Canadian Board of Examiners for Professional Surveyors
Core Syllabus Item
C 4: COORDINATE SYSTEMS AND MAP PROJECTIONS

Syllabus Topics:

Celestial sphere and its coordinate systems (horizon, right ascension, hour angle and ecliptic); Time systems (sidereal, apparent, and universal); Earth-fixed, celestial inertial and orbital coordinate systems and their transformations; Spatial reference systems and spatial reference frames, including Canadian Spatial Reference Systems (CSRS), ITRS, ITRF, NAD27, NAD83, WGS84, CGVD28, NAVD 88; and Definition of horizontal and vertical datums.

Principles of map projections, including introductory principles of derivation to enable critiquing of software output, general problem of map projections, projection surfaces (planar, conical and cylindrical), distortion characteristics (azimuthal, equidistant, conformal, equal-area, Tissot indicatrix, scale factor), aspects, and map projections classification bases.

Examples of common map projections used in Canada and internationally, including the following:

Mercator Projection, including projection characteristics, geographic to grid and grid to geographic transformations, scale factors, and loxodrome evaluations.

Transverse Mercator Projection and the Modified Transverse Mercator (MTM) projections (3 degree and 6 degree (UTM)), including projection characteristics, geographic to grid and grid to geographic transformations, scale factors, meridian convergence, and reduction (scale factor, arc to chord, etc.) of terrain measurements to the mapping surface.

Stereographic Double Projection, including projection characteristics, geographic to grid and grid to geographic transformations, scale factors, meridian convergence, and reduction (scale factor, arc to chord, etc.) of terrain measurements to the mapping surface.

Lambert Conformal Conic Projection, including projection characteristics, geographic to grid and grid to geographic transformations, scale factors, and meridian convergence.

A collection of formulae are provided with the examination questions when necessary.

Recommended Prior Knowledge and Skills:

Item C 1: Mathematics

Item C 2: Least-Squares Estimation and Data Analysis

Item C 3: Advanced Surveying

Extensive experience in survey computations and survey data analysis; familiarity with commonly used Map Projection software and its mapping procedures; ability to use the Internet resources to enhance learning experience, clarify terminology, and identify projection types commonly used by the various provincial governments in Canada.

Learning Outcomes:

In order to satisfy the requirements of this syllabus item, candidates should be able to:

1. Describe the celestial sphere and its main coordinate systems (Horizon, Right Ascension, Hour Angle, and Ecliptic).
    - State the basic assumptions and approximations involved.

- Identify the locations of the origins and the orientations of the coordinate axes.
- Relate celestial spherical coordinates to Cartesian coordinates, celestial systems to each other, and celestial systems to terrestrial coordinate systems.
- Explain major uses of each of the celestial coordinate systems.

2. Interpret and apply time systems (sidereal, apparent and universal).
   - Identify the characteristics of the time systems, their relationships and applications.
   - Define epochs, intervals and time scales with regard to the time systems.
   - Select a time system and required corrections for a given situation.
3. Describe the Earth-fixed coordinate systems (natural coordinate system and ellipsoidal coordinate system).
   - Explain the specific properties of the coordinate systems.
   - Illustrate (showing the locations of the origins and the orientations of the coordinate axes) the different coordinate systems.
   - Explain the mutual relationships among the different coordinate systems.
4. Analyze the elements of celestial inertial coordinate system.
   - Explain the importance of inertial reference system.
   - List different motions that must be eliminated from astrometric observations in order to define inertial frame of reference.
   - Relate Conventional Terrestrial (CT) system to Conventional Inertial (CI) system.
5. Describe the orbital coordinate system.
   - Identify the characteristics (origins and directions of coordinate axes) and applications of the orbital coordinate system.
   - Identify the elements involved in transforming satellite positions in instantaneous system to Conventional Terrestrial (CT) system.
6. Discuss the characteristics and applications of spatial reference systems and spatial reference frames.
   - Use the following terms correctly: coordinate system, spatial reference system, spatial reference frame, horizontal datum and vertical datum.
   - Explain the characteristics (origin, coordinate axes, etc) of commonly used reference systems (CSRS, ITRS); reference frames (NAD83, ITRF); and datums (NAD27, NAD83, WGS84, CGVD28, CGG20000 or latest version, hybrid datum, etc.).
   - Describe how reference systems and reference frames are defined.
7. Demonstrate an understanding of the principles of map projections (including introductory principles of derivation to enable critiquing of software output).
   - Identify the general problems of map projections (including edge-matching), the different models of the earth, and the uses and applications of map projections.
   - Explain different map projection types with regard to different projection surfaces (or developable shapes), aspects, cases (tangent and secant) and distortion characteristics (e.g., azimuthal, equidistant, conformal, equal-area, Tissot's indicatrix and scale factor).

