20 STATE PLANE COORDINATES AND OTHER MAP PROJECTIONS

Asterisks (*) indicate problems that have answers given in Appendix G.

20.1 Discuss the advantages of placing surveys on state plane coordinate systems.

From Section 20.1, paragraph 1: It allows computations to be made using simple coordinate geometry formulas.

20.2 Which map projection is preferred for states whose long dimensions are north-south? East-west?

The Transverse Mercator map projection is preferred for states that have long dimensions in the north-south direction, and the Lambert conformal conic map projection is preferred for states with long east-west dimensions.

20.3 Why do the states of Alaska, New York, and Florida use both the Lambert conformal conic and Transverse Mercator map projections?

These states all have a portion of their state that are long in is a dimension that is opposed to the majority of the state. In Alaska the Aleutian Islands, in New York there is long island, and Florida has the panhandle. All three use a Lambert conformal conic map projection whereas the remainder of the state uses a Transverse Mercator map projection. Alaska also uses an oblique Mercator projection for its panhandle.

20.4 What factor reduces a geodetic distance to its equivalent map projection length?

From Section 20.8.1, paragraph 2: " This is accomplished by multiplying the ellipsoidal length of the line by an appropriate *scale factor*."

20.5 What corrections must be made to geodetic azimuths prior to computing state plane coordinates?

From Section 20.8.2, paragraph 1: "As shown in Figure 20.10, all grid meridians are parallel while all geodetic meridians converge to a single point. The primary difference between these directions is the *convergence angle* γ."

From paragraph 3: "Another factor that affects the reduction of azimuths is the projection of the geodetic azimuth onto a developable mapping surface," which is known as the *second-term correction*.

20.6 What correction(s) must be made to measured angles prior to computing state plane coordinates?

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From Section 20.8.2: Since the convergence angle is the same for any direction at a particular station, the only correction necessary is the difference between the second-term corrections for each sight.

20.7 Develop a table of SPCS83 elevation factors for geodetic heights ranging from 0 to 1000 m. Use increments of 100 m and an average radius for the Earth of 6,371,000 m.

Height (m)	Scale
0	1.00000000
100	0.99998430
200	0.99996861
300	0.99995291
400	0.99993722
500	0.99992153
600	0.99990583
700	0.99989014
800	0.99987445
900	0.99985875
1000	0.99984306

20.8 Similar to Problem 20.7, except for geodetic heights from 0 to 2700 m using 300-ft increments.

Height (ft)	Scale
0	1.00000000
300	0.99995291
600	0.99990583
900	0.99985875
1200	0.99981168
1500	0.99976461
1800	0.99971755
2100	0.99967049
2400	0.99962343
2700	0.99957638

20.9 Explain how surveys can be extended from one state plane coordinate zone to another or from one state to another.

From Section 20.10, paragraph 1: "The general procedure for extending surveys from one zone to another requires that the survey proceed from the first zone into the overlap area with the second. Then the geodetic latitudes and longitudes are computed for two intervisible stations using their grid coordinates in the first zone. (Recall that this conversion is called the *inverse problem.*) Using the geodetic positions of the two points, their state plane coordinates in the new zone are then computed. (This is the *direct problem.*) Finally the grid azimuth for the line in the new zone can be obtained from the new coordinates of the two points."

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20.10 Develop a table similar to Table 20.1 for a range of latitudes from 40°30' N to 40°39' N in the Pennsylvania North Zone with standard parallels of 40°53' N and 41°57' N, and a grid origin at (40°10' N, 77°45' W).

Latitude	R (m)	Tab. Diff.	k
40°30'	7342329.667	30.84819	1.000083949
40°31'	7340478.776	30.84814	1.000079382
40°32'	7338627.887	30.84809	1.000074899
40°33'	7336777.002	30.84805	1.000070499
40°34'	7334926.119	30.84800	1.000066182
40°35'	7333075.239	30.84796	1.000061949
40°36'	7331224.361	30.84793	1.000057798
40°37'	7329373.485	30.84789	1.000053731
40°38'	7327522.612	30.84786	1.000049747
40°39'	7325671.740	30.84783	1.000045847

***20.11** The Pennsylvania North Zone SPCS83 state plane coordinates of points *A* and *B* are as follows:

Point	E(m)	N(m)
A	541,983.399	115,702.804
B	541,457.526	115,430.257

Calculate the grid length and grid azimuth of line *AB*.

