Making Sense of Evolving Datums: WGS84 and NAD83

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Abstract

The World Geodetic System 1984 (WGS84) and North American Datum of 1983 (NAD83) are presently the most widely-used spatial reference systems in North America. NAD83 is the national reference system used for georeferencing by most federal and provincial/state agencies in Canada and the U.S. while WGS84 is the default "native" system used by the Global Positioning System (GPS) and commercial GPS receivers. The physical realization of these reference systems have undergone several updates since they were first introduced over two decades ago. NAD83 has evolved from a traditional, ground-based horizontal control network to a space-based 3D realization fully supporting modern GPS techniques and the integration of both horizontal and vertical reference systems. WGS84, on the other hand, has no publicly accessible ground-based network. It is accessible only via broadcast orbits that provide positions with an accuracy of about a meter at best (with augmented corrections).

Originally, NAD83 and WGS84 were based on the same global datum using an older satellite positioning system called Transit or Doppler. The reference systems were thus completely compatible with each other. However, they diverged in 1994 when WGS84 was redefined with GPS based on a more accurate reference system called the International Terrestrial Reference Frame (ITRF). This redefinition occurred two more times using more recent and more accurate versions of the ITRF.

The redefinition of WGS84 resulted in coordinates differences of up to 1.5 m horizontally and 1 m vertically with respect to NAD83 in Canada. Although the national geodetic agencies in both Canada and the U.S. adopted a common transformation between NAD83 and the various ITRFs for use with the new realizations of WGS84, the bias between NAD83 and WGS84 was never acknowledged by the agency maintaining WGS84. Consequently, the vast majority of GPS receiver manufactures continue to treat NAD83 as being identical with the new realizations of WGS84 which results in position errors of over a meter. Moreover, ITRF-based systems are global systems in which all the continents are in continuous motion due to the Earth's tectonic forces while NAD83 is fixed to the North American tectonic plate and move with it. Consequently, NAD83 moves at about 2.5 cm/y relative to the ITRF/WGS84 systems.

Details of the adopted NAD83transformations are provided to allow users to properly account for these differences between NAD83 and ITRF-based systems such as WGS84 in a consistent way throughout North America. For further information see M. Craymer (The Evolution of NAD83 in Canada. Geomatica, Vol. 60, No. 2, pp. 151-164. <ftp://geod.nrcan.gc.ca/pub/GSD/craymer/pubs/nad83_geomatica2006.pdf>).

Outline

- Some basic concepts
- Old Systems:
  - World Geodetic System 1984 (WGS84)
  - North American Datum of 1983 (NAD83)
- Modern Systems:
  - International Terrestrial Reference Frame (ITRF)
  - WGS84(G…)
  - NAD83(CSRS)
- Some practical issues

