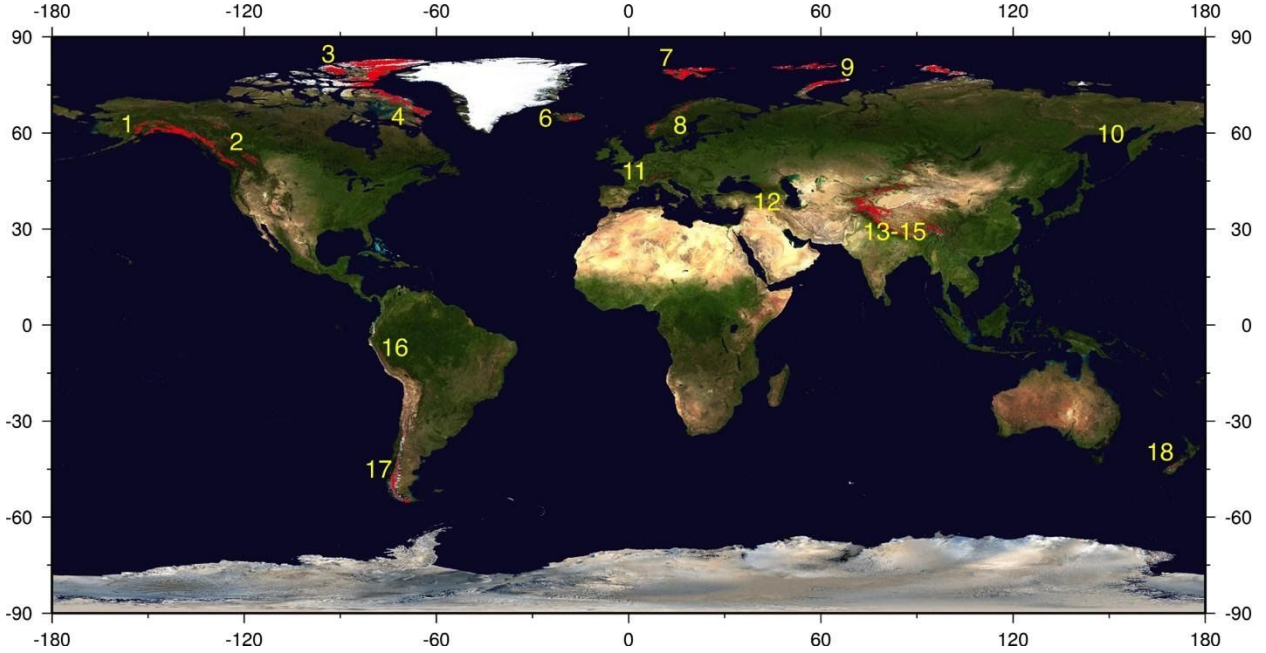
Glacier report




| | | | |
|---|---|---|---|
| **Region 1: Alaska** | **Region 2: Western Canada & US** | **Region 3: Arctic Canada North** | **Region 4: Arctic Canada South** |
| **Region 6: Iceland** | **Region 7: Svalbard** | **Region 8: Scandinavia** | **Region 9: Russian Arctic** |
| **Region 10: North Asia** | **Region 11: Central Europe** | **Region 12: Caucasus and Middle East** | |
| **Region 13-15: HMA** | **Region 16: Low Latitudes** | **Region 17: Southern Andes** | **Region 18: New Zealand** |

