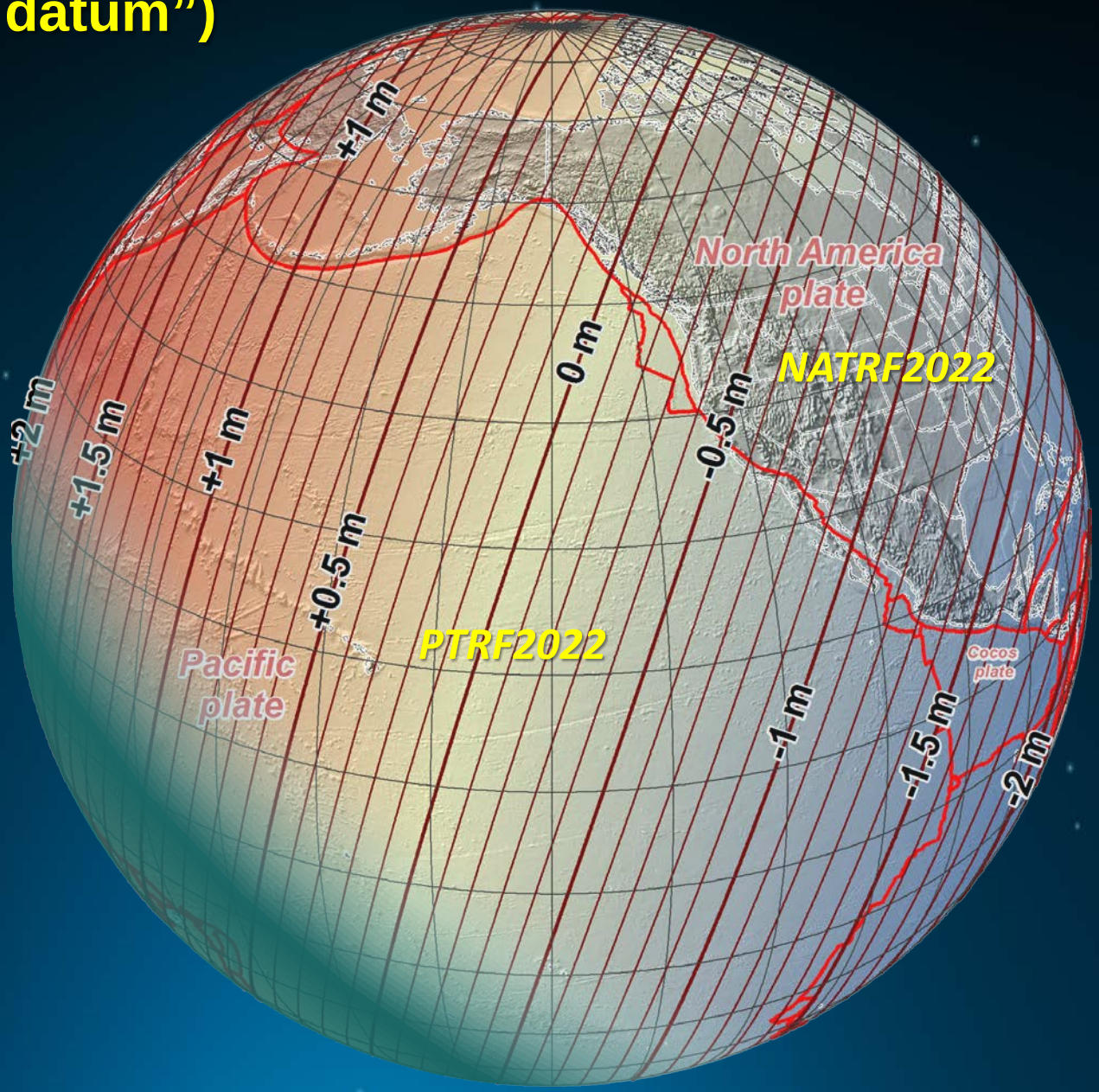
NAD 83 (2011) epoch 2010.00
→ IGS08 (“new datum”) epoch 2022.00

(contours in meters)



NAD 83 (2011) epoch 2010.00 → IGS08 ("new datum") epoch 2022.00

(contours in meters)



Conclusions about using the PCCS

- A projected coordinate system
  - Definition requires projection, datum, and linear unit
- Has no vertical component (purely horizontal)
- Defined using 3 conformal map projection types
  - Standard projections defined in most software
  - Eventually will be pre-loaded by software vendors
- Can be referenced to any realization of NAD 83
  - Transformations between NAD 83 realization should be avoided
  - Transformation involving WGS 84 should also be avoided
  - If transformations used: document, understand, verify
- Compatible with NATRF2022
  - Coordinates will change by ~4.6 ft
  - Recommend redefining grid origins for larger coordinate change

Questions?

Comments?

Discussion?

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