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Estimating long-term groundwater storage and its controlling factors in Alberta, Canada

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1 Statistical equations:

$$\text{RMSE} = \sqrt{\sum_{i=1}^{n} \frac{(x_i - y_i)^2}{n}} \quad (1)$$

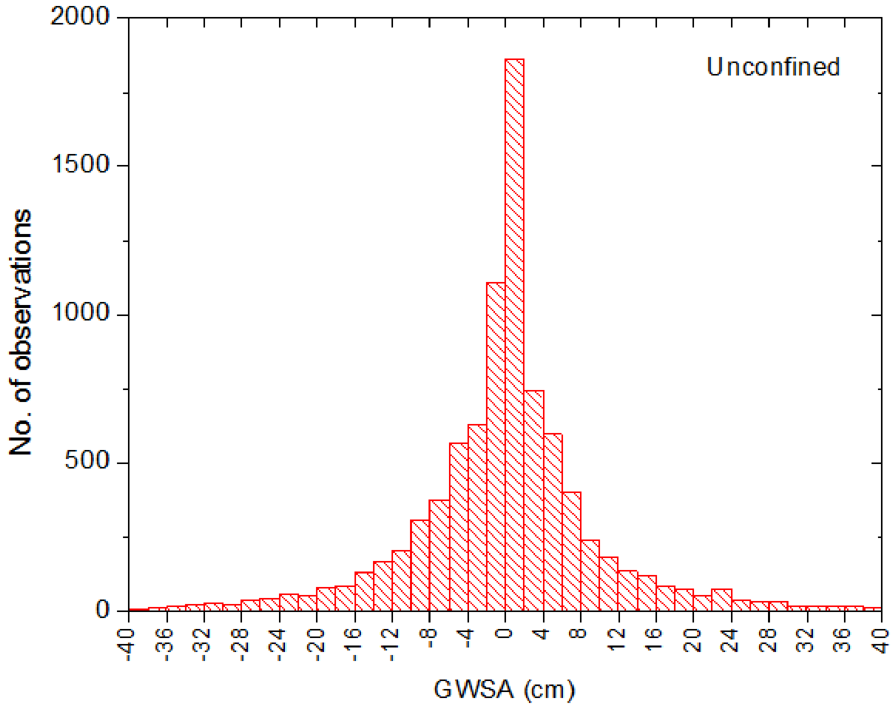
$$\text{Pearson's correlation (r)} = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2} \sqrt{\sum_{i=1}^{n} (y_i - \bar{y})^2}} \quad (2)$$

$$\text{Skewness} = \frac{\frac{1}{n}\sum_{i=1}^{n} (x_i - \bar{x})^3}{\sqrt{\frac{1}{n-1}\sum_{i=1}^{n} (x_i - \bar{x})^2}^{\,3}} \quad (3)$$

$$\text{Kurtosis} = \left\{\frac{n(n+1)}{(n-1)(n-2)(n-3)} \sum_{i=1}^{n} \frac{(x_i - \bar{x})^4}{\sigma}\right\} - \frac{3(n-1)^2}{(n-2)(n-3)} \quad (4)$$

$$\text{Coefficient of variation (CV)} = \frac{\sigma}{\mu} \quad (5)$$

Where, x_i and y_i are the two different GWSA estimates i.e. $GWSA_{obs}$ and $GWSA_{sat}$, i (= 1, 2, 3, …, n) is the number of samples; $\bar{x}$ and μ indicate mean values; σ indicate standard deviation.