**Fig. 1** Regions (1-4, 6-18) of Randolph Glacier Inventory (RGI) Version 6.0 [1].
References:

**Table 1:** Regional areas and mass budgets. I, ICESat; C, Cryosat-2.

| | Region Name | Total area ($km^2$) | Mass balance changes (Gt $yr^{-1}$) | Density (kg $m^3$) | Method |
|---|---|---|---|---|---|
| 1 | Alaska | 86725.053 | -65.06±5.3 | 750 [2] | I,C |
| 2 | Western Canada and US | 14524.224 | -13.1±1.67 | 900 | I,C |
| 3 | Arctic Canada North | 105110.642 | -30.13±5.29 | 900 | I,C |
| 4 | Arctic Canada South | 40888.228 | -17.03±2.76 | 900 | I,C |
| 6 | Iceland | 11059.7 | -0.41 ± 1.13 | 900 | I,C |
| 7 | Svalbard | 33958.934 | -5.39 ± 2.23 | 900 | I,C |
| 8 | Scandinavia | 2949.103 | -0.45 ± 0.31 | 900 | I,C |
| 9 | Russian Arctic | 51591.6 | -1.23 ± 2.77 | 900 | I,C |
| 10 | North Asia | 2410.051 | -1.81±0.88 | 900 | I |
| 11 | Central Europe | 2092.146 | -2.36 ± 0.4 | 900 | I,C |
| 12 | Caucasus and Middle East | 1306.992 | -0.11±0.54 | 900 | I |
| 13-15 | HMA | 97605.706 | -16.55 ± 6.97 | 850 [3] | I,C |
| 16 | Low Latitudes | 2341.036 | -0.08±0.53 | 900 | I,C |
| 17 | Southern Andes | 29429.08 | -20.21±4.27 | 900 | I,C |
| 18 | New Zealand | 1161.801 | -0.17±0.22 | 900 | I,C |
| Global Total | | 483154.507 | -173.98±12.19 | | |

**Table 2.** Height change difference between ICESat and Cryosat-2.

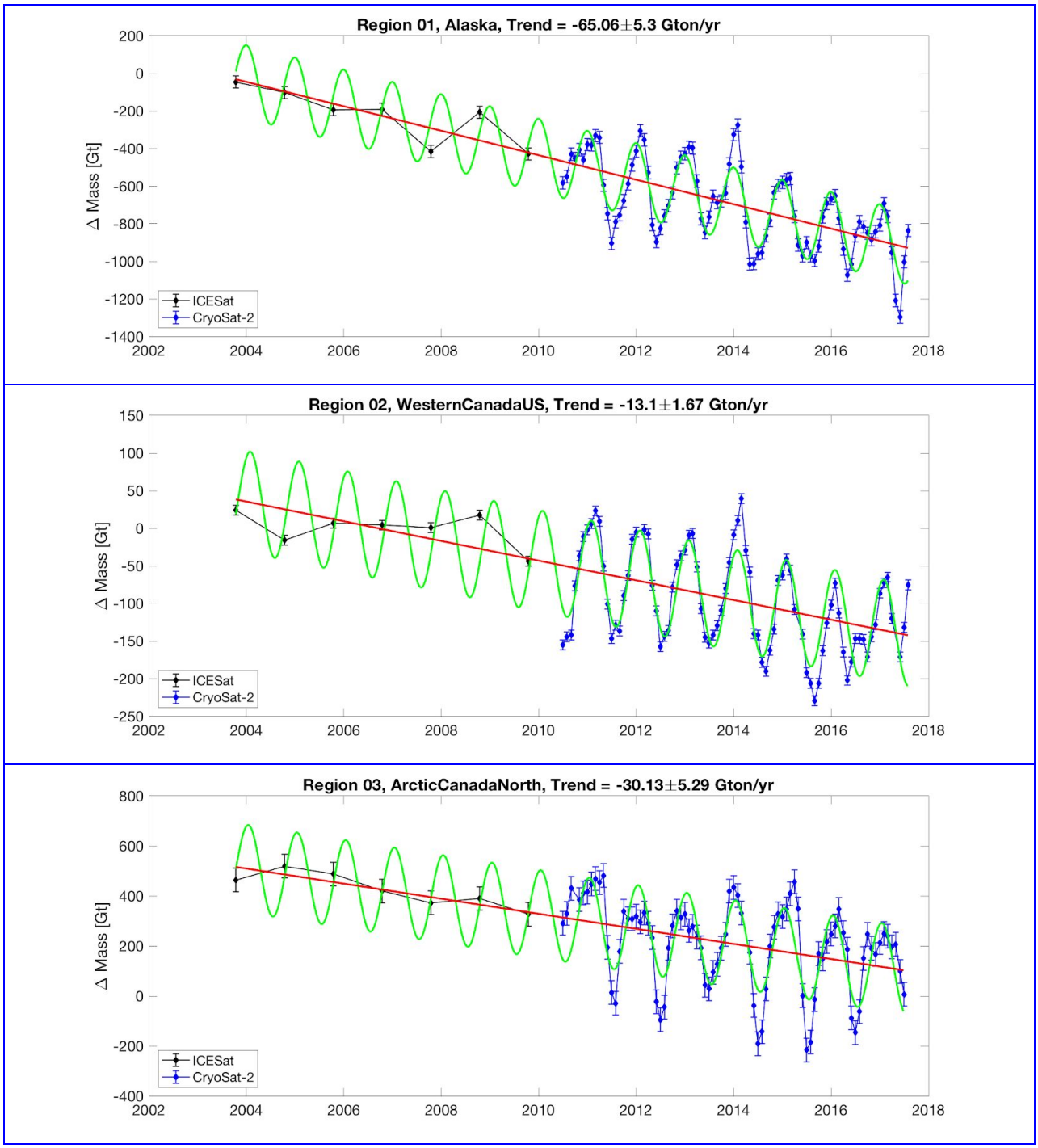
| | Region Name | Diff. (m) |
|---|---|---|

