



# Evaluation of the GRACE-based Global Gravity Models in Canada

Jianliang Huang and Marc Véronneau, Geodetic Survey Division, CCRS



Natural Resources  
Canada

Ressources naturelles  
Canada

Canada 

# Outline



1. Objectives
2. Gravity Comparisons
3. GPS-Leveling Comparisons
4. Comparisons with Deflections of the Vertical
5. Comparisons with Regional Geoid Models
6. Summary

# 1. Objectives



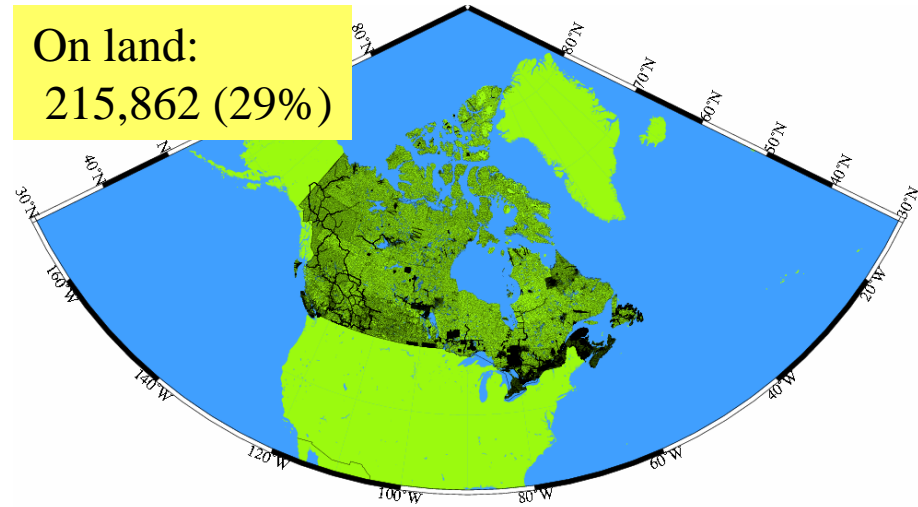
- To assess GRACE-based global gravity models, in particular EGM08, using surface gravity observations, GPS-levelling data, deflections of the vertical in Canada.
- To examine the impact of EGM08 on the regional geoid modelling by comparing it with Canadian Gravimetric Geoid models based on the remove-restore Stokes numerical integration.

# 2. Gravity Comparisons (1/6)

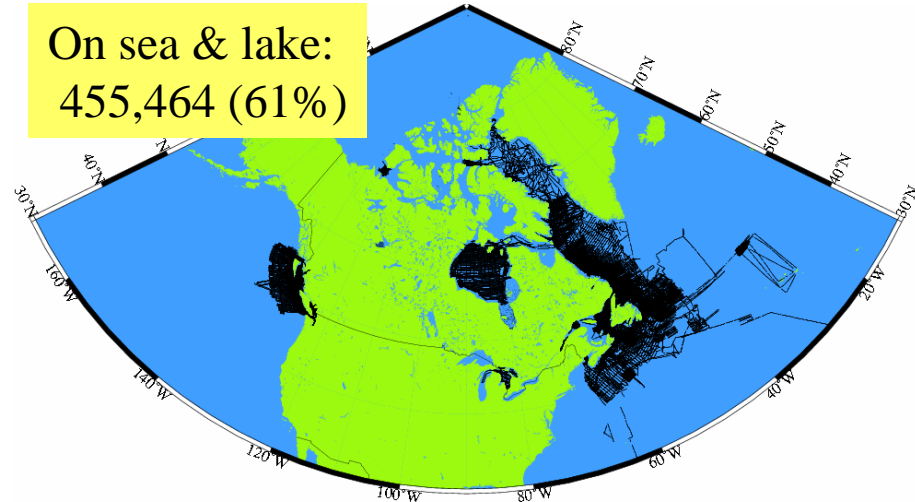
## - Gravity Stations



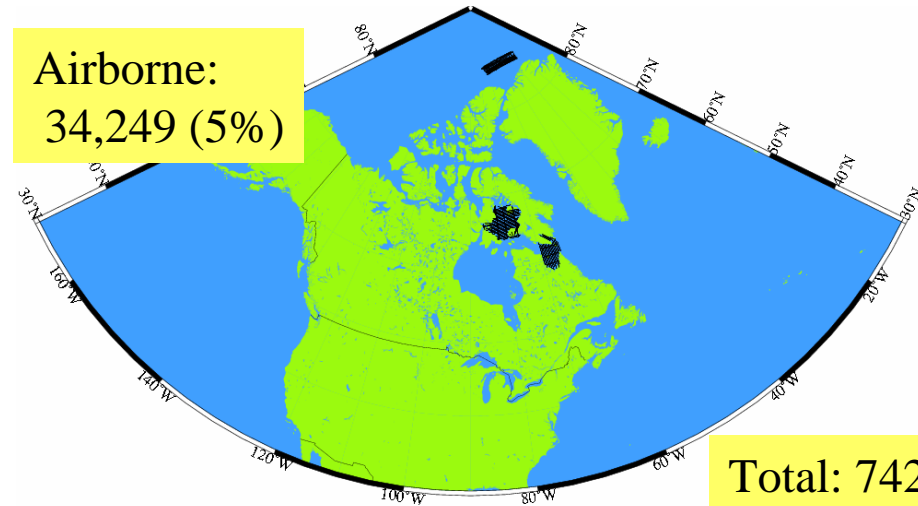
On land:  
215,862 (29%)



