Making Sense of Evolving Reference Frames for North America

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Abstract

The World Geodetic System 1984 (WGS84) and North American Datum of 1983 (NAD83) are 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 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). More recently, a new reference systems called the Stable North American Reference Frame (SNARF) has been created primarily in support of Plate Boundary Observatory component of the EarthScope project. We explain the differences between these global and regional reference frames and as well as their relationship to each other. We also discuss some problems that occur when these relationships are not properly represented as done, for example, with NAD83 in the vast majority of GPS receivers.

Outline

- Old Reference Frames :
  - World Geodetic System 1984 (WGS84)
  - North American Datum of 1983 (NAD83)
- Modern Reference Frames:
  - International Terrestrial Reference Frame (ITRF)
  - WGS84(G…)
  - NAD83(CSRS/CORS96)
  - SNARF
- Some practical issues

Old Reference Frames

WGS84

NAD83

Original WGS84

Native reference frame of GPS

Datum

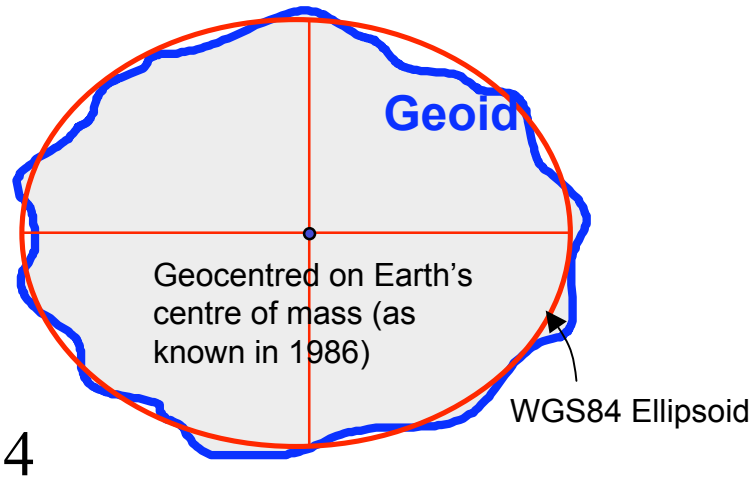
- WGS84 ellipsoid (=GRS80)