Basic Concepts

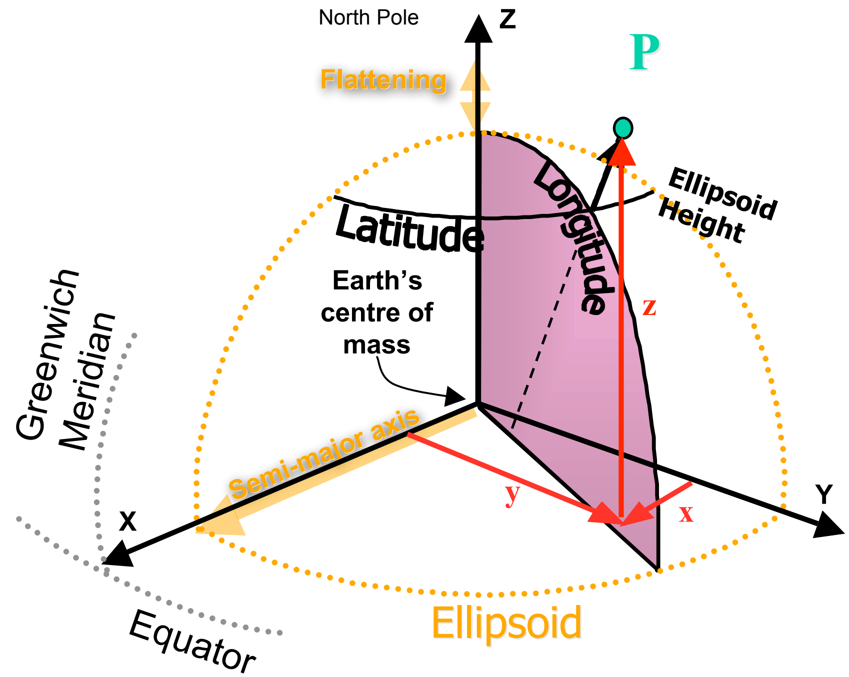
Spatial Reference System

- A prescription for physically realizing a reference system
  - Orderly collection of logically related principles, facts, objects and techniques that can be used for a quantitative description of positions and motions in space

Basic Concepts (con't)

Datum

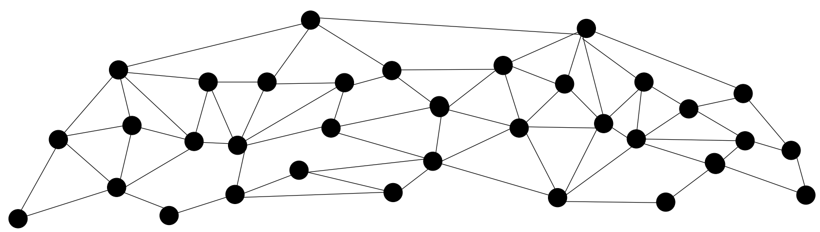
- Theoretical reference surface
- Geometric model of the Earth
  Reference ellipsoid
  - Semi-major axis (equatorial radius)
  - Semi-minor axis (polar radius)
  - Aligned with coordinate system



Basic Concepts (con’t)

Spatial Reference Frame

- Physical realization of a Spatial Reference System
- Usually a network of monumented points



- Established using geodetic survey techniques
- Published coordinates define the frame
- New realizations/versions as technology evolves

Old Reference Frames

WGS84

NAD83

Original WGS84

Native reference frame of GPS

Datum

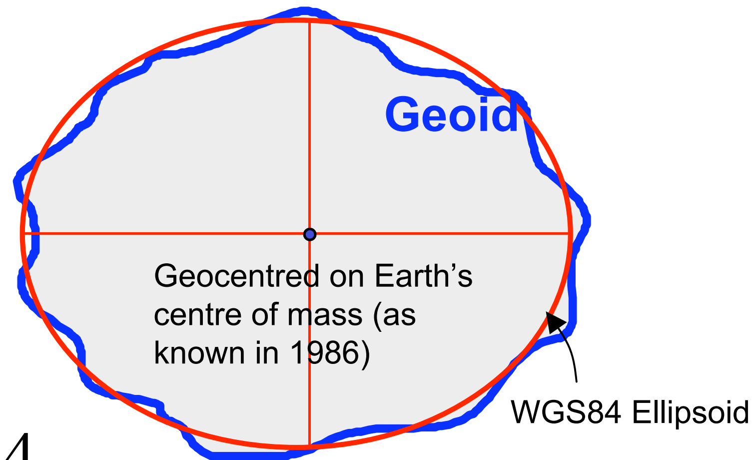
- WGS84 ellipsoid (=GRS80)

Based on Doppler & BTS84

- Aligned to international BTS84
- Near-geocentric +/- 1 m (best could do at the time)

No physical ground network or coordinates

- Satellites (brdcst orbits) are only accessible "control"
- Enables point positioning only: 1-10 m accuracy



Original NAD83

National reference system in Canada & U.S.