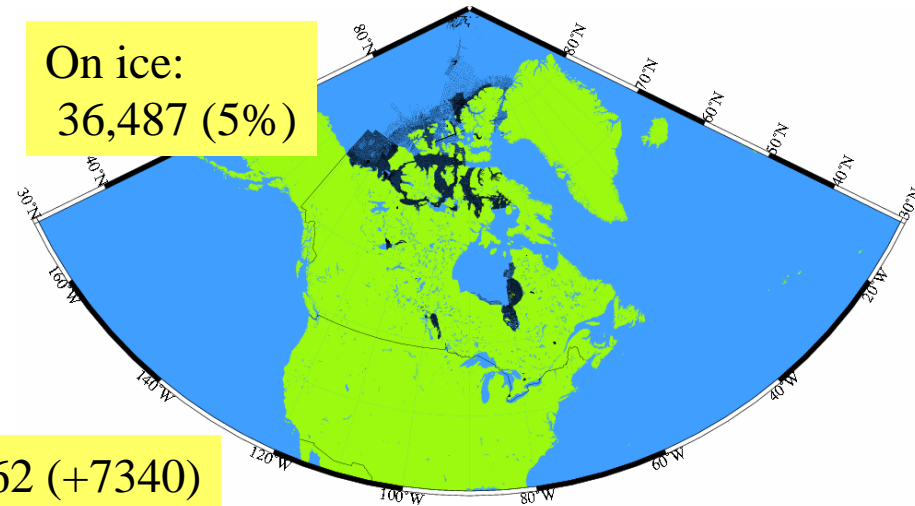
On sea & lake:  
455,464 (61%)



Airborne:  
34,249 (5%)



On ice:  
36,487 (5%)



Total: 742,062 (+7340)

## 2. Gravity Comparisons (2/6)

### - Data Types



#### Sub-types of the gravity data in Canada:

Type Code	Number	Percentage	Description
Land	215,862	28.8%	On land
SLS	455,464	60.8%	On Sea and Lake Surfaces
SLB	6,538	0.9%	On Sea and Lake Bottoms
SLI	36,487	4.9%	On Sea and Lake Ice Surfaces
IC	802	0.1%	On Ice Cap
Airborne	34,249	4.6%	Airborne
All	749,402	100%	

## 2. Gravity Comparisons (3/6)

- Gravity data



### Statistical description of the free-air gravity anomalies:

Data Code	Min	Max	Mean	StdDev	R.M.S.
Land	-183.62	393.31	-9.50	29.38	30.88
SLS	-160.78	240.66	-6.09	35.80	36.31
SLB	-102.70	102.16	-18.37	25.75	31.63
SLI	-167.94	106.98	-23.13	30.03	37.91
IC	-98.18	217.99	55.14	42.83	69.82
Airborne	-100.49	54.110	-26.75	30.39	40.49
All	-183.62	393.31	-8.89	34.00	35.14

## 2. Gravity Comparisons (4/6)

- Observations - Predictions *without* Continuation



Data Code	Model	Min	Max	Mean	StdDev	RMS
Land	PGM07A	-177.41	114.89	-1.65	13.39	13.49
	EGM08	-178.09	114.27	-1.70	13.34	13.45
SLS	PGM07A	-202.10	48.58	-1.20	4.78	4.93
	EGM08	-203.91	53.54	-1.15	4.61	4.76
SLB	PGM07A	-43.08	28.75	-0.77	4.00	4.08
	EGM08	-44.10	27.77	-0.68	4.17	4.22
SLI	PGM07A	-80.92	49.91	-0.50	4.47	4.50
	EGM08	-88.63	49.76	-0.57	4.15	4.19
IC	PGM07A	-122.98	95.19	-1.60	20.58	20.63
	EGM08	-107.03	95.01	-2.51	20.27	20.41
Airborne	PGM07A	-23.44	39.39	1.46	4.97	5.18
	EGM08	-23.06	36.65	1.64	4.73	5.00
All	PGM07A	-202.10	114.89	-1.17	8.29	8.37
	EGM08	-203.91	114.27	-1.15	8.19	8.27

## 2. Gravity Comparisons (5/6)

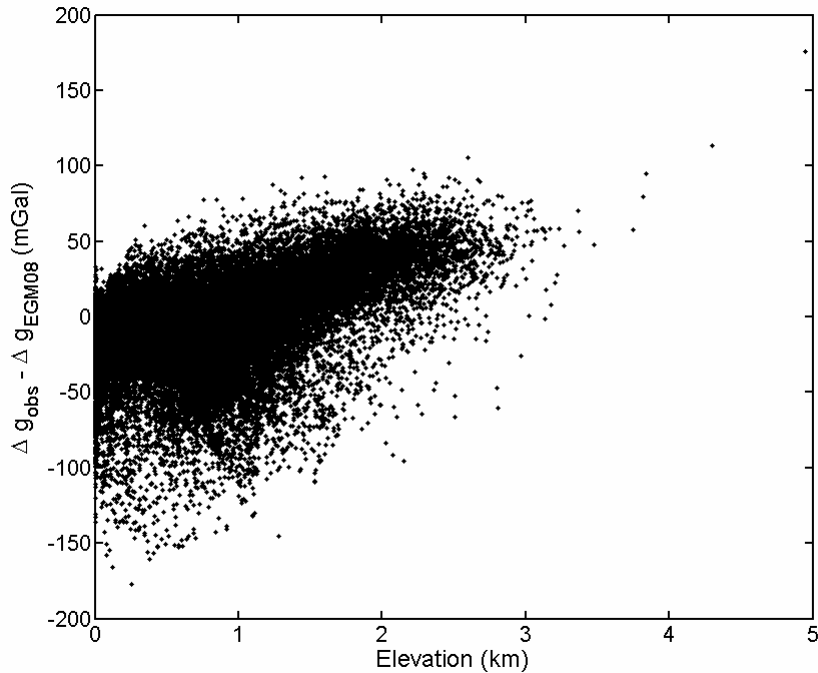
- Observations - Predictions *with* Continuation