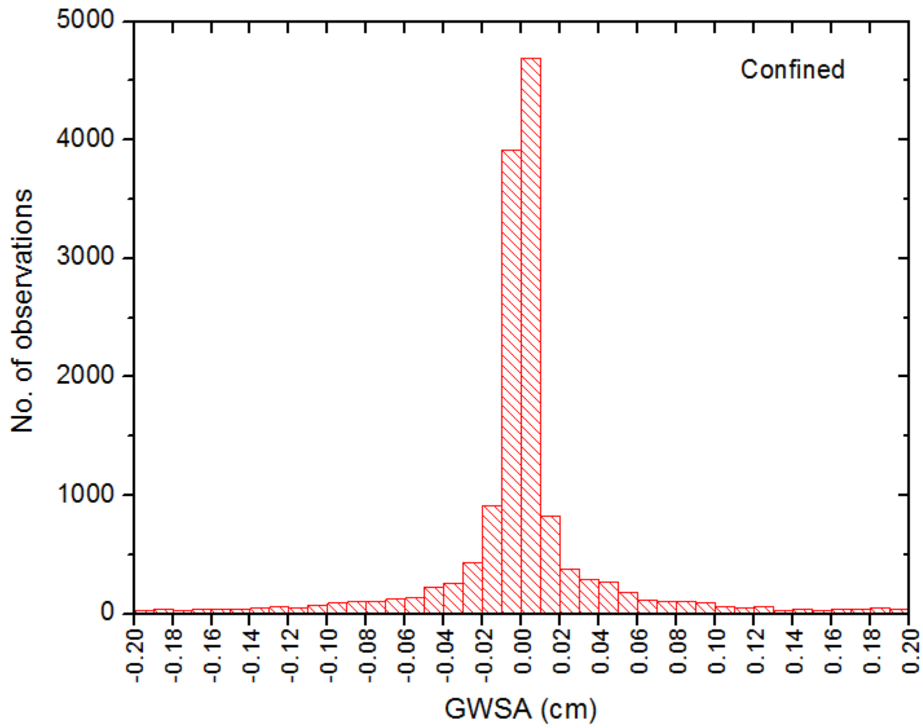


Figure S1: Histogram of GWSA estimates from unconfined and confined aquifers

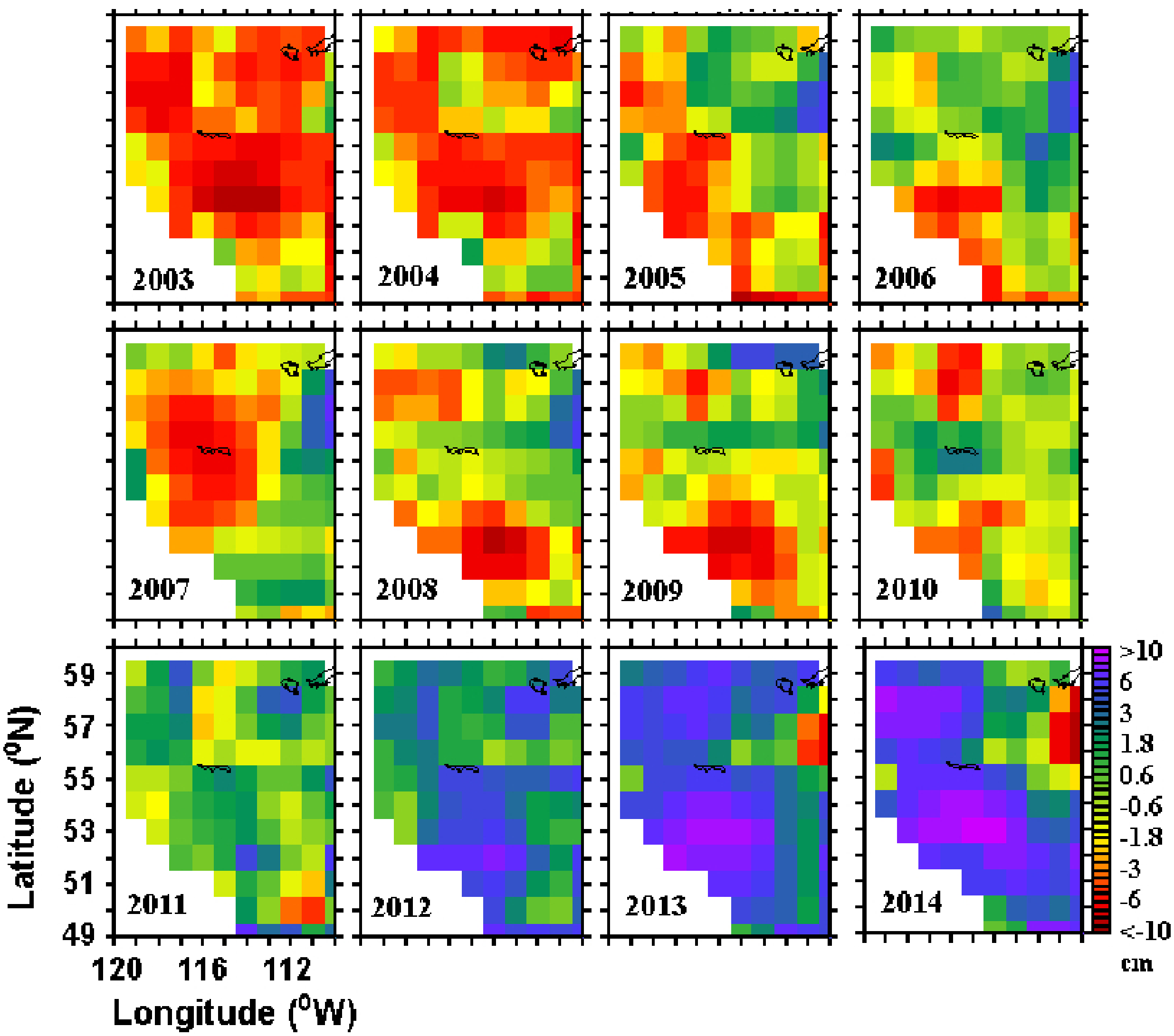


Figure S2: Maps of annual GWSA+SWA (i.e. after removing SMA and SNA from TWSA) from GRACE-MS estimates