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

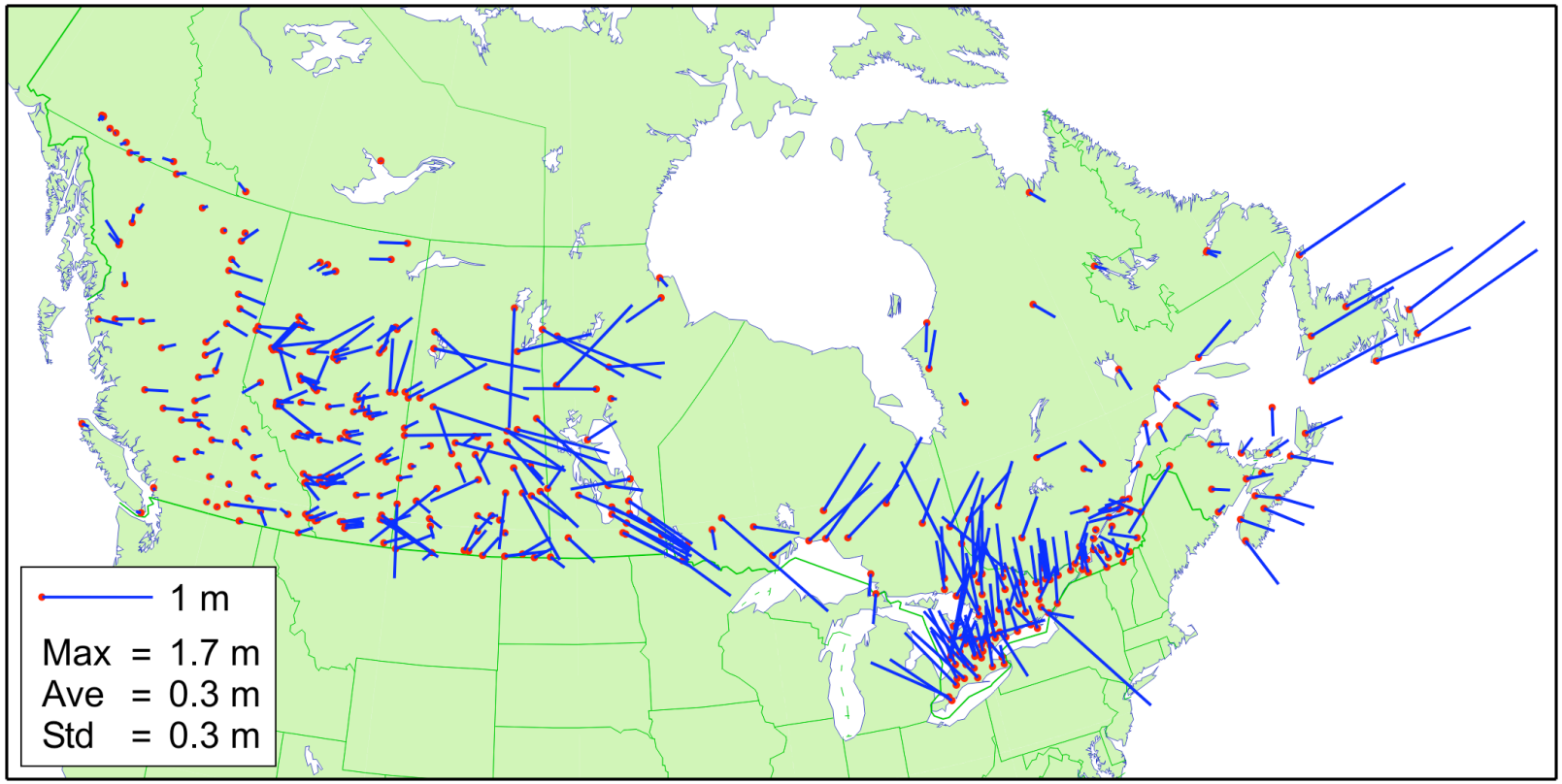
Limitations of Original WGS84/NAD83

Revealed by advances in GPS

1) Non-geocentric
   - Offset from geocenter by 1-2 meters
   - 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 Original NAD83



Modern Reference Frames

ITRF

WGS84 “G” series

NAD83(CSRS/CORS96)

SNARF

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

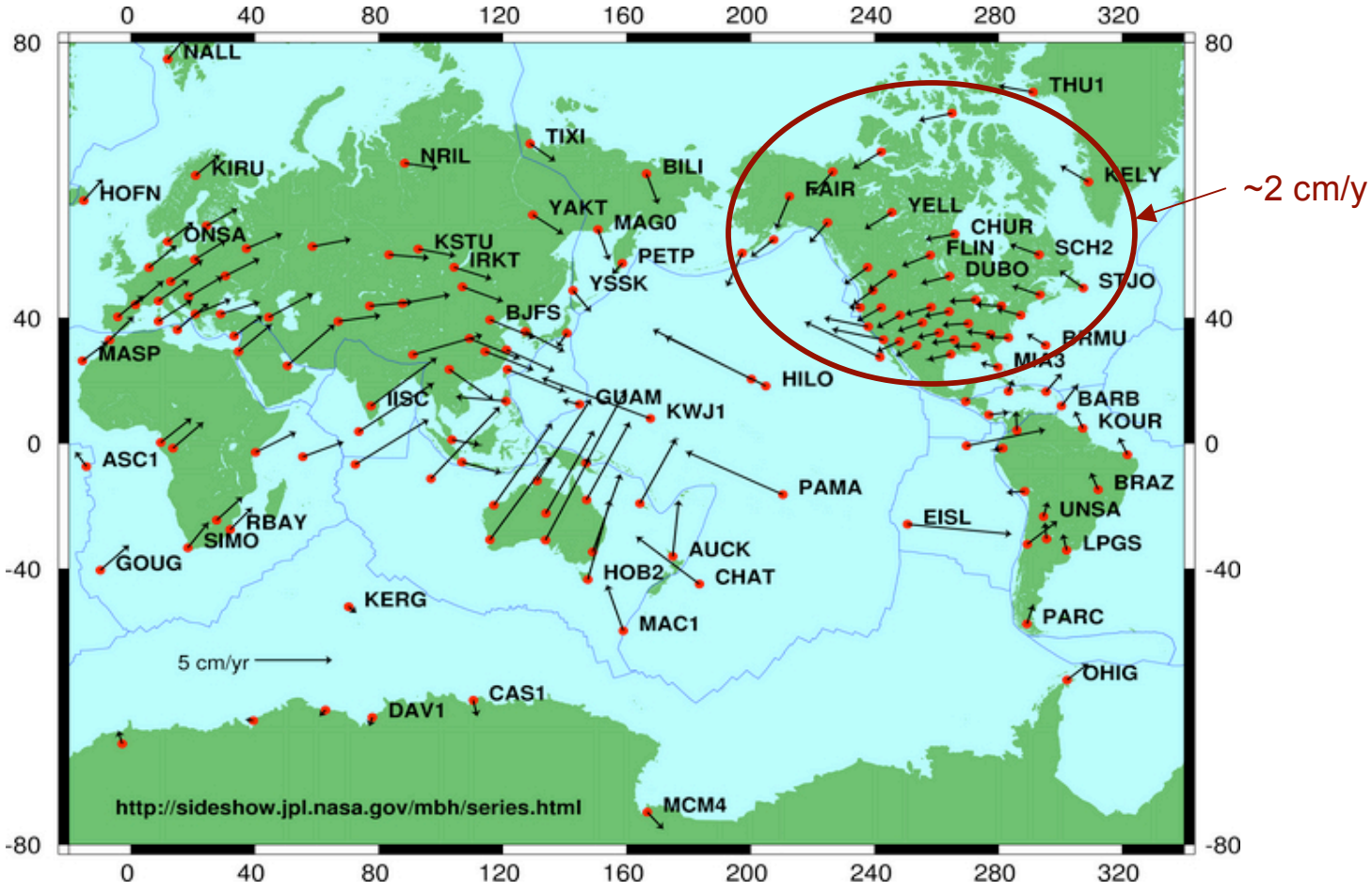
- Coordinates changing due to plate tectonics
  - Valid only for a specific date (epoch)
  - Velocities provided to update to other epochs