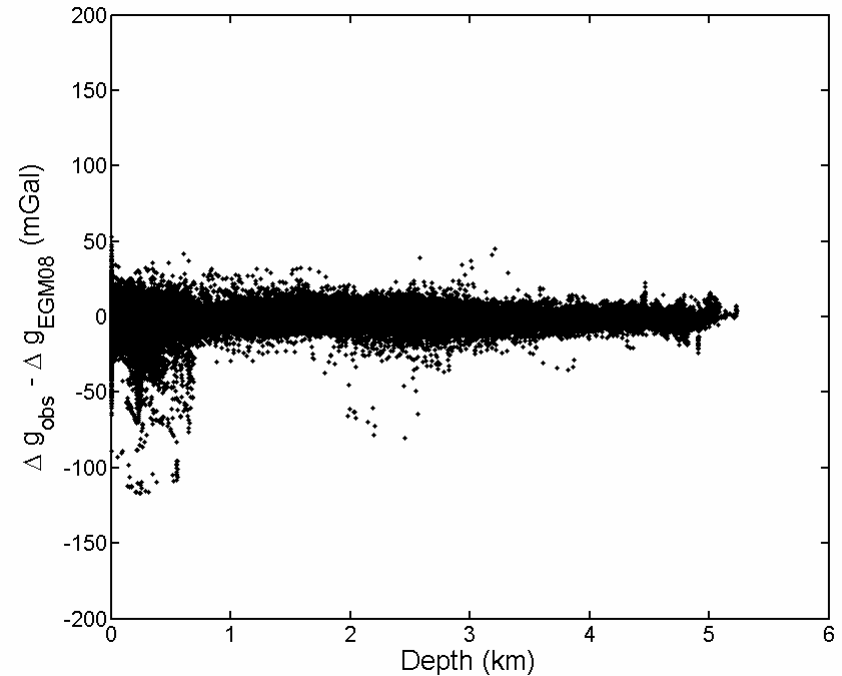
Data Code	Model	Min	Max	Mean	StdDev	RMS
Land	PGM07A	-176.15	174.43	-1.64	13.75	13.85
	EGM08	-176.85	175.62	-1.69	13.71	13.81
SLS	PGM07A	-201.76	48.11	-1.19	4.78	4.93
	EGM08	-203.75	53.01	-1.14	4.61	4.75
SLB	PGM07A	-43.09	28.76	-0.78	4.00	4.08
	EGM08	-44.11	27.78	-0.68	4.17	4.22
SLI	PGM07A	-80.93	49.80	-0.49	4.47	4.49
	EGM08	-88.67	49.64	-0.56	4.14	4.18
IC	PGM07A	-64.78	82.26	-1.30	19.61	19.64
	EGM08	-61.11	81.81	-2.29	19.61	19.73
Airborne	PGM07A	-22.96	38.73	1.40	4.84	5.04
	EGM08	-23.36	36.37	1.57	4.61	4.88
All	PGM07A	-201.96	174.43	-1.16	8.45	8.52
	EGM08	-203.75	175.62	-1.14	8.36	8.44

## 2. Gravity Comparisons (6/6)

- Differences vs. Elevation/Depth



Gravity anomaly differences vs. elevation over **land** (215,862 observations).



Gravity anomaly differences vs. depth over **seas and lakes** (455,464 observations).

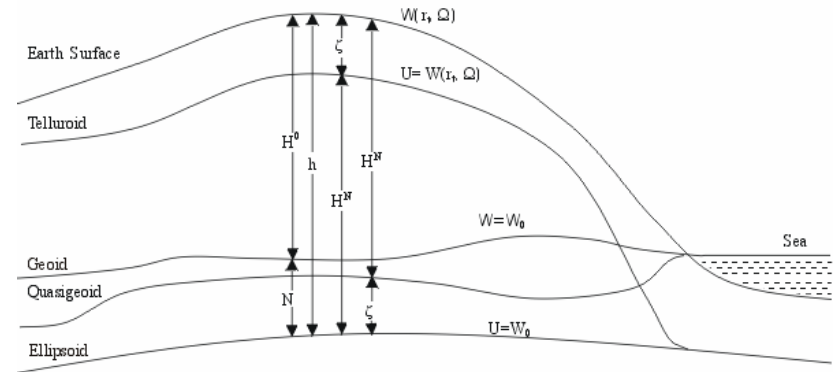
# 3. GPS-Levelling Comparisons (1/4)

## - Principle and Computation



### Basic relation between h, H and N:

$$H^0 + N = \zeta + H^N = h$$



### The geoid from a spherical harmonic model:

$$N_L = \frac{G\delta M}{r_e \gamma_0} - \frac{\delta W}{\gamma_0} + \frac{GM}{r_e \gamma_0} \sum_{n=2}^L \left( \frac{a}{r_e} \right)^n \sum_{m=0}^n \left( (\bar{C}_{nm} - \frac{GM^e}{GM} \left( \frac{a^e}{a} \right)^n \bar{J}_n) \cos m\lambda + \bar{S}_{nm} \sin m\lambda \right) \bar{P}_{nm}(\sin \phi) + C_{TB}$$

$$C_{TB} = -\frac{2\pi G\rho H^2}{\gamma_0} \left( 1 + \frac{2H}{3R} \right)$$

$$\delta M = M - M'$$

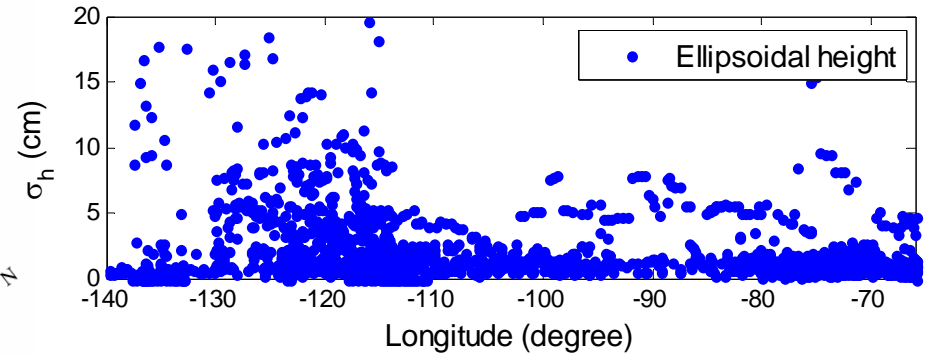
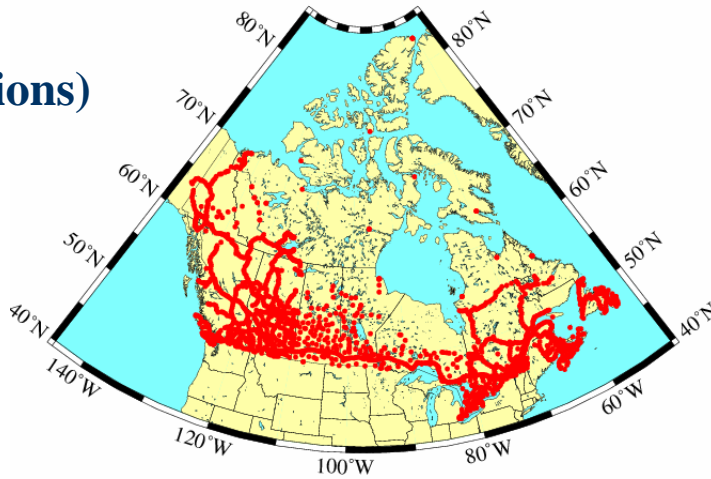
$$\delta W = W_0 - U_0$$