Datum

- GRS80 ellipsoid (=WGS84)

Defined same as WGS84

- Identical to WGS84
- Fixed to North American plate

Physical realization

- Traditional control networks & published coordinates

Limitations of Original WGS84/NAD83

Revealed by advances in GPS

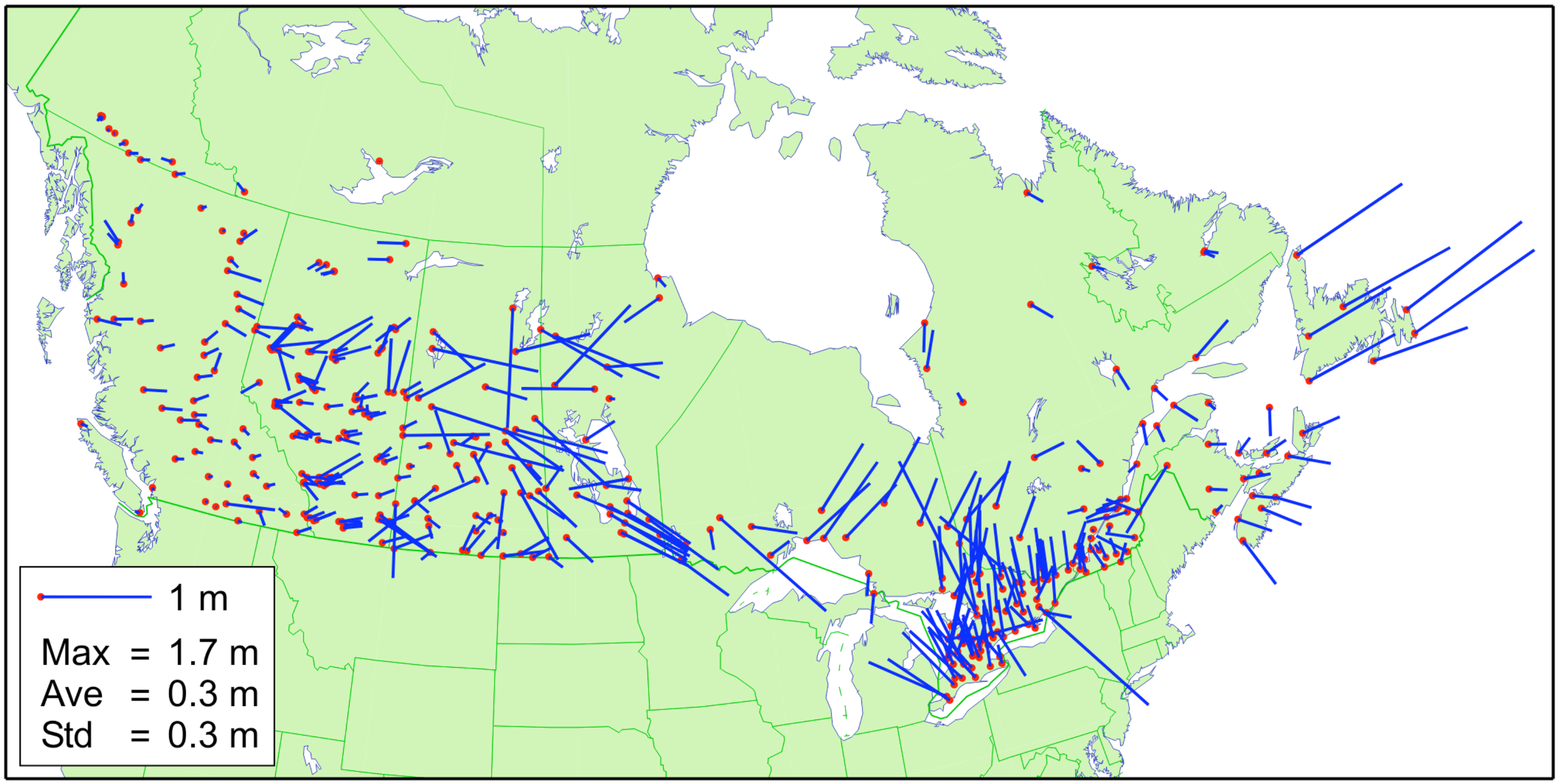
1) Non-geocentric

- Offset from geocenter by about a meter
- Incompatible with modern reference frames

2) NAD83 primarily a horizontal reference frame

- Densified using traditional 2D survey methods
- Errors of up to 1 m and more

Errors in NAD83(Original)



Modern Reference Frames

ITRF

WGS84 “G” series

NAD83(CSRS)

International Terrestrial Reference Frame

Best geocentric system available

- Stable to about a cm
- Maintained by IERS under auspices of IAG
- Primarily for scientific community & national datums