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)

- Better accuracy & stability than original
- Based on (compatible with) internationally adopted ITRF

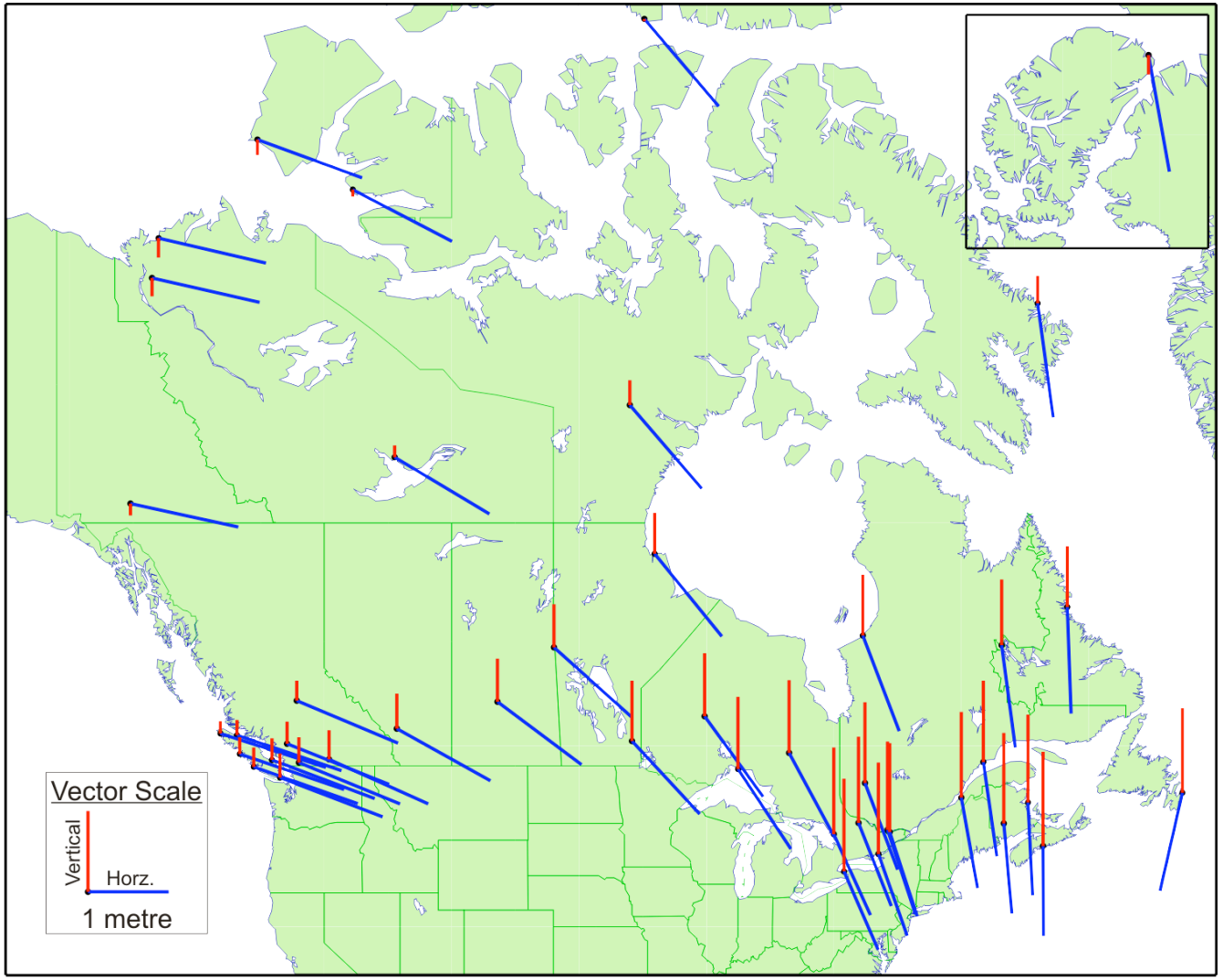
Version	Based on	Introduced
WGS84(G730)	ITRF91	1994
WGS84(G873)	ITRF94	1996
WGS84(G1150)	ITRF2000	2002