# 3. GPS-Levelling Comparisons (2/4)

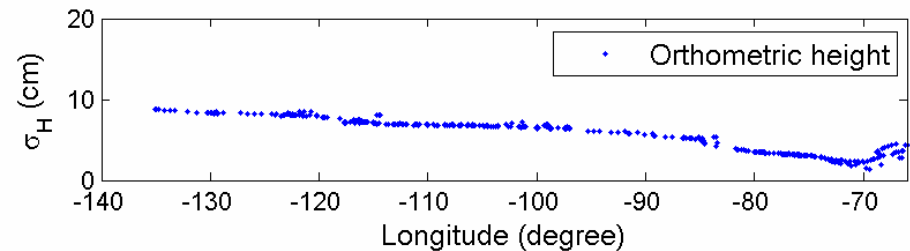
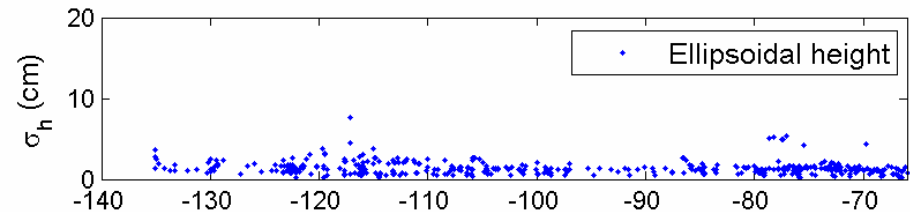
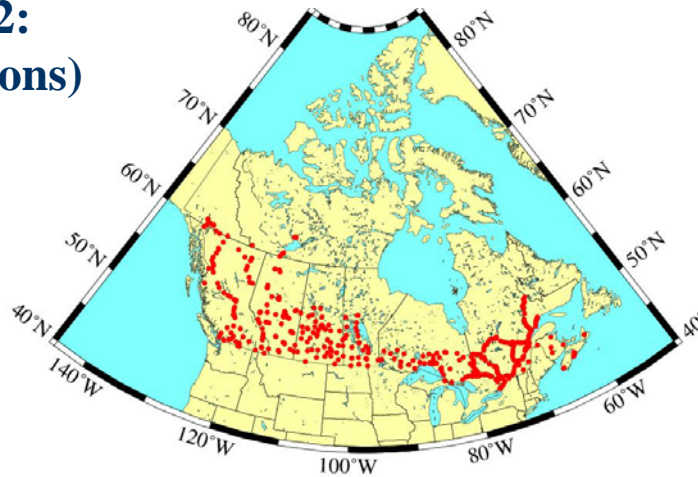
## - GPS-Leveling Data



**SN3307:**  
(2579 stations)



**SNPRE32:**  
(430 stations)



# 3. GPS-Levelling Comparisons (3/4)

## - Results



Comparisons of EGM models against two GPS-Levelling data sets in Canada (SNPRE32: **430** stations) and SN3307: **2579** stations). Unit: m.

Models	GPS-Levelling (SNPRE32)				GPS-Levelling (SN33h07)			
	Min	Max	Mean	StDev	Min	Max	Mean	StDev
GGM02S*	-0.672	-0.147	-0.351	<b>0.102</b>	-0.923	0.088	-0.375	<b>0.135</b>
GL04S1*	-0.661	-0.157	-0.354	<b>0.100</b>	-0.929	0.080	-0.375	<b>0.132</b>
PGM2007A	-0.741	-0.069	-0.356	<b>0.105</b>	-0.913	0.123	-0.367	<b>0.136</b>
EGM08	-0.669	-0.149	-0.356	<b>0.100</b>	-0.922	0.090	-0.380	<b>0.133</b>

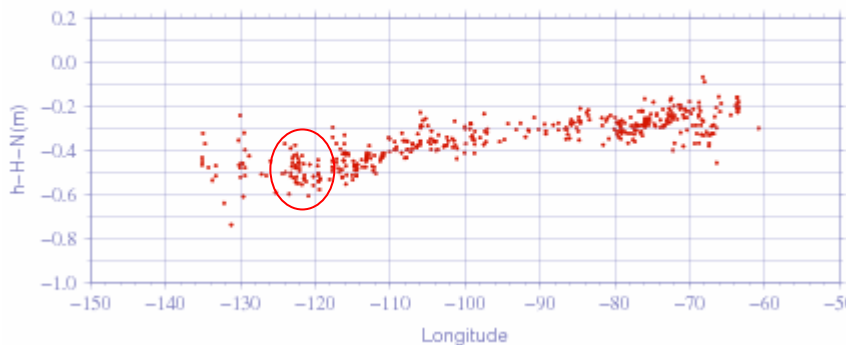
\* *Models are truncated at degree 90, then extended to degree 2190 using EGM08.*