592.304 m, 242°36'12"

20.12 Similar to Problem 20.11, except points *A* and *B* have the following New Jersey SPCS83 state plane coordinates:

Point	E(m)	N(m)
A	126,365.872	25,586.411
B	126,684.680	25,336.494

405.089 m, 128°05'36"

20.13 What are the SPCS83 coordinates (in sft) and convergence angle for a station in the North zone of Pennsylvania with geodetic coordinates of 41°15'26.30486" N and 78°23'08.97165" W?

From WolfPack: **X = 1,793,683.61 sft Y = 398,014.54 sft**

Scale = 0.9999607261 ; Radius : 7,258,228.8811 m

Convergence angle = **−0°25'14.24"**

20.14* Similar to Problem 20.13 except that the station's geodetic coordinates are 41°13'20.03582" N and 75°58'46.28764" W. Give coordinates in meters.

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From WolfPack:

X = 2,455,513.33 sft Y = 389,571.28 sft

Scale = 0.9999626142 Radius : 7,262,124.0805

Convergence angle = **1°10'16.46"**

20.15 What is the scale factor for the station in Problem 20.13? **k = 0.9999607261**

20.16 What is the scale factor for the station in Problem 20.14? **k = 0.9999626142**

20.17* What are the SPCS83 coordinates in meters for a station in New Jersey with geodetic coordinates of 40°50'23.2038" N and 74°15'36.4908" W?

(170227.750, 222784.094)

20.18 Similar to Problem 20.17 except that the geodetic coordinates of the station are 39°01'25.0486" N and 74°29'36.9641"W.

(150,554.070, 21,122.925)

20.19 What are the convergence angle and scale factor at the station in Problem 20.17?

0°09'24.6903" and 0.9999050344

20.20 What are the convergence angle and scale factor at the station in Problem 20.18?

0°00'14.50" and 0.9999000038

20.21* What are the geodetic coordinates for a point *A* in Problem 20.11?

X = 541983.399 m, *Y* = 115702.804 m

(41°12'23.2037"N, 78°26'30.3340"W)

20.22 Similar to Problem 20.21 except for point B in Problem 20.11?

X = 541457.526 m, *Y* = 115430.257 m

(41°12'14.2321"N, 78°26'52.8116"W)

***20.23** What are the geodetic coordinates for a point *A* in Problem 20.12?

X = 126,365.872 m Y = 25,586.411 m

Latitude = 39°03'48.65298"N, Longitude = 74°46'23.15865"W

Scale = 0.9999068756
Convergence angle =−-0°10'19.5713"

20.24 Similar to Problem 20.23 except for point *B* in Problem 20.12.

X = 126,684.680 m Y = 25,336.494 m

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Latitude = 39°03'40.57891"N, Longitude = 74°46'09.86586"W

Scale = 0.9999066914 ; Convergence angle = −0°10'11.16"

20.25 In computing state plane coordinates for a project area whose mean orthometric height is 848 m, an average scale factor of 0.99992381 was used. The average geoidal separation for the area is −28.832 m. The given distances between points in this project area were computed from SPCS83 state plane coordinates. What horizontal length would have to be observed to lay off these lines on the ground? (Use 6,371,000 m for an average radius for the Earth.)

Elevation factor = 0.999871439; Combined factor = 0.99979526

(a)* 2834.79 ft **2835.13 ft**

(b) 608.803 m **608.928 m**

(c) 1013.25 ft **1013.46 ft**

20.26 Similar to Problem 20.25, except that the mean project area elevation was 2201 m, the geoidal separation −24.372 m, the scale factor 0.99996053, and the computed lengths of lines from SPCS83 were:

Elevation factor = 0.999998959; Combined factor = 0.999969489

(a) 558.028 m **558.261 m**

(b) 1202.39 ft **1202.89 ft**

(c) 610.803 m **1013.673 m**

20.27 The horizontal ground lengths of a three-sided closed polygon traverse were measured in feet as follows: *AB* = 2187.66, *BC* = 2993.59, and *CA* = 3923.68 ft. If the average orthometric height of the area is 2345 ft and the average geoid separation is −29.55 m, calculate ellipsoid lengths of the lines suitable for use in computing SPCS83 coordinates. (Use 6,371,000 m for an average radius for the Earth.)