- Still no ground network -- point positioning only

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

Original WGS84/NAD83 vs WGS84(G1150)/ITRF2000



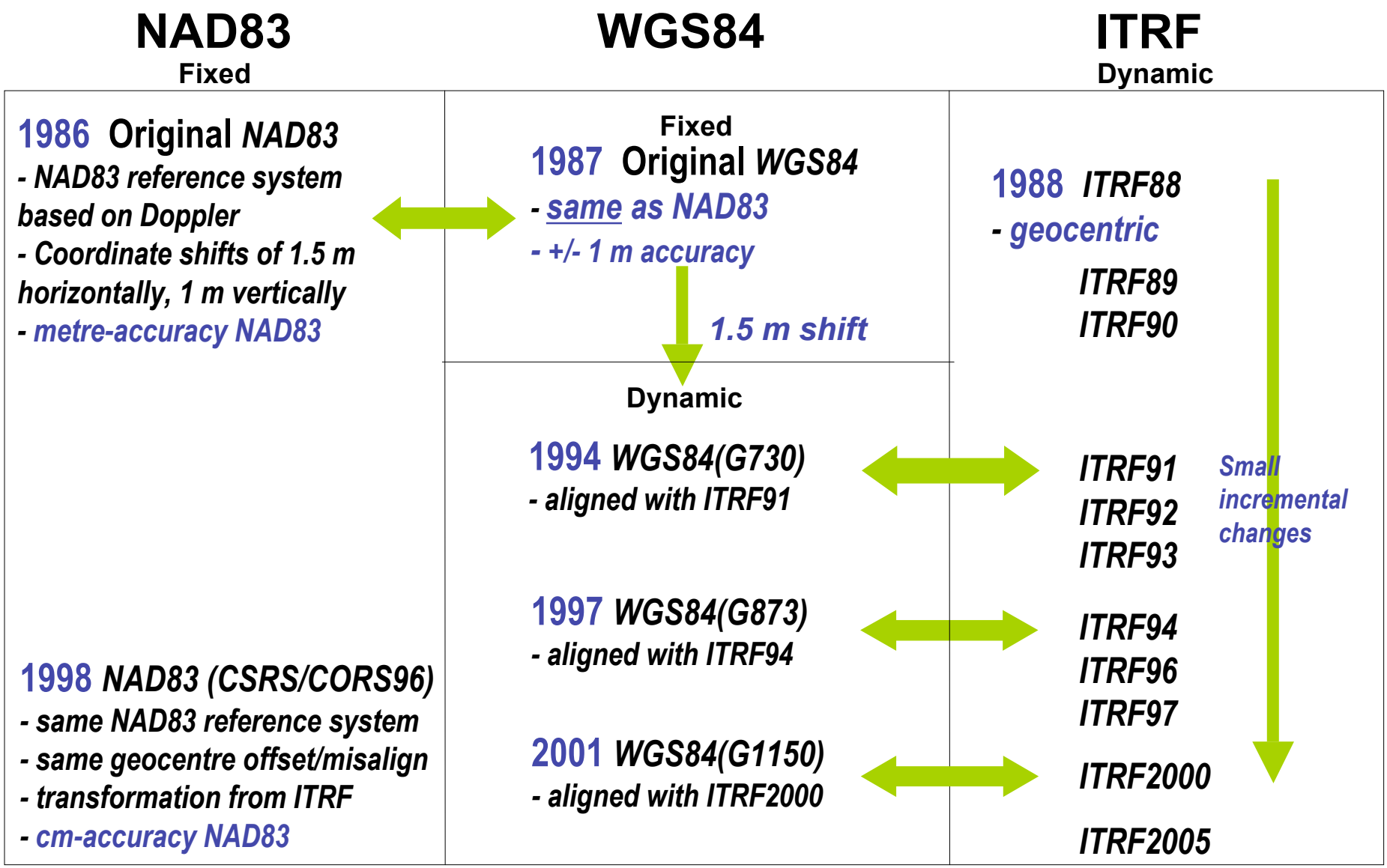
NAD83(CSRS/CORS96)