# 3. GPS-Levelling Comparisons (4/4)

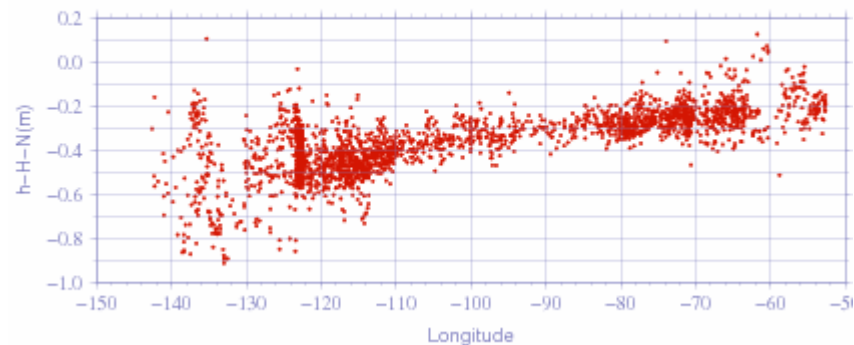
-  $h-H-N$  vs. *Longitude*



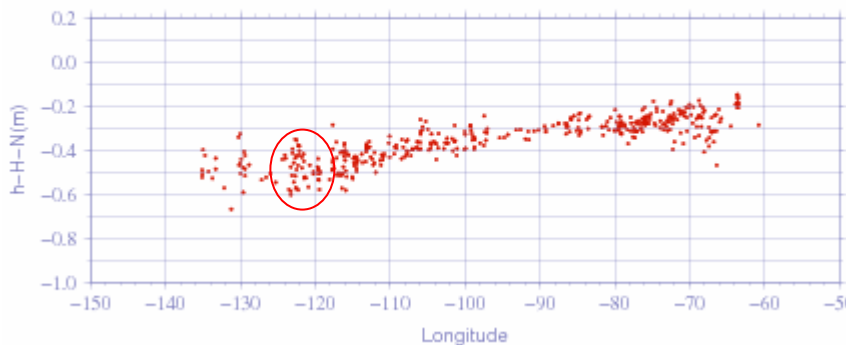
**PGM2007A at 430 stations:**



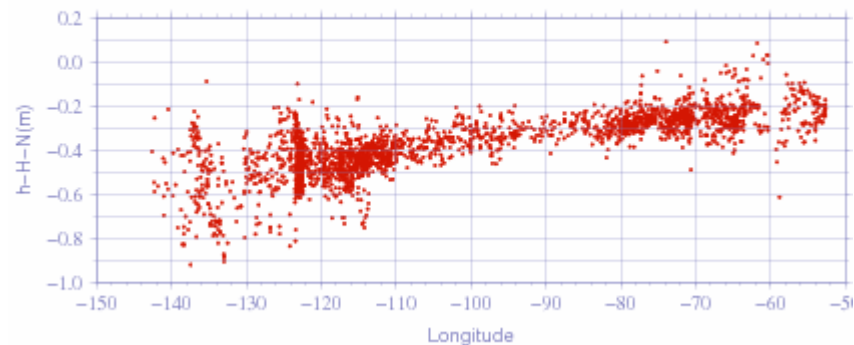
**PGM2007A at 2579 stations:**



**EGM08 at 430 stations:**



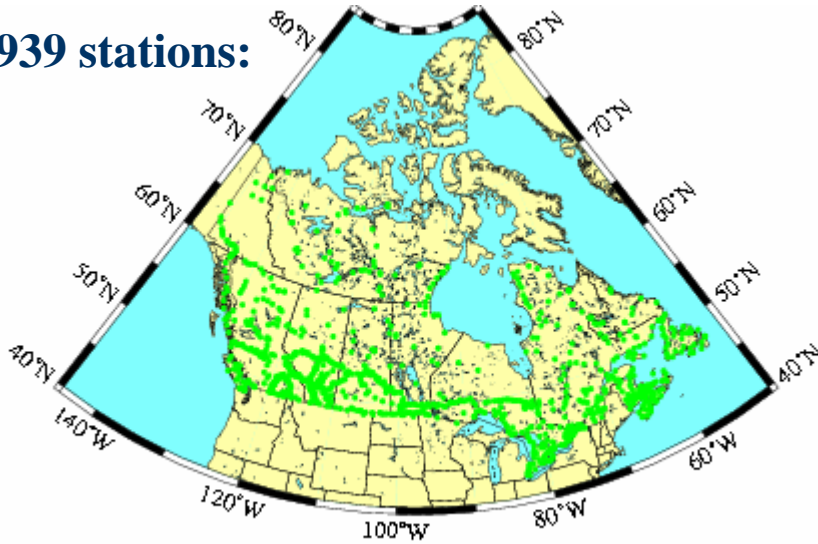
**EGM08 at 2579 stations:**



# 4. Comparisons with Deflections of the Vertical



939 stations:



Deflections of the vertical in arc-second.

Type	Min	Max	Mean	StdDev	RMS
xi (N-S)	-23.410	17.880	0.205	4.501	4.505
eta (E-W)	-22.390	24.350	-0.232	6.137	6.142

Differences of North - South DfV (xi) in arc-second:

Differences of East - West DfV (eta) in arc-second:

Models	Min	Max	Mean	StdDev
PGM07A	-12.364	9.946	-0.013	1.785
EGM08	-12.429	9.948	-0.014	1.760

Models	Min	Max	Mean	StdDev
PGM07A	-12.839	14.944	0.203	2.111
EGM08	-12.814	15.266	0.197	2.101

# 5. Comparisons with Regional Geoid Models (1/6) – *Canadian Geoid Models*



1. Canadian Gravimetric Geoid 2005 (**CGG05**) is computed using the degree-banded remove-restore numerical Stokes integration. GGM02C (degree 2 to 200)+EGM96 (degree 201 to 360) is used to define the low degree components (degree 2 to 90) and the far-zone contribution (or so called the truncation error of the Stokes integration) of CGG05. It spans from 20°N-84°N and 10°W-170°W in the spacing of 2' by 2'.
2. Preliminary Canadian Geoid 2008A (**PCG08A**) uses the same method as that of CGG05. EGM08 truncated at degree 360 is used instead of GGM02C and EGM96. The terrestrial gravity data has been updated in some regions.

# 5. Comparisons with Regional Geoid Models (2/6) – *h-H-N, xi, and eta Tests*



Comparisons against two GPS-Levelling data sets in Canada. Unit: m.