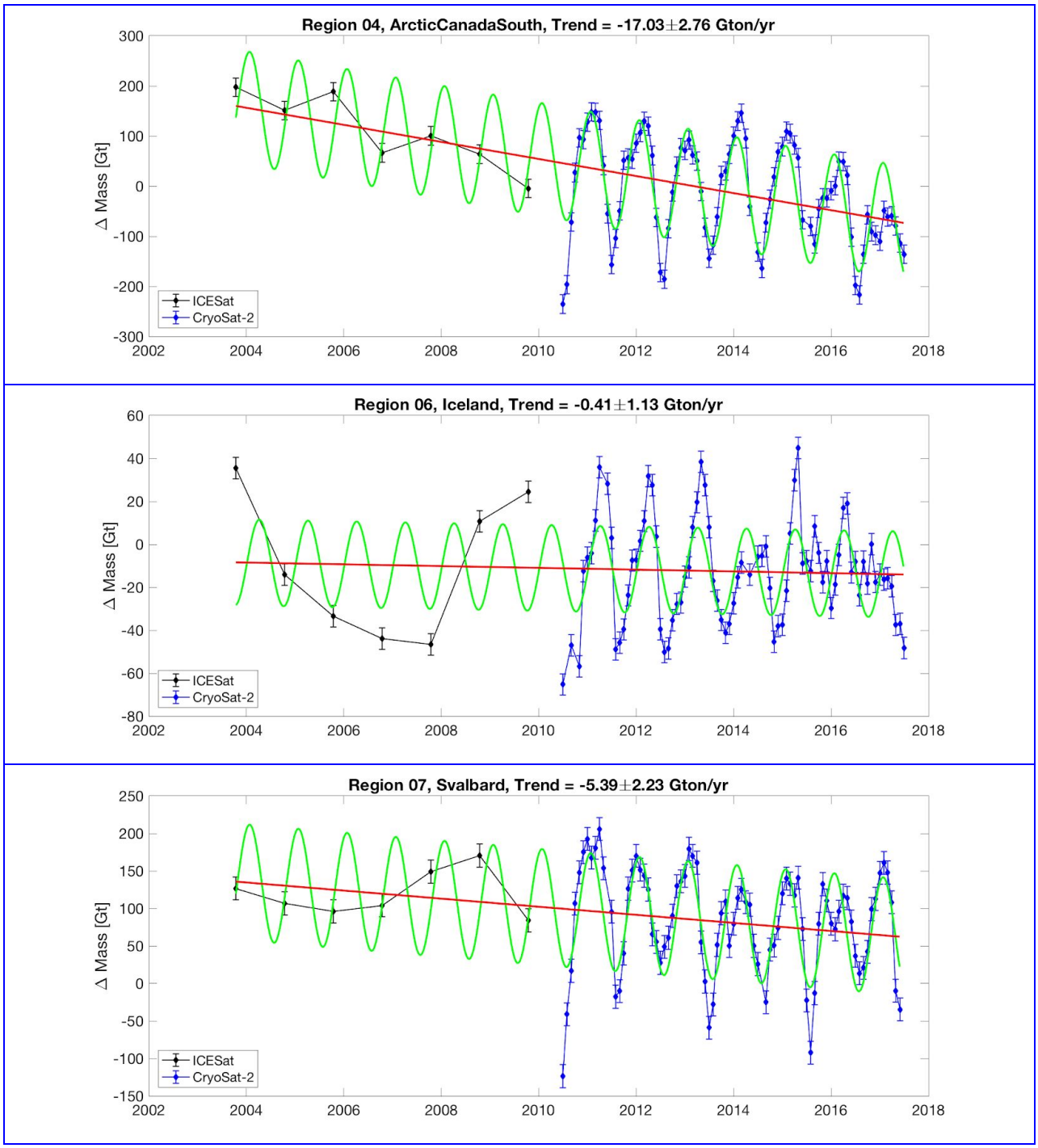
| | | |
|---|---|---|
| 1 | Alaska | -39.2 |
| 2 | Western Canada and US | -35.63 |
| 3 | Arctic Canada North | -8.0 |
| 4 | Arctic Canada South | -24.38 |
| 6 | Iceland | -15.4 |
| 7 | Svalbard | -8.08 |
| 8 | Scandinavia | -43.56 |
| 9 | Russian Arctic | -12.78 |
| 10 | North Asia | NA |
| 11 | Central Europe | -41.17 |
| 12 | Caucasus and Middle East | NA |
| 13-15 | HMA | -47.53 |
| 16 | Low Latitudes | -73.48 |
| 17 | Southern Andes | -9.95 |
| 18 | New Zealand | -42.04 |