Defined as a best fitting transformation from ITRF

- 14 parameter transformation
- Models tectonic motion of North America
- As accurate & stable as ITRF
- Adopted in Canada (CSRS) and U.S. (CORS96)
- Transformation updated for new ITRFs
- ***Web & software tools available at NRCan & NGS***

Still compatible with NAD83(Orig)

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


NAD83
Fixed
WGS84
ITRF
Dynamic
1986 Original NAD83
- NAD83 reference system based on Doppler
- Coordinate shifts of 1.5 m horizontally, 1 m vertically
- metre-accuracy NAD83
Fixed
1987 Original WGS84
- same as NAD83
- +/- 1 m accuracy
1.5 m shift
Dynamic
1988 ITRF88
- geocentric
ITRF89
ITRF90
1994 WGS84(G730)
- aligned with ITRF91
ITRF91
ITRF92
ITRF93
Small incremental changes
1997 WGS84(G873)
- aligned with ITRF94
ITRF94
ITRF96
ITRF97
2001 WGS84(G1150)
- aligned with ITRF2000
ITRF2000
ITRF2005
1998 NAD83 (CSRS/CORS96)
- same NAD83 reference system
- same geocentre offset/misalign
- transformation from ITRF
- cm-accuracy NAD83

Stable North American Reference Frame (SNARF)

Fixed to stable part of North American tectonic plate

- True geocentric version of NAD83
- Defined by translation + rotation rates from ITRF that minimizes motion of "frame" sites
- More stable & consistent frame for EarthScope/PBO studies