Dynamic system

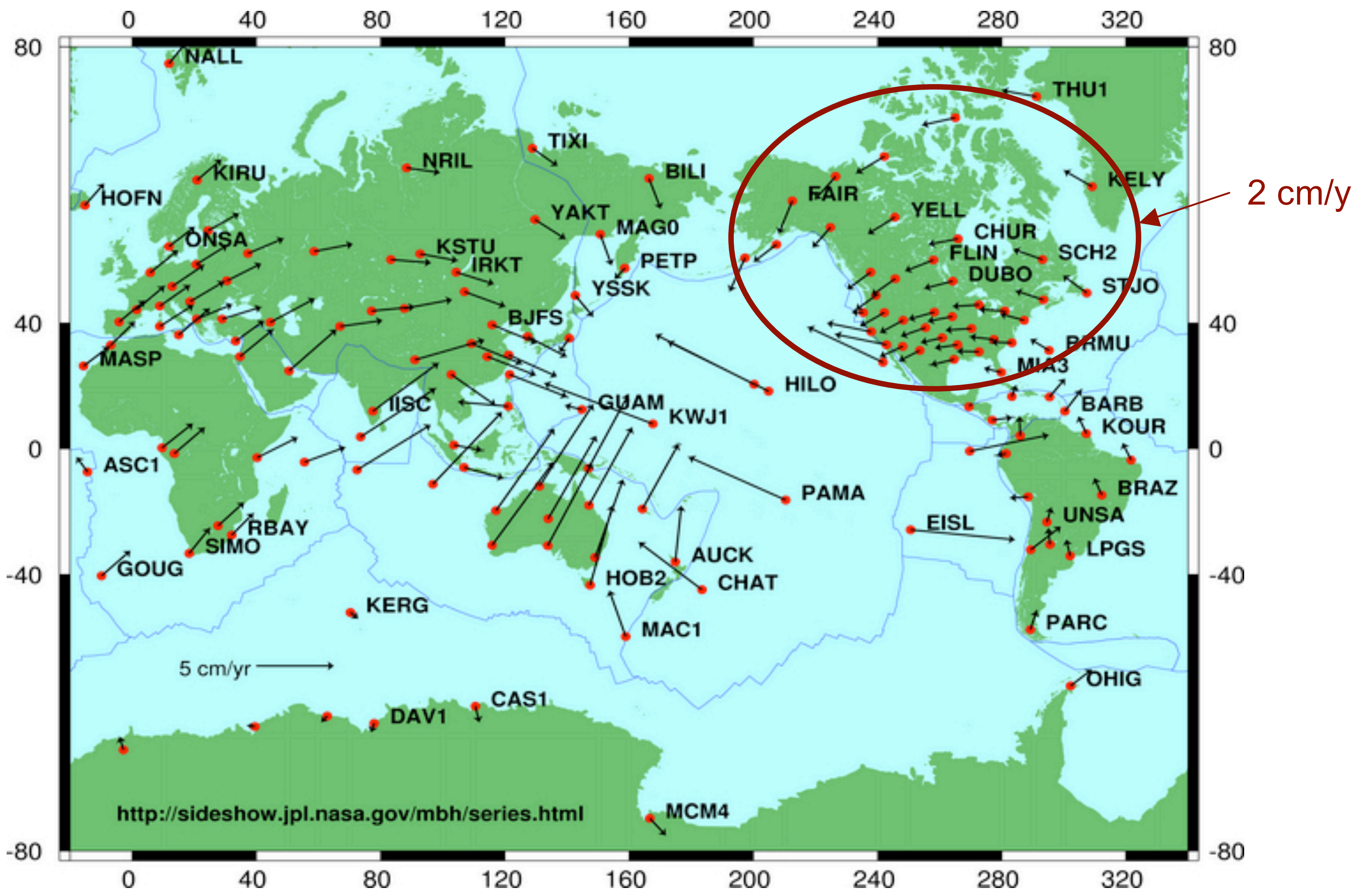
- Coordinates changing due to plate tectonics
  - Valid only for a specific date (epoch)
  - Velocities provided to update to other epochs