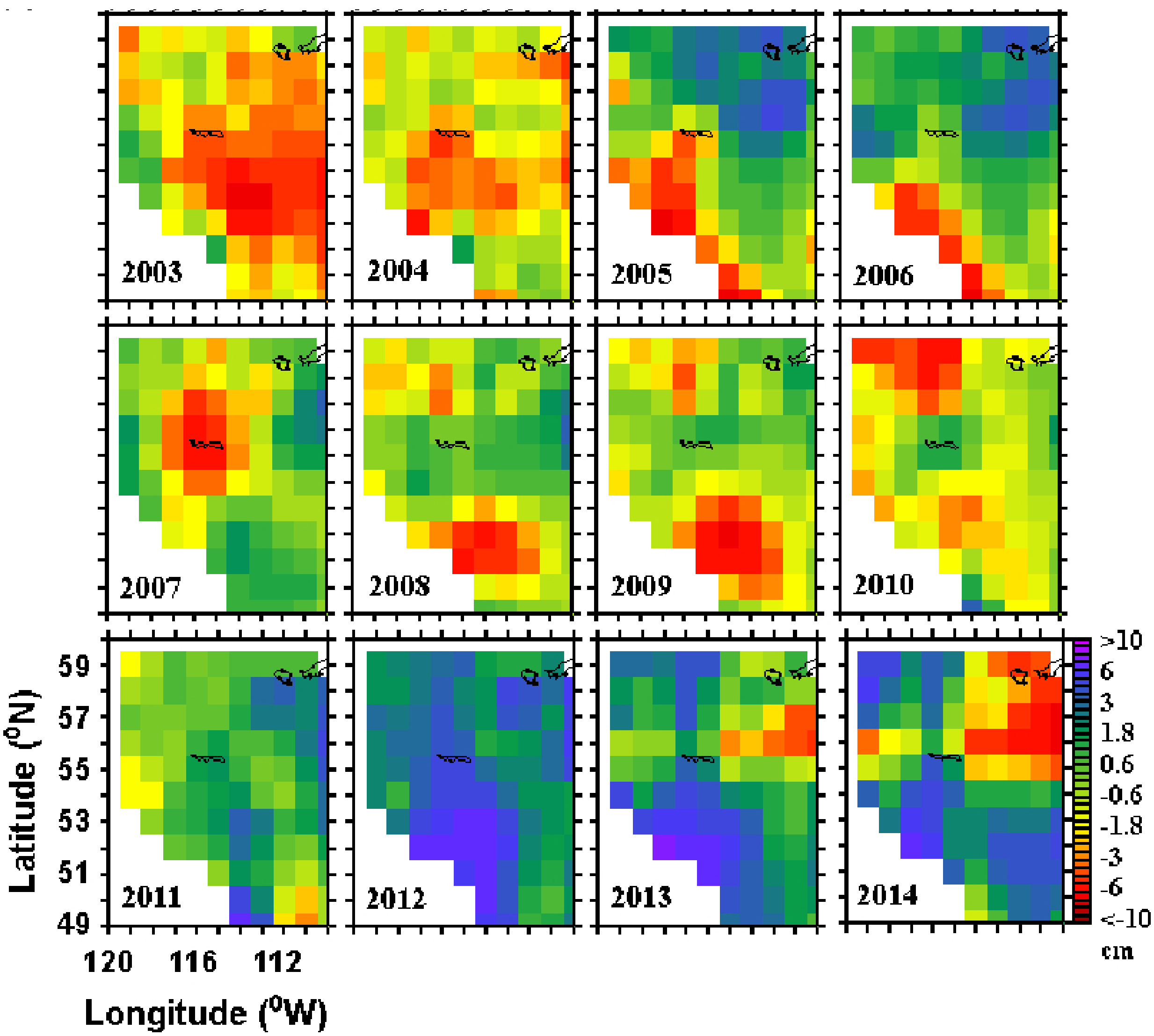


Figure S3: Maps of annual GWSA+SWA (i.e. after removing SMA and SNA from TWSA) from GRACE-SH estimates