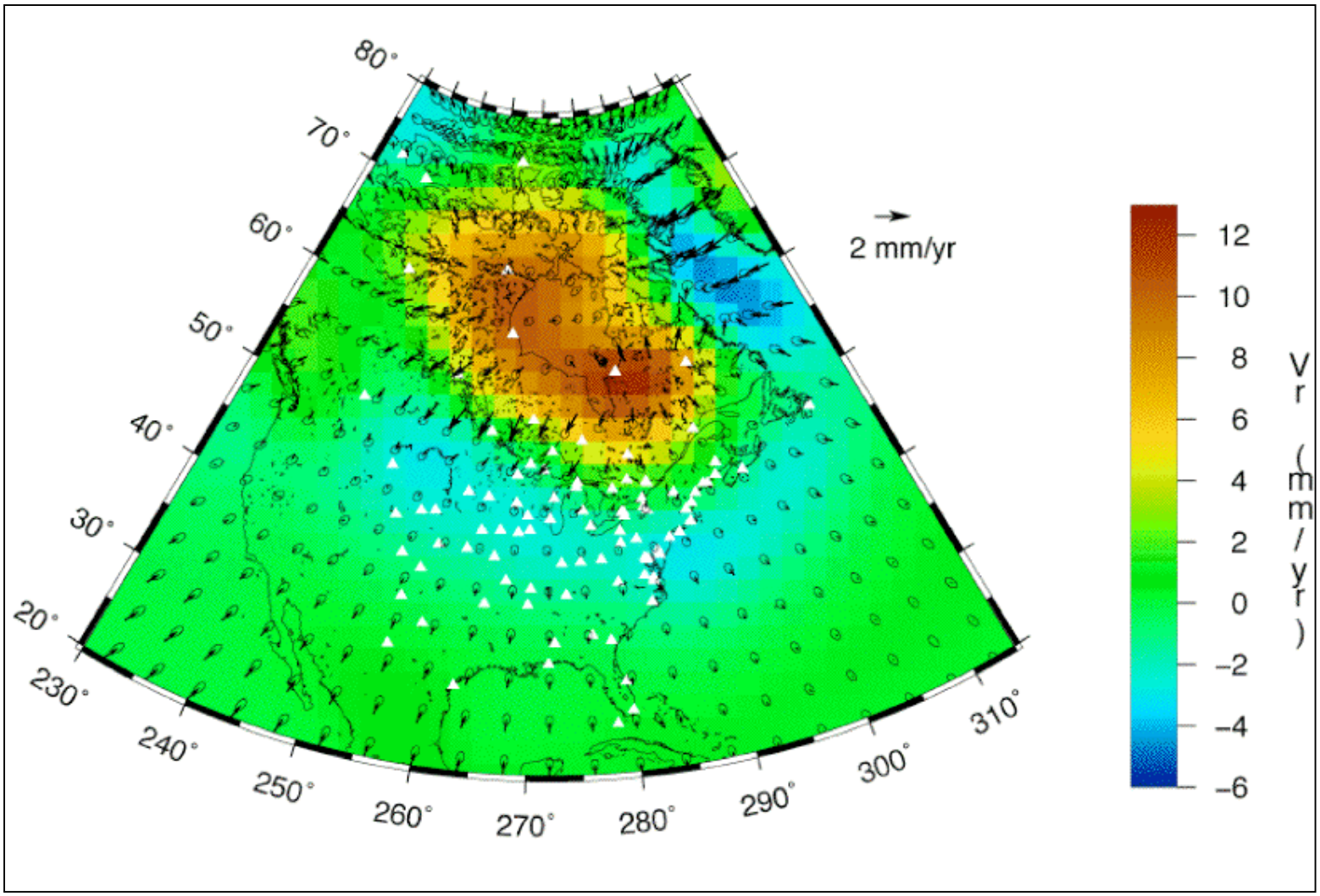
Includes model of glacial isostatic adjustment

- Based on novel technique by Jim Davis
- Weighted assimilation of GPS and a priori GIA model
- Provides estimates of both vertical & horizontal velocities

SNARF Releases

- Initial release Dec 2006 -- in use by PBO
- Next version planned for end of 2007
- Will use more reliable GPS velocity fields

SNARF v1.0 GIA Model



Practical Issues

NGA Datum Shift for NAD83

GPS Correction Sevices

National Geospatial-Intelligence Agency 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)	Δf x 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
zero
3 parameter shift
(incorrect)

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

GPS Correction/Processing Services

Reference frame depends on service/source

- *Uncorrected or WAAS corrections*
  - Receiver positions always in WGS84
  - But ***still in WGS84*** if receiver applies zero shift to NAD83
- *Canadian CDGPS or Coast Guard corrections*
  - Receiver positions in NAD83(CSRS)
  - ***Falls back to WGS84 without warning if service signal lost***
- *Post-processing with OPUS (US)*
  - Output in both NAD83(CORS96) & ITRF/WGS84(G)
- *Post-processing with CSRS-PPP (Canada)*
  - Select output in either NAD83(CSRS) or ITRF/WGS84(G)

For More Information

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

Soler, T., R. Snay (2004). **Transforming Positions and Velocities between the International Terrestrial Reference Frame of 2000 and North American Datum of 1983**. *Journal of Surveying Engineering*, Vol. 130, No. 2, pp. 49-55.

Snay, R. (2003) **NGS Geodetic Toolkit, Part 5, Horizontal Time-Dependent Positioning**. *Professional Surveyor*, Vol. 23, No. 11, p. 30.

Stable North American Reference Frame <http://www.naref.org/snarf/>