Models	430 GPS-Levelling stations				2579 GPS-Levelling stations			
	Min	Max	Mean	StDev	Min	Max	Mean	StDev
CGG05	-0.668	-0.120	-0.396	<b>0.102</b>	-0.932	0.067	-0.420	<b>0.134</b>
<b>PCG08A</b>	-0.662	-0.161	-0.366	<b>0.091</b>	-0.912	0.092	-0.390	<b>0.125</b>
EGM08	-0.669	-0.149	-0.356	<b>0.100</b>	-0.922	0.090	-0.380	<b>0.133</b>

Differences of North – South DfV (*xi*)  
in arc-second:

Models	Min	Max	Mean	StdDev
CGG05	-5.331	9.835	0.051	<b>1.215</b>
<b>PCG08A</b>	-5.386	9.888	0.053	<b>1.209</b>
EGM08	-12.429	9.948	-0.014	<b>1.760</b>

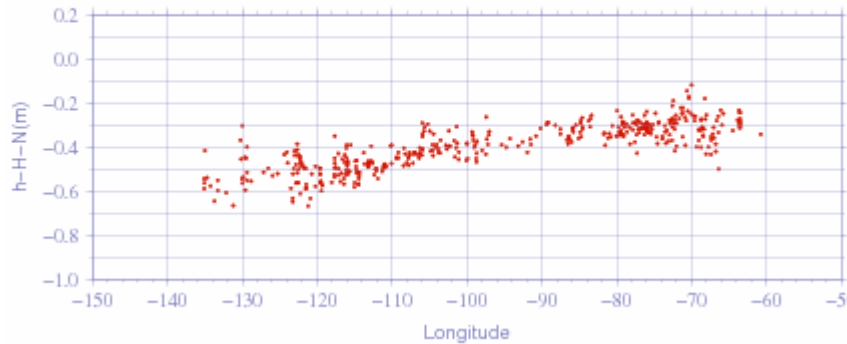
Differences of East - West DfV (*eta*)  
in arc-second:

Models	Min	Max	Mean	StdDev
CGG05	-12.703	9.159	0.232	<b>1.643</b>
<b>PCG08A</b>	-12.644	9.224	0.228	<b>1.623</b>
EGM08	-12.814	15.266	0.197	<b>2.101</b>

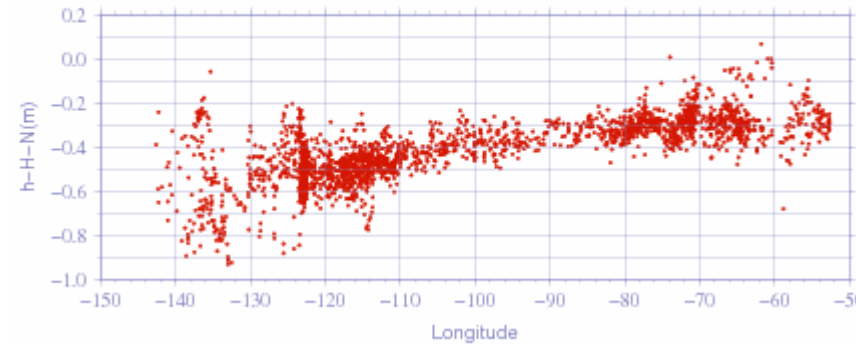
# 5. Comparisons with Regional Geoid Models (3/6) – $h-H-N$ vs. Longitude