Elevation factor = 0.999892461

AB = **2187.425 ft**

BC = **2993.268 ft**

CA = **3923.258 ft**

20.28 Assuming a scale factor for the traverse of Problem 20.27 to be 1.0001053, calculate grid lengths for the traverse lines.

AB = **2187.655 ft**

BC = **2993.583 ft**

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CA = **3923.671 ft**

20.29 For the traverse of Problem 20.27, the grid azimuth of a line from *A* to a nearby azimuth mark was 10°07'59" and the clockwise angle measured at *A* from the azimuth mark to *B*, 213°32'06". The measured interior angles were *A*= 41°12'26", *B* = 38°32'50", and *C*= 100°14'53". Balance the angles and compute grid azimuths for the traverse lines. (Note: Line BC bears easterly.)

From Wolfpack

Angle Summary

Station	Unadj. Angle	Adj. Angle
1	49°11'08.0"	49°11'04.0"
2	97°14'16.0"	97°14'12.0"
3	33°34'48.0"	33°34'44.0"

Angular misclosure (sec): 12"

Course	Length	Azimuth	Unbalanced Dep	Unbalanced Lat
1-2	2,187.655	**268°54'08.0"**	-2187.2535	-41.9125
2-3	2,993.583	**186°08'20.0"**	-320.1306	-2976.4166
3-1	3,923.671	**39°43'04.0"**	2507.2513	3018.0929
Sum =	9,104.909		-0.1327	-0.2362

20.30 Using grid lengths of Problem 20.28 and grid azimuths from Problem 20.29, calculate departures and latitudes, linear misclosure and relative precision for the traverse.

From WolfPack (see 20.29)

Balanced Dep	Balanced Lat	Point	Coordinates X	Coordinates Y
-2187.222	-41.856	1	1,999,028.19	171,676.04
-320.087	-2976.339	2	1,996,840.97	171,634.18
2507.309	3018.195	3	1,996,520.88	168,657.85

Linear misclosure = 0.271
Relative Precision = 1 in 33,600

20.31 If station *A* has SPCS83 state plane coordinates *E* = 1,999,028.19 ft and *N* = 171,676.04 ft, balance the departures and latitudes computed in Problem 20.30 using the compass rule, and determine SPCS83 coordinates of stations *B* and *C*.

Station	N (ft)	E (ft)
B	1,996,840.97	171,634.18
C	1,996,520.88	168,657.85

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20.32* What is the combined factor for the traverse of Problems 20.27 and 20.28?

0.99999775

20.33 The horizontal ground lengths of a four-sided closed polygon traverse were measured as follows: *AB* = 479.549 m, *BC* = 830.616 m, *CD* = 685.983 m and *DA* = 859.689 m. If the average orthometric height of the area is 1250 m, the geoidal separation is −31.785 m, and the scale factor for the traverse 0.99995704, calculate grid lengths of the lines for use in computing SPCS83 coordinates. (Use 6,371,000 m for an average radius of the Earth.)

k	0.99995704
EF	0.99980882
CF	0.99976587

Course	Obs. Dist.	Grid Dist.
AB	479.549	**479.4367**
BC	830.616	**830.4215**
CD	685.983	**685.8224**
DA	859.689	**859.4877**

20.34 For the traverse of Problem 20.33, the grid bearing of line BC is N57°39'48"W. Interior angles were measured as follows: *A* = 120°26'28", *B* = 73°48'58", *C*= 101°27'00", and *D* 64°17'26". Balance the angles and compute grid bearings for the traverse lines. (Note: Line CD bears southerly.)

misclosure = −8"

Station	Adj. Angle
A	120°26'30"
B	73°49'00"
C	101°27'02"
D	64°17'28"

Course	Azimuth
BC	S43°47'14"W
CD	S72°4'42"E
DA	S13°38'12"E
AB	N61°27'12"E

20.35 Using grid lengths from Problem 20.33 and grid bearings from Problem 20.34, calculate departures and latitudes, linear misclosure, and relative precision for the traverse. Balance the departures and latitudes by the compass rule. If the SPCS83 state plane coordinates of point *B* are *E*= 255,086.288 m and *N* = 280,654.342 m, calculate SPCS83 coordinates for points *C*, *D*, and *A*.