- Derive distortion characteristics (conformality, equivalency and equidistancy conditions, scale factor, etc.) from given mapping equations (from the reference sphere or from the reference ellipsoid, to the plane).
- Use the graticule appearance of map projection and distortion theory to recognize and classify map projections.
- Use general map projection selection guidelines to choose a suitable map projection for a region.

8. Demonstrate an understanding of the characteristics of the Mercator projection.
   - Identify the characteristics, appearance and applications of the projection.
   - Use appropriate formulas to solve direct and inverse problems (geographic to grid and grid to geographic transformations), including loxodrome evaluations.
   - Use the appropriate formulas to compute the meridian convergence and scale factor on the projection plane.
9. Demonstrate an understanding of the characteristics of the Transverse Mercator Projection and MTM projections (3 degree and 6 degree (UTM)).
   - Illustrate the graticule appearances and the interrelationship of the following specific map projections: Transverse Mercator (TM); Universal Transverse Mercator (UTM) and its extensions; and Local Transverse Mercator (LTM), such as Transverse Mercator in 3 degree zones (3° TM).
   - Discuss the uses and applications of the projections.
   - Use appropriate formulas to solve direct and inverse problems (geographic to grid and grid to geographic transformations) for the TM, UTM and LTM projections.
   - Use appropriate formulas to compute the meridian convergence and scale factor on the TM, UTM and LTM projection planes.
   - Carry out the reduction of angle (direction), azimuth and distance observations onto the TM, UTM and LTM projection planes.
10. Demonstrate an understanding of the characteristics of the Stereographic Double Projection.
    - Illustrate the graticule appearance of the projection.
    - Discuss the uses and applications of the projection.
    - Use appropriate formulas to solve direct and inverse problems (geographic to grid and grid to geographic transformations) of the projection.
    - Use appropriate formulas to compute the meridian convergence and scale factor on the projection plane.
    - Carry out the reduction of angle (direction), azimuth and distance observations onto the Stereographic Double Projection plane.
11. Demonstrate an understanding of the characteristics of the Lambert Conformal Conic projection.
    - Illustrate the graticule appearance of the projection.
    - Discuss the uses and applications of the projection.
    - Use appropriate formulas to solve direct and inverse problems (geographic to grid and grid to geographic transformations) of the projection.

- Use appropriate formulas to compute the meridian convergence and scale factor on the projection plane.

Essential Reference Material:

The list of essential and supplementary references is extensive; however, all references are readily available and many are short articles rather than texts. Every effort has been made to refer to specific sections or pages in the learning outcomes and study guide.

 # prefix on items to be available from CBEPS for downloading.

Hradilek, L. and A.C. Hamilton [1973]. *Systematic Analysis of Distortions in Map Projections.* Geodesy and Geomatics Engineering Department Lecture Notes No. 34, University of New Brunswick, Fredericton, Canada.

Available via <gge.unb.ca> under "Publications": "Technical Reports" or via <http://gge.unb.ca/Pubs/LN34.pdf>

A good treatment of the theory (including useful derivations) of distortions of various map projections.

Junkins, D. And G. Garrard [1998]. "Demystifying Reference Systems: A Chronicle of Spatial Reference Systems in Canada", Geomatica, volume 52, No. 4.

Available via http://www.geod.nrcan.gc.ca/publications/papers/pdf/datums_e.pdf

An Internet resource providing useful explanations on various terms relating to 2D coordinate systems.

Krakiwsky, E.J. [1973]. *Conformal Map Projections in Geodesy*. Department of Geodesy and Geomatics Engineering Lecture Notes No. 37, University of New Brunswick, Fredericton, Canada.

Available via <gge.unb.ca> under "Publications": "Technical Reports" or via <http://gge.unb.ca/Pubs/LN37.pdf>

A comprehensive treatment of conformal Map projections with useful derivations provided.

Krakiwsky, E.J. and D.E. Wells [1971]. *Coordinate Systems in Geodesy*. Department of Geodesy and Geomatics Engineering Lecture Notes No. 16, University of New Brunswick, Fredericton.

Available via <gge.unb.ca> under "Publications": "Technical Reports"

A good treatment of the theory of coordinate systems as used in Geomatics.

Note: Average Terrestrial Pole is used instead of Conventional International Origin (a more modern terminology); Average Terrestrial System instead of Conventional Terrestrial Reference System or Conventional Terrestrial System; and Mean Observatory instead of Greenwich zero Meridian.