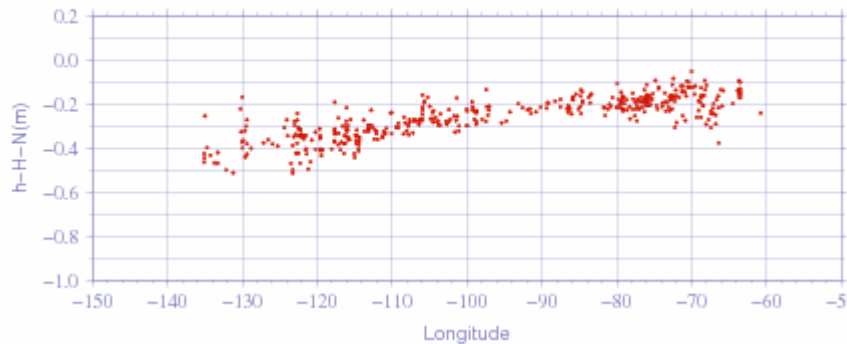
**CGG05 at 430 stations:**



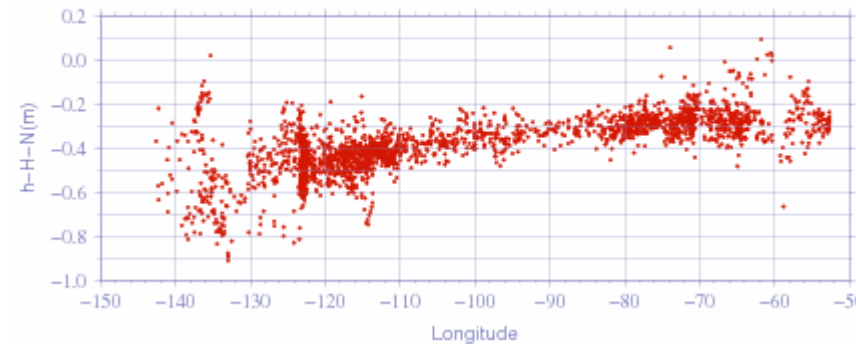
**CGG05 at 2579 stations:**



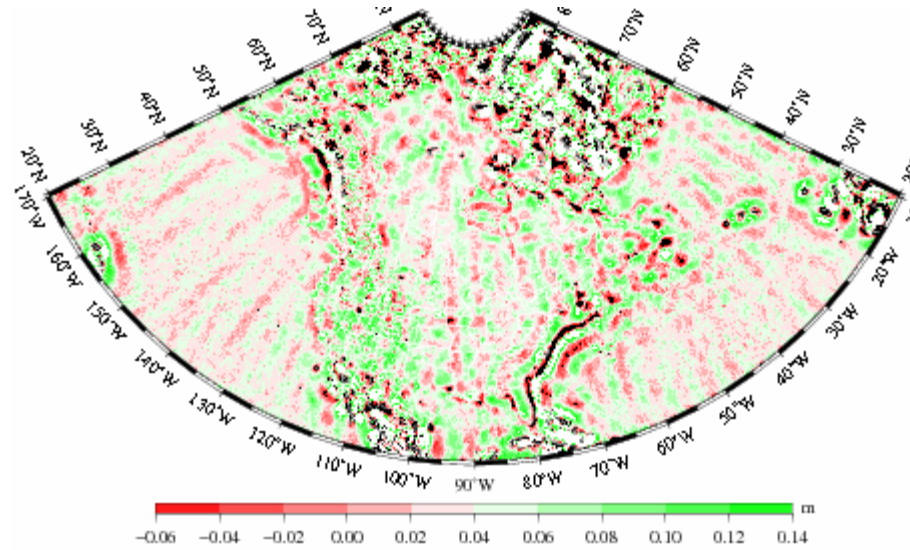
**PCG08A at 430 stations:**



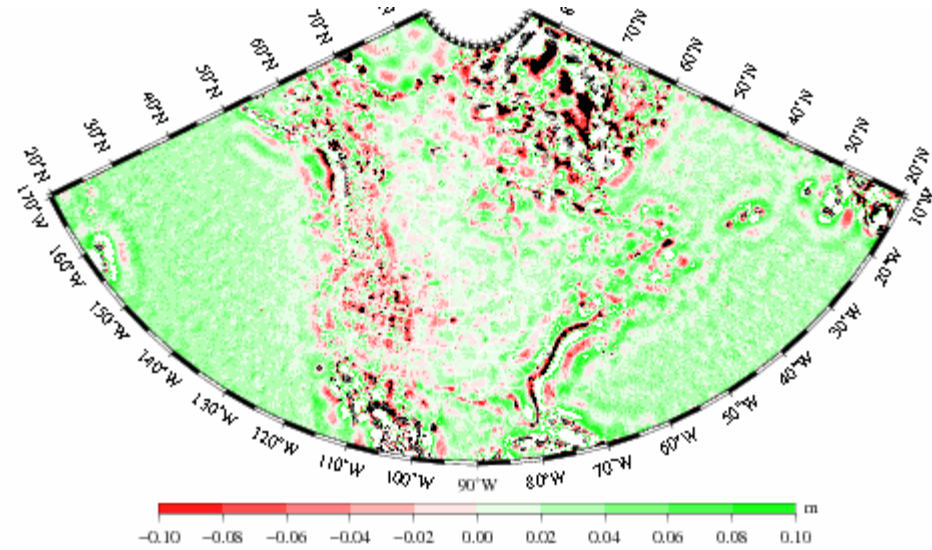
**PCG08A at 2579 stations:**



# 5. Comparisons with Regional Geoid Models (4/6) – Geoid Differences



CGG05 – EGM08  
Mean = 0.044 m  
StdDev = 0.123 m

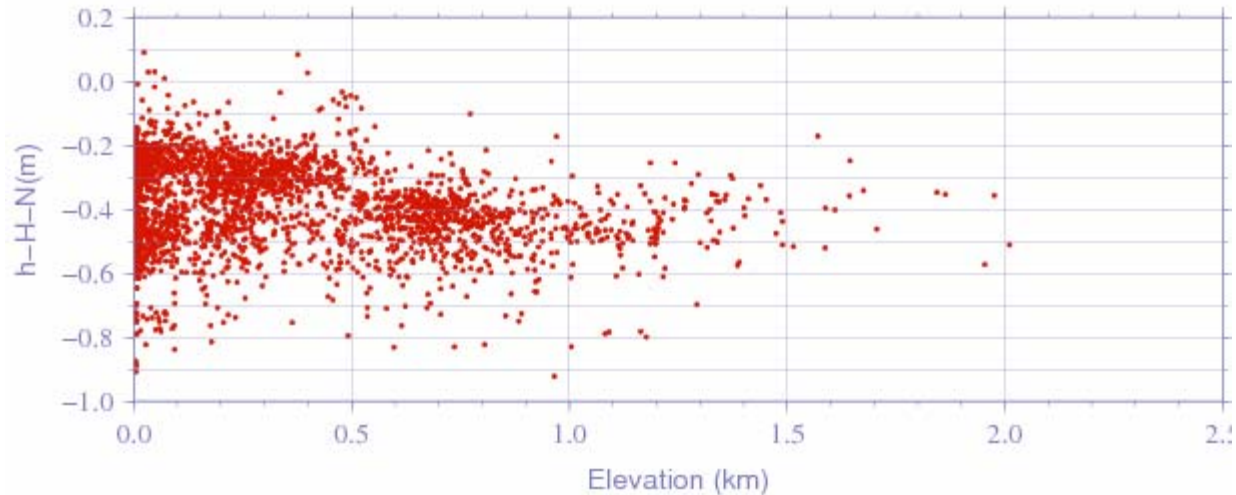


PCG08A – EGM08  
Mean = 0.013 m  
StdDev = 0.115 m

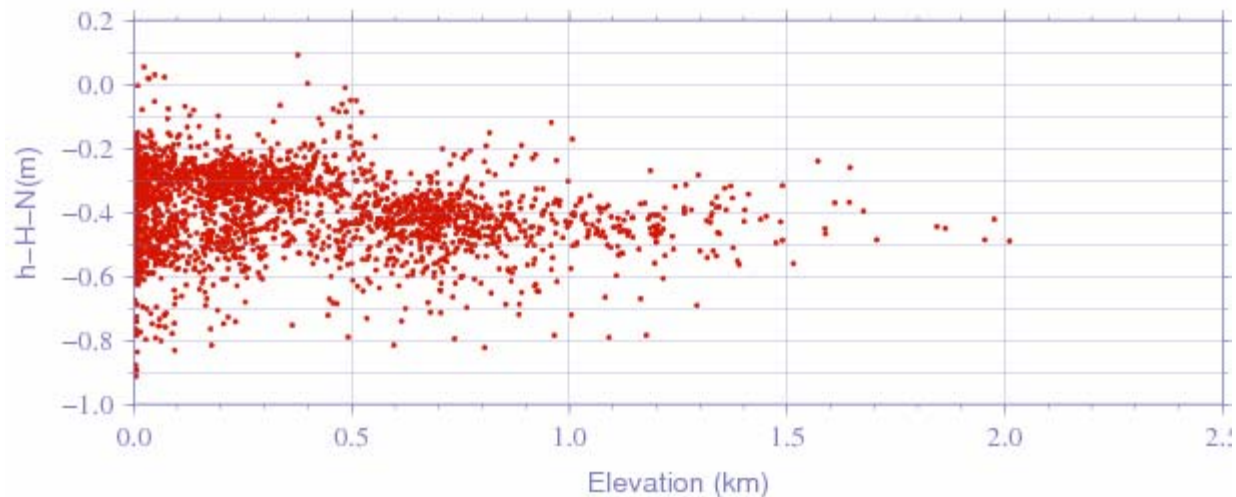
# 5. Comparisons with Regional Geoid Models (5/6) – $h-H-N$ vs. Elevation