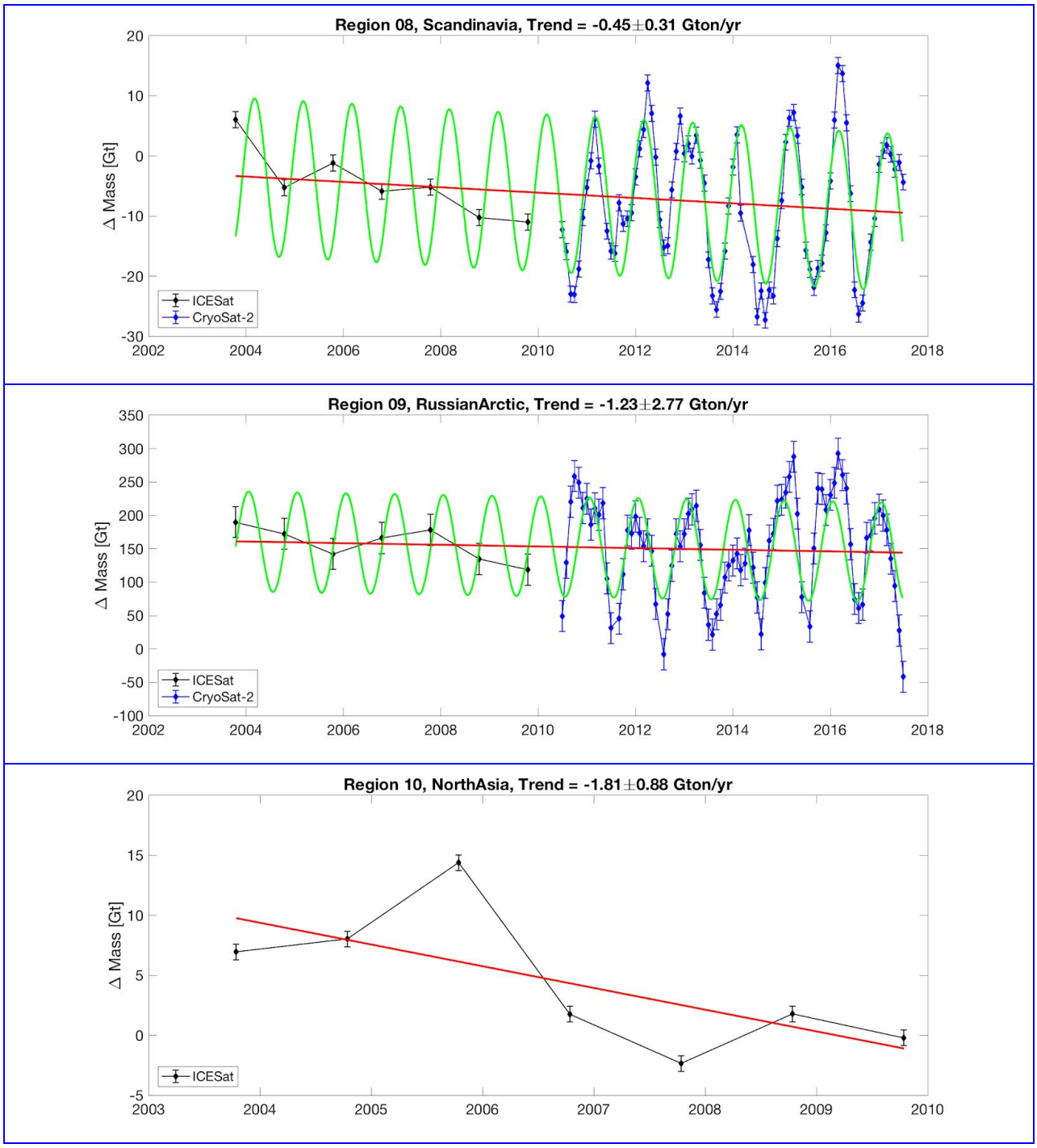
**Table 3.**

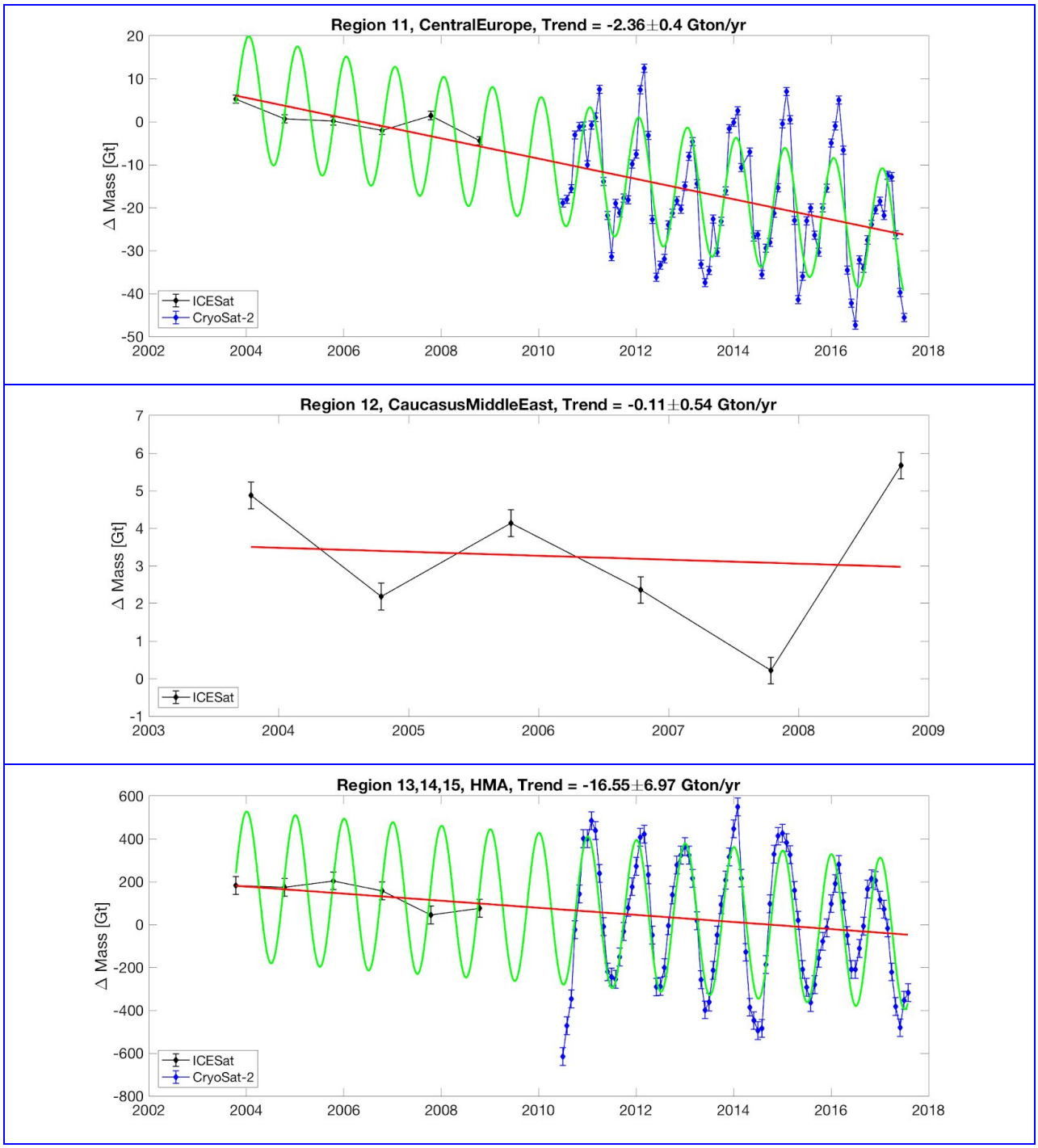
| | Region Name | Mass Balance (Gt $yr^{-1}$) | Ref. | New result (2003-2017, Gt $yr^{-1}$) | Method |
|---|---|---|---|---|---|
| 1 | Alaska | -75±11 (1994-2013) | [2] | -65.06±5.3 | I,C |
| | | -50±17 (2003-2009) | [4] | | |
| 2 | Western Canada and US | -14±3 (2003-2009) | [4] | -13.1±1.67 | I,C |
| 3 | Arctic Canada North | -33±4 (2003-2009) | [4] | -30.13±5.29 | I,C |
| 4 | Arctic Canada South | -27±4 (2003-2009) | [4] | -17.03±2.76 | I,C |
| 6 | Iceland | -10±2 (2003-2009) | [4] | -0.41 ± 1.13 | I,C |