Snyder, J.P. [1987]. *Map Projections – A Working Manual.* U.S.A. Geological Survey Professional Paper 1395. United States Government Printing Office, Washington. Chapters 1-8, 14, 15, 21 and Appendix A.

Available via < http://pubs.er.usgs.gov/djvu/PP/PP_1395.pdf>

A comprehensive treatment of Map projections with useful examples provided in the Appendix A.

Thomson, D. B., E. J. Krakiwsky, R. R. Steeves [1977]. *A manual for Geodetic Coordinate Transformations in the Maritime Provinces*, Geodesy and Geomatics Engineering Department Technical Report No. 48, University of New Brunswick, Fredericton, Canada.

Available via <gge.unb.ca> under "Publications": "Technical Reports" or via <http://gge.unb.ca/Pubs/TR48.pdf>

A readily available manual with no derivations or extensive explanations of mathematical formulae, but providing good numerical examples on geodetic coordinate transformations in the Atlantic Provinces.

Thomson, D. B., M. P. Mephan, and R. R. Steeves [1998]. *The Stereographic Double Projection,* Geodesy and Geomatics Engineering Department Technical Report No. 46, University of New Brunswick, Fredericton, Canada. Chapters 1 - 4.

Available via <gge.unb.ca> under "Publications": "Technical Reports" or via <http://gge.unb.ca/Pubs/TR46.pdf>

A readily available material with comprehensive treatment of the theory (including the derivations) of Stereographic Double Projection as used in the Atlantic Provinces.

Torge, W. [2001]. *Geodesy*. 3rd edition, Walter de Gruyter, N.Y. , ISBN 3-110-17072-8. [Reference systems (18-44); Natural coordinates (64-66); The Geodetic Earth Model (91-102)].

A good treatment of some aspect of coordinate systems with more modern terminology used in comparison with Krakiwsky and Wells [1971].

Note: The Conventional Terrestrial System is referred to as Global Earth-Fixed Geocentric System; CIO is referred to as Conventional "Mean" Terrestrial Pole.

Véronneau, M [2006]. *Demystifying the vertical datum in Canada: A case study in the Mackenzie Delta.* Natural Resources Canada.

Available via http://www.geod.nrcan.gc.ca/hm/pdf/verticaldatumsdeltav10_e.pdf

An Internet resource providing useful explanations on various terms relating to vertical datum.

Supplementary Reference Material:

The list of essential and supplementary references is extensive; however, all references are readily available and many are short articles rather than texts. Every effort has been made to refer to specific sections or pages in the learning outcomes and study guide.

 # prefix on items to be available from CBEPS for downloading.

Altamimi, Z. et al. [2001]. Papers - International Terrestrial Reference Frame (ITRF). Natural Resources Canada.

available at <http://www.geod.nrcan.gc.ca/publications/papers/pdf/itrf2000.pdf>

A useful Internet resource providing useful explanations on various terms relating to ITRF.

anon. [2007]. *Canadian Spatial Reference System*, Natural Resources Canada .

Available at <http://www.geod.nrcan.gc.ca/edu/geod/reference/index_e.php>

A readily available Internet resource providing a comprehensive overview of the Canadian spatial reference system.

anon. [2009]. *Map Projections.* Natural Resources Canada.

Available at <http://atlas.nrcan.gc.ca/site/english/learningresources/carto_corner/map_projections.html>

A good Internet resource that summarizes, in simple terms, some basic aspect of map projections.

Dana, P. H. [1999]. Coordinate Systems.

http://www.colorado.edu/geography/gcraft/notes/coordsys/coordsys_f.html.

An Internet resource providing useful summary of various coordinate systems.

Dana, P. H. [2000]. Map Projections.
http://www.colorado.edu/geography/gcraft/notes/mapproj/mapproj.html.

An Internet resource providing useful summary of various map projections.

Donnelly, M. and D. Raymond [2002]. *Map Projections and Datums of the Atlantic Provinces Making it Fit-or-Having a Fit.*

Available at
<http://luxor.acadiau.ca/library/data/GIS/gis_workshop/ex/Introduction_to_Projections.ppt>

A useful overview of various map projections used in the Atlantic Provinces.

Furuti, C. A. [1997]. *Map Projections*.
http://www.progonos.com/furuti/MapProj/Normal/TOC/cartTOC.html.

Internet resource with comprehensive treatment of various map projections with lots of graphics, including Tissot indicatrices of various map projections.

Maling, D.H. [1992]. *Coordinate Systems and Map Projections*, 2nd edition, Pergamon Pr. (ISBN-13 9780080372341) or Butterworth-Heinemann (ISBN-13: 9780080372334).

Detailed treatment of coordinate systems and map projections. The book, however, has been out of print for some times now; the available copies may cost above C$200.00 per copy.