EGM08:



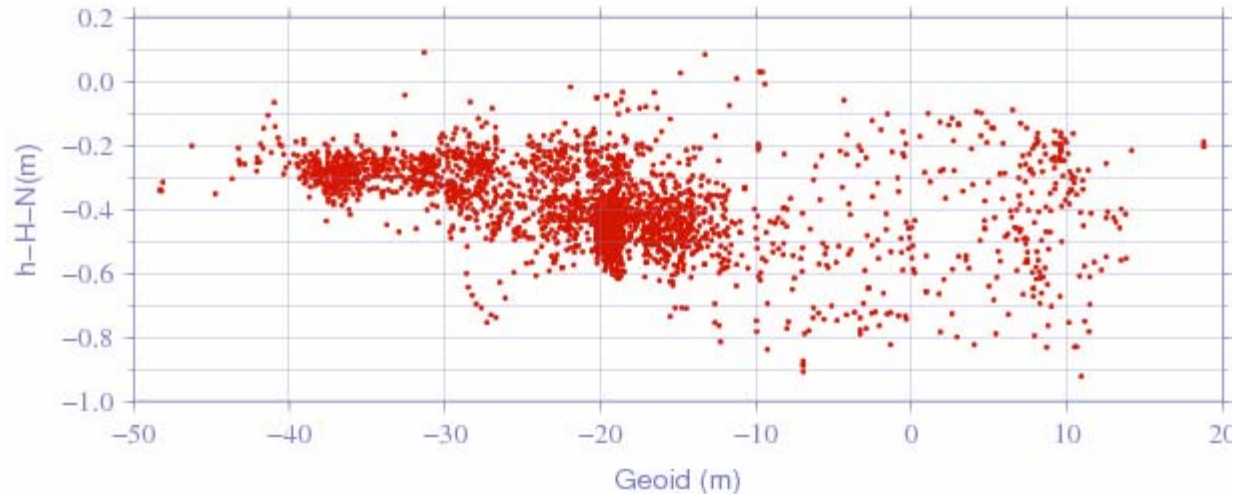
PCG08A:



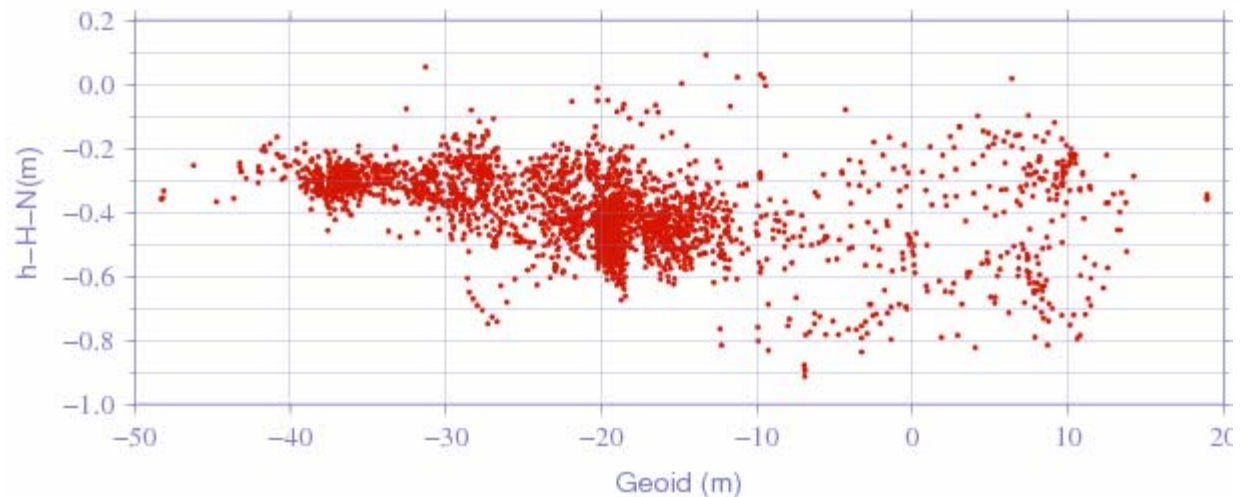
# 5. Comparisons with Regional Geoid Models (6/6) – $h-H-N$ vs. *Geoid*



EGM08:



PCG08A:



## 6. Summary



- 1) The RMS of the differences between the EGM08-predicted gravity anomalies and the observed gravity anomalies is smaller than 5 mGal over seas and lakes in contrast to about 14 mGal over land in Canada. The RMS increases with increasing elevation with an evident trend over land, while the RMS decreases with increasing depth without an evident trend over seas and lakes.
- 2) The GPS-Leveling comparisons suggest that EGM08 models the geoid as accurate as, or even better than 10 cm in terms of RMS in Canada, and the latest releases of GRACE models show noteworthy improvement over the previous releases.
- 3) The comparisons with deflections of the vertical show the RMS of 1.8 arc-seconds in the north-south direction, and 2.1 arc-seconds in the east-west direction.
- 4) The comparison with CGG05 and PCG08A suggests that EGM08 contributes to the improvement of the Canadian geoid modeling.
- 5) The Canadian regional geoid model (PCG08A) performs better than EGM08 in terms of the comparisons with the GPS-leveling and the deflections of the vertical. The higher spatial resolution of the regional model is speculated as the major contributor to the better performance