Table S1: Land cover percentages within major river basins in Alberta

Land cover type	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Water	1.9	2.7	2.1	0.8	0.4	0.6	0.9	0.4	0.2	0.4	4.2
Forest	83.1	78.8	83.1	32.5	0.4	9.2	26.4	13.0	0.3	0.6	68.0
Shrubland	4.0	0.9	0.3	0.4	0.0	0.1	0.4	0.0	0.0	0.0	0.0
Savanna	6.0	2.9	1.3	1.0	0.1	0.4	1.2	0.2	0.1	0.1	1.5
Grassland	1.1	1.8	3.3	6.8	14.6	27.8	29.2	24.9	72.6	71.7	0.6

Permanent wetland	3.6	1.0	0.8	0.2	0.1	0.1	0.1	0.1	0.1	0.0	0.5
Cropland	0.2	11.8	9.1	57.5	84.3	61.8	40.2	61.1	26.5	27.1	25.1
Urban built up	0.0	0.0	0.1	0.7	0.1	0.1	1.7	0.3	0.2	0.0	0.1

Table S2: Basin-wide distribution of wells screened in different types of aquifers

Basin ID	**Unconfined**	**Semi-confined**	**Confined**	**Unclassified**	**Total**
1				3	**3**
2	6		7	2	**15**
3	2		6		**8**
4	5	2	14		**21**
5	3	6	19		**28**
6	1	3	16	1	**21**
7	3	1	4	7	**15**
8	2	1	6	1	**10**
9		1	4	1	**6**
10	1	1	7		**9**
11	1	2	17	1	**21**
Total	**24**	**17**	**100**	**16**	**157**

Table S3: Specific yields of different aquifer materials (based on Morris and Johnson, 1967; Todd and Mays, 2005)

Aquifer materials	**Specific Yield (%)**
Gravel, coarse	21
Gravel, medium	24
Gravel, fine	25
Sand, coarse	27
Sand, medium	26

Sand, fine	21
Silt	8
Clay	3
Sandstone, fine grained	21
Sandstone, medium grained	27
Limestone	14
Dune sand	38
Loess	18
Peat	44
Schist	26
Siltstone	12
Till, predominantly silt	6
Till, predominantly sand	16
Till, predominantly gravel	16
Tuff	21
Sand	25
Sandstone	24
Gravel	23
Till	13
Sandy clay	3
Sandy silt	16
Sandy gravel	25
Gravelly sand	25

Clay and gravel	5
Silty sand	20
Sandy silt and clay	3
Clayey gravel	7
Clay sand	8
Clay silt	5
Silty clay	2
Shale	2

Table S4: Specific storage values for an aquifer material (based on Domenico and Mifflin, 1965; Batu, 1998)

Aquifer materials	Specific storage mean (m^{-1})
Plastic clay	0.0023
Stiff clay	0.00192
Medium hard clay	0.0011
Loose sand	0.00076
Dense sand	0.00017
Dense sandy gravel	7.6E-05
Rock, fissured	3.6E-05
Rock, sound	1.6E-06
Sand and gravel	0.0001
Shale	0.00003
Sandstone	0.00003
Gravel	0.00007
Till	0.00007
Sand and till	0.0001

Sand and silt	0.0007
Sand and clay	0.001
Shale and gravel	0.00003
Cleyey sand and gravel	0.0004
Sand	0.0002
Coarse sand	0.0007

Table S5: Correlation analysis between Hodrick-Prescott trend of precipitation and $GWSA_{obs}$ (no lag, 1 month lag and 2 months lag)

BASIN ID	**R** **NO LAG**	**R** **1 MONTH LAG**	**R** **2 MONTHS LAG**
1	0.92	0.93	0.94
2	0.35	0.28	0.22
3	-0.30	-0.33	-0.36
4	-0.62	-0.59	-0.56
5	-0.32	-0.28	-0.24
6	-0.67	-0.65	-0.63
7	0.36	0.39	0.43
8	-0.23	-0.24	-0.25
9	-0.18	-0.19	-0.19
10	0.67	0.70	0.73
11	-0.41	-0.37	-0.32

Table S6: Correlation analysis between Hodrick-Prescott trend of rainfall+snowmelt and $GWSA_{obs}$ (no lag, 1 month lag and 2 months lag)

BASIN ID	**R** **NO LAG**	**R** **1 MONTH LAG**	**R** **2 MONTHS LAG**

1	0.69	0.72	0.75
2	0.50	0.47	0.43
3	0.00	-0.02	-0.03
4	-0.01	0.02	0.05
5	0.02	0.06	0.10
6	0.10	0.13	0.16
7	0.77	0.76	0.74
8	0.08	0.06	0.05
9	-0.18	-0.19	-0.20
10	0.33	0.37	0.40
11	0.77	0.77	0.76

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