| 7 | Svalbard | -5±2 (2003-2009) | [4] | -5.39 ± 2.23 | I,C |
| 8 | Scandinavia | -2±0 (2003-2009) | [4] | -0.45 ± 0.31 | I,C |
| 9 | Russian Arctic | -11±4 (2003-2009) | [4] | -1.23 ± 2.77 | I,C |
| 10 | North Asia | -2±1 (2003-2009) | [4] | -1.81±0.88 (2003-2009) | I |
| 11 | Central Europe | -2±0 (2003-2009) | [4] | -2.36 ± 0.4 | I,C |
| 12 | Caucasus and Middle East | -1±0 (2003-2009) | [4] | -0.11±0.54 (2003-2009) | I |
| 13-15 | HMA | -26±12 (2003-2009) | [4] | -16.55 ± 6.97 | I,C |
| | | -16.3±3.5 (2000-2016) | [3] | | |
| 16 | Low Latitudes | -4±1 (2003-2009) | [4] | -0.08±0.53 | I,C |
| 17 | Southern Andes | -29±10 (2003-2009) | [4] | -20.21±4.27 | I,C |
| 18 | New Zealand | 0±1 (2003-2009) | [4] | -0.17±0.22 | I,C |

ICESat/GLAS elevation accuracy is reported to be 15 cm over flat terrain [5]. However, the computed elevation accuracy varies from 30 cm to 80 cm over ice-sheet regions [6]. Average error of 20cm has been reported in estimating glacier ice thickness change in the Alps/Himalaya [5]. The vertical error from Level 2 product of Cryosat-2 SARIn data is reported can be nearly 30 cm in West Antarctic Ice Sheet [7]. In **Fig. 2,** we used 50 cm as vertical error for both ICESat and Cryosat-2 elevations.