From WolfPack:

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Course	Length	Bearing	Unbalanced Dep	Unbalanced Lat
BC	830.422	N57°39'48.0"W	-701.6396	444.1868
CD	685.822	S43°47'14.0"W	-474.5769	-495.1052
DA	859.488	S71°55'18.0"E	817.0576	-266.7136
AB	479.437	N48°31'12.0"E	359.1878	317.5591
Sum =	2,855.169		0.0289	-0.0729

Balanced Dep	Balanced Lat	Point	Coordinates X	Coordinates Y
-701.6480	444.2080	1	255,086.288	280,654.342
-474.5838	-495.0877	2	254,384.640	281,098.550
817.0489	-266.6917	3	253,910.056	280,603.462
359.1829	317.5713	4	254,727.105	280,336.771

Linear misclosure = 0.0784
Relative Precision = 1 in 36,400

20.36 The traverse in Problems 10.9 through 10.11 was performed in the Pennsylvania North Zone of SPCS83. The average elevation for the area was 505.87 m and the average geoidal separation was −31.56 m. Using the data in Table 20.1 and a mean radius for the Earth, reduce the observations to grid and adjust the traverse. Compare this solution with that obtained in Chapter 10. (Use 6,371,000 m for an average radius of the earth.)

Using the initial coordinates (in meters) from Chapter 10, the scale factor at each station is (from WolfPack):

Station	X	Y	Scale
A	310,630.892 m	121,311.411 m	0.9999635428
B	310,544.945 m	121,105.619 m	0.9999636633
C	310,676.353 m	120,999.637 m	0.9999637217
D	310,823.019 m	121,107.996 m	0.9999636555
E	310,837.294 m	121,336.597 m	0.9999635237

Reduced distances are:

Course	Obs. Dist	k avg	C.F.	Grid. Dist.
AB	223.011	0.9999636	0.9998891	222.9863
BC	168.818	0.9999636	0.9998892	168.7993
CD	182.358	0.9999637	0.9998892	182.3378
DE	229.024	0.9999636	0.9998892	228.9986
EA	207.930	0.9999636	0.9998891	207.9069

Traverse Adjustment from WolfPack:

Angle Summary

Station	Unadj. Angle	Adj. Angle
1	119°37'20.0"	119°37'22.0"

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          2     106°12'58.0"     106°13'00.0"
          3     104°39'22.0"     104°39'24.0"
          4     130°01'54.0"     130°01'56.0"
          5      79°28'16.0"      79°28'18.0"

      Angular misclosure (sec): -10"

                                                Unbalanced
Course      Length       Azimuth         Dep        Lat
-----------------------------------------------------------
 1-2       223.056    202°40'04.0"  -85.9629  -205.8260
 2-3       168.852    128°53'04.0"  131.4367  -105.9971
 3-4       182.395     53°32'28.0"  146.6973   108.3875
 4-5       229.070      3°34'24.0"   14.2770   228.6247
 5-1       207.972    263°02'42.0" -206.4417   -25.1833
          ----------                 ---------  ---------
  Sum =  1,011.345                    0.0064     0.0057

            Balanced                          Coordinates
        Dep        Lat     Point         X              Y
-------------------------------------------------------------
     -85.9643  -205.8273     A    310,630.892    121,311.411
     131.4356  -105.9981     B    310,544.928    121,105.584
     146.6961   108.3864     C    310,676.363    120,999.586
      14.2756   228.6234     D    310,823.059    121,107.972
    -206.4430   -25.1844     E    310,837.335    121,336.595