Frequent new realizations

- Due to more data & improved techniques

ITRF88
ITRF89
ITRF90
ITRF91
ITRF92
ITRF93
ITRF94
ITRF96
ITRF97
ITRF2000
ITRF2005

Plate Tectonic Motions



WGS84 "G" Series

Original WGS84 Realigned to ITRF (shifted/reoriented)

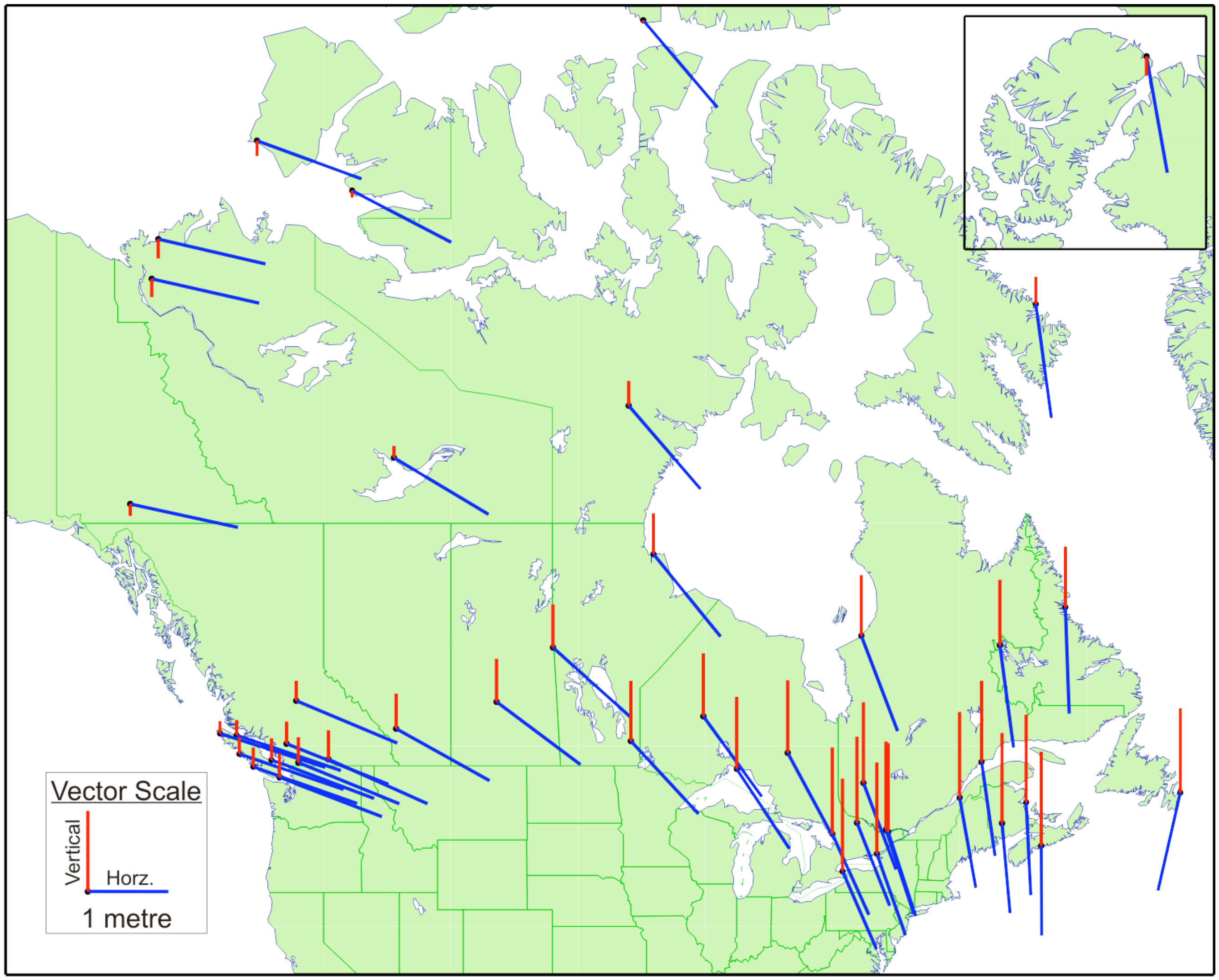
- Greater accuracy & stability
- Compatible with internationally adopted ITRF