Region 01, Alaska, Trend = -65.06±5.3 Gton/yr
Δ Mass [Gt]
ICESat
CryoSat-2
Region 02, WesternCanadaUS, Trend = -13.1±1.67 Gton/yr
Δ Mass [Gt]
ICESat
CryoSat-2
Region 03, ArcticCanadaNorth, Trend = -30.13±5.29 Gton/yr
Δ Mass [Gt]
ICESat
CryoSat-2


Region 04, ArcticCanadaSouth, Trend = -17.03±2.76 Gton/yr
Δ Mass [Gt]
ICESat
CryoSat-2
Region 06, Iceland, Trend = -0.41±1.13 Gton/yr
Δ Mass [Gt]
ICESat
CryoSat-2
Region 07, Svalbard, Trend = -5.39±2.23 Gton/yr
Δ Mass [Gt]
ICESat
CryoSat-2


Region 08, Scandinavia, Trend = -0.45±0.31 Gton/yr
Δ Mass [Gt]
ICESat
CryoSat-2
Region 09, RussianArctic, Trend = -1.23±2.77 Gton/yr
Δ Mass [Gt]
ICESat
CryoSat-2
Region 10, NorthAsia, Trend = -1.81±0.88 Gton/yr
Δ Mass [Gt]
ICESat


Region 11, CentralEurope, Trend = -2.36±0.4 Gton/yr
Δ Mass [Gt]
ICESat
CryoSat-2
Region 12, CaucasusMiddleEast, Trend = -0.11±0.54 Gton/yr
Δ Mass [Gt]
ICESat
Region 13,14,15, HMA, Trend = -16.55±6.97 Gton/yr
Δ Mass [Gt]
ICESat
CryoSat-2