     Linear misclosure  = 0.0086
     Relative Precision = 1 in 118,000

     Area: 66,800 sq. ft.
           1.534 acres {if distance units are feet}

Adjusted Observations
---------------------
    Course    Distance   Azimuth     Point      Angle
-------------------------------------------------------
       AB     223.058202°40'04.8"    A  119°37'23.8"
       BC     168.852128°53'05.7"    B  106°13'01.0"
       CD     182.393 53°32'28.2"    C  104°39'22.4"
       DE     229.069  3°34'22.8"    D  130°01'54.6"
       EA     207.973263°02'41.0"    E   79°28'18.2"
```

Note: The adjusted coordinates from Chapter 10 and here are provided below. The same linear misclosure and relative precision was achieved even though the coordinates vary as shown since the traverse was scaled incorrectly in Chapter 10.

	Initial Coordinates		Grid Coordinates	
Sta	E (m)	N (m)	E (m)	N (m)
A	310,630.892	121,311.411	310,630.892	121,311.411
B	**310,544.945**	**121,105.619**	**310,544.928**	**121,105.584**
C	**310,676.353**	**120,999.637**	**310,676.363**	**120,999.586**
D	**310,823.019**	**121,107.996**	**310,823.059**	**121,107.972**

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E	**310,837.294**	**121,336.597**	**310,837.335**	**121,336.595**

20.37 The traverse in Problems 10.12 through 10.14 was performed in the New Jersey zone of SPCS83. The average elevation for the area was 134.93 m and the average geoidal separation was −32.86 m. Using the data in Table 20.3 and 20.4, and a mean radius for the earth, reduce the observations to grid and adjust the traverse. Compare this solution with that obtained in Chapter 10.

Using the initial coordinates from Chapter 10, the scale factor at each station is:

Sta	E (m)	N (m)	k
A	243,605.596	25,393.201	1.00000786
B	243,725.074	25,204.886	1.00000813
C	243,887.212	25,251.913	1.00000851
D	243,882.380	25,434.202	1.00000849
E	243,703.157	25,576.825	1.00000808

The reduced distances are:

EF 0.9999840

Course	kavg	C.F.	Obs. Dist.	Grid Dist.
AB	1.00000799	0.99999	223.011	223.0092
BC	1.00000832	0.99999	168.818	168.8167
CD	1.00000850	0.99999	182.358	182.3566
DE	1.00000829	0.99999	229.024	229.0222
EA	1.00000797	0.99999	207.930	207.9283

The adjusted traverse from WolfPack:

```
Angle Summary
Station   Unadj. Angle     Adj. Angle
--------------------------------------
    1     119°37'20.0"     119°37'22.0"
    2     106°12'58.0"     106°13'00.0"
    3     104°39'22.0"     104°39'24.0"
    4     130°01'54.0"     130°01'56.0"
    5      79°28'16.0"      79°28'18.0"
Angular misclosure (sec): -10"
```

```
                                          Unbalanced
Course      Length       Azimuth         Dep         Lat
-----------------------------------------------------------
 1-2       223.009    147°36'25.0"   119.4715   -188.3074
 2-3       168.817     73°49'25.0"   162.1330     47.0315
 3-4       182.358    358°28'49.0"    -4.8363    182.2939
 4-5       229.022    308°30'45.0"  -179.2035    142.6088
 5-1       207.928    207°59'03.0"   -97.5657   -183.6168
```

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```
          ----------                    ---------  ---------
  Sum =  1,011.134                      -0.0011     0.0100

            Balanced                            Coordinates
         Dep        Lat     Point         X              Y
-------------------------------------------------------------
     119.4717  -188.3096     A    243,605.596     25,393.201
     162.1332    47.0299     B    243,725.068     25,204.891
      -4.8361   182.2920     C    243,887.201     25,251.921
    -179.2033   142.6065     D    243,882.365     25,434.213
     -97.5655  -183.6188     E    243,703.161     25,576.820

     Linear misclosure  = 0.0101
     Relative Precision = 1 in 100,200

     Area: 66,800 sq. ft.
           1.534 acres {if distance units are feet}

Adjusted Observations
---------------------
    Course    Distance   Azimuth     Point      Angle
-----------------------------------------------------
       AB     223.011147°36'25.9"     A 119°37'24.1"
       BC     168.816 73°49'27.0"     B 106°13'01.1"
       CD     182.356358°28'49.2"     C 104°39'22.1"
       DE     229.021308°30'43.5"     D 130°01'54.4"
       EA     207.930207°59'01.8"     E  79°28'18.3"
```

Note: The adjusted coordinates from Chapter 10 and here are provided below. The same linear misclosure and relative precision was achieved even though the coordinates vary as shown since the traverse was scaled incorrectly in Chapter 10.

	10's Solution		Current Solution	
Sta	E (m)	N (m)	E (m)	N (m)
A	243,605.596	25,393.201	243,605.596	25,393.201
B	**243,725.074**	**25,204.886**	**243,725.068**	**25,204.891**
C	**243,887.212**	**25,251.913**	**243,887.201**	**25,251.921**
D	**243,882.380**	**25,434.202**	**243,882.365**	**25,434.213**
E	**243,703.157**	**25,576.825**	**243,703.161**	**25,576.820**

20.38 The traverse in Problem 10.22 was performed in the New Jersey SPCS 1983. The average elevation of the area was 85.78 m and the average geoidal separation was −30.85 m. Using 6,371,000 m for the mean radius of the earth, reduction the observations to grid and adjust the traverse using the compass rule. Compare this solution with that obtained in Problem 10.22.