Version	Based on	Introduced
WGS84(G730)	ITRF91	1994
WGS84(G873)	ITRF94	1996
WGS84(G1150)	ITRF2000	2002

Introduced a coordinate shift

- In Canada: 1.5 m horiz. 0.2-1.0 m vert.
- Not noticeable in WGS84 (+/- 1 m) but is in NAD83

WGS84(Orig)/NAD83 vs WGS84(G1150)/ITRF2000



NAD83(CSRS)

Defined as a best fitting transformation from ITRF

- Also models tectonic motion of North America
- As accurate & stable as ITRF
- Adopted in Canada and U.S.
- Transformation updated for new ITRFs
- ***Web & software tools available (www.geod.nrcan.gc.ca)***

Still compatible with NAD83(Orig)

- Differences due to errors in original
- ***Different from new WGS84(G…) by 1.5 m !!***

NAD83

Fixed

1986 ***NAD83 (Orig)***

- NAD83 reference system based on Doppler

- Coordinate shifts of 1.5 m horizontally, 1 m vertically

- metre-accuracy NAD83

1998 ***NAD83 (CSRS)***

- same NAD83 reference system

- same geocentre offset/misalign

- transformation from ITRF

- cm-accuracy NAD83

WGS84

Fixed

1987 ***WGS84 (Orig)***

- same as NAD83

- +/- 1 m accuracy

1.5 m shift

Dynamic

1994 ***WGS84(G730)***

- aligned with ITRF91

1997 ***WGS84(G873)***

- aligned with ITRF94

2001 ***WGS84(G1150)***

- aligned with ITRF2000

ITRF

Dynamic

1988 ***ITRF88***

- geocentric

ITRF89

ITRF90

ITRF91

ITRF92

ITRF93

Small incremental changes

ITRF94

ITRF96

ITRF97

ITRF2000

Practical Issues

NGA Datum Shift for NAD83

Correction Sevices

NGA Datum Shift for NAD83

- NGA (publishers of WGS84) official datum shift table

`http://earth-info.nga.mil/GandG/publications/tr8350.2/tr8350_2.html`

Local Geodetic Datums		Reference Ellipsoids and Parameter Differences			No. of Satellite Stations Used	Transformation Parameters								
Name	Code	Name	Δa(m)	$\Delta f \times 10^4$		Cycle Number	Pub. Date	ΔX(m)		ΔY(m)		ΔZ(m)		
NORTH AMERICAN 1983	NAR	GRS 80	0	-0.00000016										
Alaska (Excluding Aleutian Islands)	NAR-A				42	0	1987	0	±2	0	±2	0	±2	
Aleutian Islands	NAR-E				4	0	1993	-2	±5	0	±2	4	±5	
Canada	NAR-B				96	0	1987	0	±2	0	±2	0	±2	

NAD83-WGS84
3 parameter shift
(incorrect)

- Used by majority of GSP receivers
  - Set receiver to NAD83
  - Zero datum shift applied (incorrect)
  - *Still in WGS84 -- need to transform using adopted procedure*

Correction Services

Reference frame depends on service/source

- *Uncorrected or WAAS corrections*
  - Receiver positions always in WGS84
  - Still in WGS84 if NGA (zsero) shift to NAD83 applied
- *CDGPS or Coast Guard corrections*
  - Receiver positions in NAD83(CSRS)
  - *Falls back to WGS84 without warning if service signal lost*
- *Post-processing with CSRS-PPP*
  - User selects either NAD83(CSRS) or ITRF/WGS84(G)
- *CSRS Database ("published" values)*
  - Either NAD83 or NAD83(CSRS)

For More Information

Craymer, M. (2006). The evolution of NAD83 in Canada. *Geomatica*, Vol. 60, No. 2, pp. 151-164.

<ftp://geod.nrcan.gc.ca/pub/GSD/craymer/pubs/nad83_geomatica2006.zip>