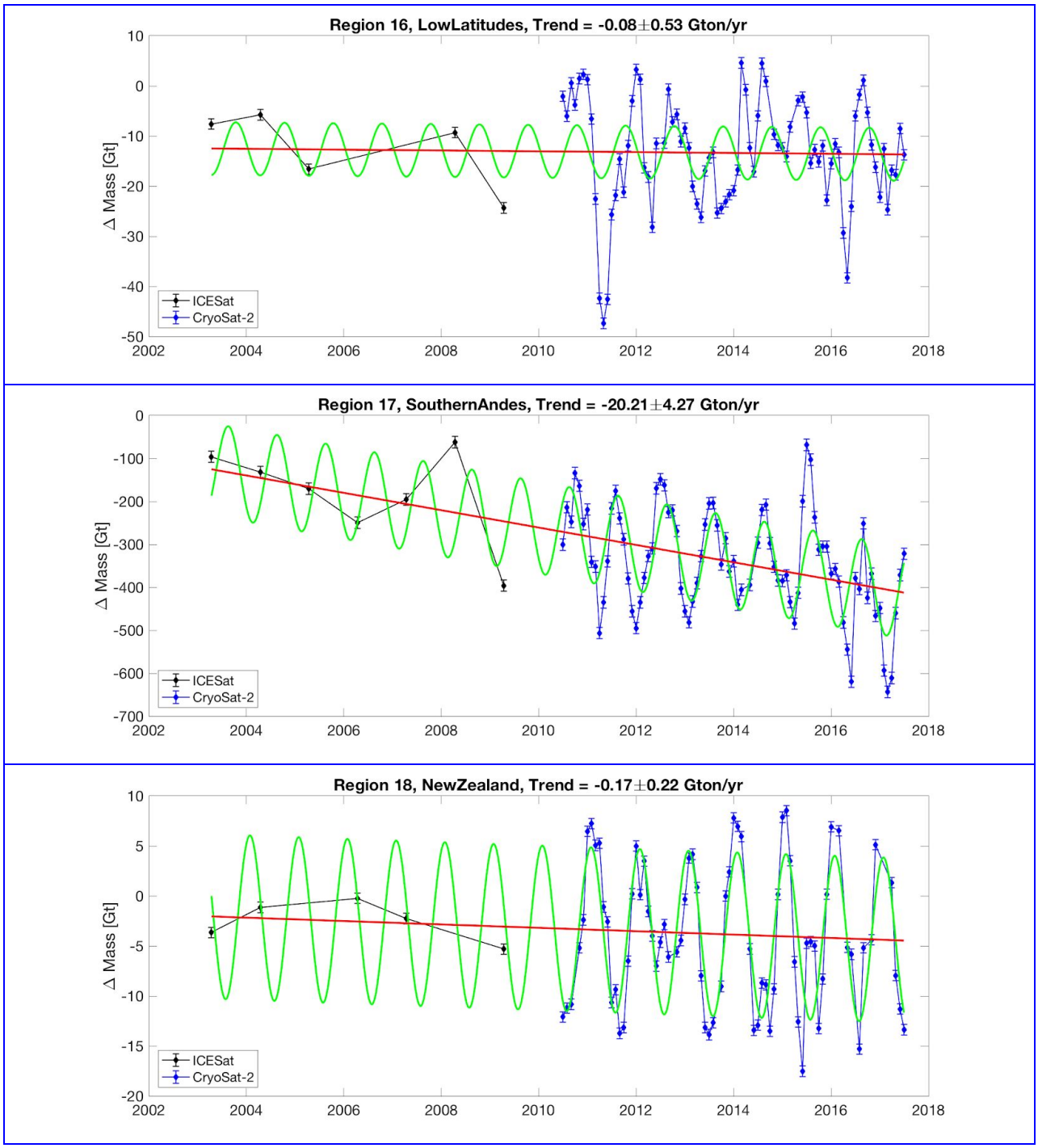



**Fig. 2** Mountain glacier mass balance estimates combining ICESat and CryoSat-2 altimeter data (10/22/2003–16/01/2017, with 1.5 year data gap).

References:

[1] RGI Consortium (2017). Randolph Glacier Inventory – A Dataset of Global Glacier Outlines: Version 6.0: Technical Report, Global Land Ice Measurements from Space, Colorado, USA. Digital Media. DOI: https://doi.org/10.7265/N5-RGI-60.

[2]. Larsen, C. F., E. Burgess, A. A. Arendt, S. O'Neel, A. J. Johnson, and C. Kienholz (2015), Surface melt dominates Alaska glacier mass balance, Geophys. Res. Lett., 42, 5902–5908, doi:10.1002/ 2015GL064349.
[3]. F. Brun, E. Berthier, P. Wagnon, A. Kääb, D. Treichler (2017), A spatially resolved estimate of High Mountain Asia glacier mass balances from 2000 to 2016, Nature geoscience 10 (9), 668-673.
[4]. Gardner, A. S., Moholdt, G., Cogley, J. G., Wouters, B., Arendt, A. A., Wahr, J., et al. (2013), A reconciled estimate of glacier contributions to sea level rise: 2003 to 2009. Science 340, 852–857. doi: 10.1126/science.1234532.
[5]. Ritesh Agrawal, Gunjan Rastogi and Ajai (2017), Estimation of change in glacier ice thickness using ICESat laser altimetry data, Journal of Geomatics, Vol 11 No. 1.
[6] Toutin, T. (2011), Digital elevation model generation over glacierized region, Encyclopedia of Snow, Ice and Glaciers, edited by Singh, P. H., Umesh Kumar Dordrecht, Netherlands: Springer, (p204).
[7] Seung Hee Kim and Duk-jin Kim (2017), Combined Usage of TanDEM-X and CryoSat-2 for Generating a High Resolution Digital Elevation Model of Fast Moving Ice Stream and Its Application in Grounding Line Estimation, Remote Sens. 2017, 9, 176; doi:10.3390/rs9020176.