The initial coordinates, k, and convergence angles are

Sta	E (m)	N (m)	k	γ	Latitude	Longitude
A	194,325.090	25,353.988	0.99992418	0°19'21.878"	39°03'38.21780"N	73°59'16.19484"W
B	194,193.440	25,535.326	0.99992404	0°19'18.495"	39°03'44.12252"N	73°59'21.62856"W
C	194,097.180	25,469.288	0.99992394	0°19'15.947"	39°03'41.99845"N	73°59'25.64806"W

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D	193,892.720	25,577.937	0.99992371	0°19'10.628"	39°03'45.55896"N	73°59'34.12765"W
E	193,819.150	25,514.391	0.99992364	0°19'08.676"	39°03'43.51149"N	73°59'37.20266"W

The elevation factor is 0.99999138
The reduced distances are:

Course	Obs. Dist.	kavg	CF	Grid Dist.
AB	224.111	0.99992411	0.99991549	224.0921
BC	116.738	0.99992399	0.99991537	116.7281
CD	231.566	0.99992383	0.99991520	231.5464
DE	97.217	0.99992368	0.99991505	97.2087

The traverse computations are:

Angle Summary

Station	Unadj. Angle	Adj. Angle
1	253°03'38.0"	253°03'40.0"
2	91°32'06.0"	91°32'08.0"
3	242°25'54.0"	242°25'56.0"
4	111°12'02.0"	111°12'04.0"
5	295°31'13.0"	295°31'15.0"

Angular misclosure (sec): -10"

Course	Length	Azimuth	Unbalanced Dep	Unbalanced Lat
1-2	224.092	324°01'03.0"	-131.6627	181.3345
2-3	116.728	235°33'11.0"	-96.2599	-66.0264
3-4	231.546	297°59'07.0"	-204.4713	108.6519
4-5	97.209	229°11'11.0"	-73.5714	-63.5356
Sum =	669.575		-505.9652	160.4244

Misclosure in Departure = -505.9652 - -505.9400 = -0.0252
Misclosure in Latitude = 160.4244 - 160.4030 = 0.0214

Balanced Dep	Balanced Lat	Point	Coordinates X	Coordinates Y
-131.6542	181.3274	A	194,325.090	25,353.988
-96.2555	-66.0301	B	194,193.436	25,535.315
-204.4625	108.6445	C	194,097.180	25,469.285
-73.5678	-63.5388	D	193,892.718	25,577.930
		E	193,819.150	25,514.391

Linear misclosure = 0.0330
Relative Precision = 1 in 20,300

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```
Adjusted Observations
---------------------
    Course    Distance   Azimuth     Point      Angle
-------------------------------------------------------
       AB     224.081324°01'05.4"    A  253°03'42.4"
       BC     116.727235°33'01.2"    B   91°31'55.8"
       CD     231.535297°59'04.8"    C  242°26'03.6"
       DE      97.208229°11'00.9"    D  111°11'56.1"
                                     E  295°31'15.0"
```

Note: That solution from Chapter 10 and here are different since this is a link traverse. The relative precision went from 1:8,800 to 1:20,300. The coordinates vary as shown below since the traverse was scaled incorrectly in Chapter 10.

	Initial coordinates		Final coordinates	
Sta	E (m)	N (m)	E (m)	N (m)
A	194,325.090	25,353.988	194,325.090	25,353.988
B	194,193.440	25,535.326	194,193.436	25,535.315
C	194,097.180	25,469.288	194,097.180	25,469.285
D	193,892.720	25,577.937	193,892.718	25,577.930
E	193,819.150	25,514.391	193,819.150	25,514.391

20.39 The traverse in Problem 10.21 was performed in the Pennsylvania North Zone of SPCS83. The average elevation for the area was 367.89 m and the average geoidal separation was −30.23 m. Using the mean radius of the earth of 6,371,000 m, reduce the observations to grid and adjust the traverse using the compass rule. Compare this solution with that obtained in Problem 10.21.

The initial coordinates, scale factors, and convergence angles are:

Sta	X (ft)	Y (ft)	k	γ
A	2,521,005.86	379,490.84	0.99996463	1°19'41.271"
B	2,521,180.16	379,589.99	0.99996461	1°19'42.799"
C	2,521,432.84	379,566.02	0.99996462	1°19'44.980"
D	2,521,575.16	379,714.76	0.99996459	1°19'46.241"

The elevation factor is 0.99994700.

The reduced distances are:

Course	Obs. Dist.	k_{avg}	C.F.	Grid Dist.
AB	200.55	0.9999646	0.99991163	200.532
BC	253.84	0.9999646	0.99991162	253.818
CD	205.89	0.9999646	0.99991161	205.872

The recomputed traverse using grid distances is:

```
Angle Summary
Station   Unadj. Angle     Adj. Angle
-------------------------------------
    1     258°12'18.0"     258°12'27.0"
    2     215° 2'53.0"     215°03'02.0"
```

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```
              3     128°19'11.0"     128°19'20.0"
              4     237°34' 5.0"     237°34'14.0"

          Angular misclosure (sec): -36"

                                                  Unbalanced
Course      Length       Azimuth        Dep         Lat
-----------------------------------------------------------
 1-2        200.53     60°21'55.0"   174.301     99.157
 2-3        253.82     95°24'57.0"   252.685    -23.956
 3-4        205.87     43°44'17.0"   142.332    148.744
          ----------                 ---------  ---------
  Sum =     660.22                   569.319    223.945

Misclosure in Departure = 569.319 - 569.300 = 0.019
Misclosure in Latitude  = 223.945 - 223.920 = 0.025

            Balanced                          Coordinates
        Dep        Lat     Point         X              Y
-----------------------------------------------------------------
      174.296     99.149     1   2,521,005.86     379,490.84
      252.678    -23.966     2   2,521,180.16     379,589.99
      142.326    148.736     3   2,521,432.83     379,566.02
                             4   2,521,575.16     379,714.76

     Linear misclosure  = 0.031
     Relative Precision = 1 in 21,300
```

Note: That solutions from Chapter 10 and here are different since this is a link traverse. The relative precision went from 1:8100 to 1:21,300. The coordinates vary slightly as shown below since the traverse was scaled incorrectly in Chapter 10.

	Initial coordinates		Final coordinates	
Sta	X (ft)	Y (ft)	X (ft)	Y (ft)
A	2,521,005.86	379,490.84	2,521,005.86	379,490.84
B	2,521,180.16	379,589.99	2,521,180.16	379,589.99
C	2,521,432.84	379,566.02	2,521,432.83	379,566.02
D	2,521,575.16	379,714.76	2,521,575.16	379,714.76

20.40* If the geodetic azimuth of a line is 205°06'36.2" the convergence angle is −0°42'26.1" and the arc-to-chord correction is +0.8" what is the equivalent grid azimuth for the line?

205°39'03.1" = 205°06'36.1" + 0°42'36.2" + 0.8"

20.41 If the geodetic azimuth of a line is 306°27'10.1" the convergence angle is −1°58'22.8" and the arc-to-chord correction is −1.5", what is the equivalent grid azimuth for the line?

308°25'22.3" = 18°47'20.1" + 1°08'06.8" − 1.5"

20.42 Using the values given in Problems 20.40 and 20.41, what is the obtuse grid angle between the two azimuths?

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102°36'19.2"

20.43 The grid azimuth of a line is 42°07'58". If the convergence angle at the endpoint of the azimuth is −1°58'02.9" and the arc-to-chord correction is 0.7", what is the geodetic azimuth of the line?

40°09'54.4" = 42°07'58" − 1°58'02.9" − 0.7"

20.44 Similar to Problem 20.43, except the convergence angle is −1°02'20.7" and the arc-to-chord correction is −1.3".

41°05'38.6" = 42°07'58" − 1°02'20.7" + 1.3"

20.45 Using the defining parameters given in Example 20.10, compute oblique stereographic map projection coordinates for Station B.

Sta	Π	m	A	E	N	k
B	0.71759585	0.75229451	6368873.37	**−868.958**	**188.599**	1.000000
C	0.71758724	0.75230019	8114471	581.130	170.326	1.274083
D	0.71754043	0.75233104	9260051.2	534.544	−239.047	1.453954

20.46 Similar to Problem 20.47 except for Station C.

NE = (**170.326, 581.130)** See Problem 20.47 for intermediate values.

20.47 Similar to Problem 20.47 except for Station D.

NE = (**−239.047, 534.544**) See Problem 20.47 for intermediate values.

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