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Remote Sensing 4 – Global mass changes from remote sensing

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Why glacier mass changes?

- Water resources
- Energy generation
- Sea-level rise
- Climate

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Global mass changes : an overview

- Glaciers

  Which regions matter for sea level?

  Regional overview of mass changes

  The global picture

- Ice Sheets

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Region	All glaciers Number	All glaciers Area km^2
01 Alaska	26 944	86 715
02 Western Canada and US	15 215	14 559
03 Arctic Canada North	4538	104 873
04 Arctic Canada South	7347	40 894
05 Greenland Periphery	19 323	89 721
06 Iceland	568	11 060
07 Svalbard and Jan Mayen	1615	33 922
08 Scandinavia	2668	2851
09 Russian Arctic	1069	51 592
10 North Asia	4403	3430
11 Central Europe	3920	2063
12 Caucasus and Middle East	1386	1139
13 Central Asia	46 543	62 606
14 South Asia West	22 822	33 859
15 South Asia East	14 095	21 799
16 Low Latitudes	2863	2346
17 Southern Andes	16 046	29 333
18 New Zealand	3537	1162
19 Antarctic and Subantarctic	2752	132 867
00 Total	**197 654**	**726 792**

RGI glacier area

Pfeffer et al (2014)

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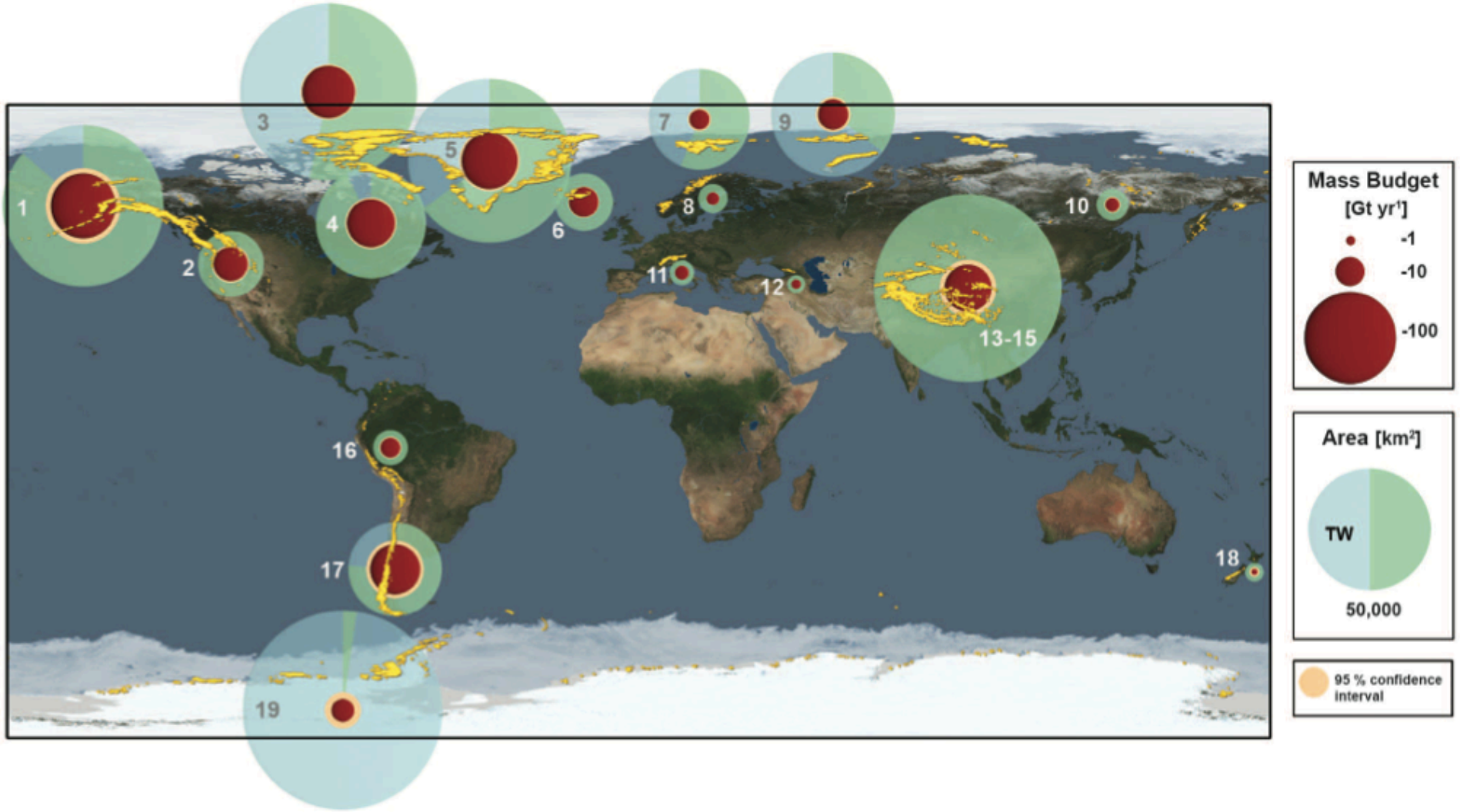
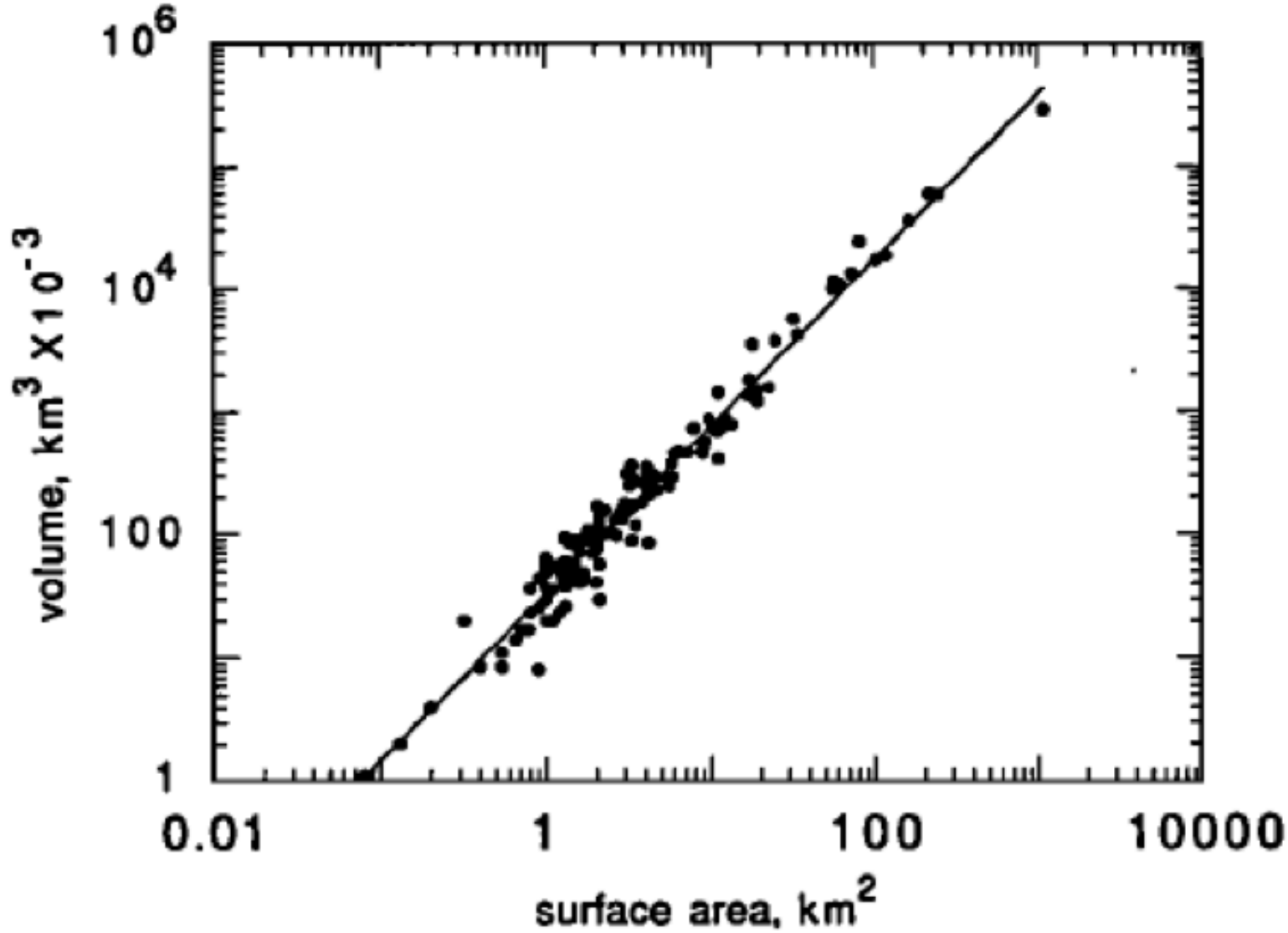
Where's the ice?



Gardner et al (2013)

From area to volume



Bahr et al (1997)

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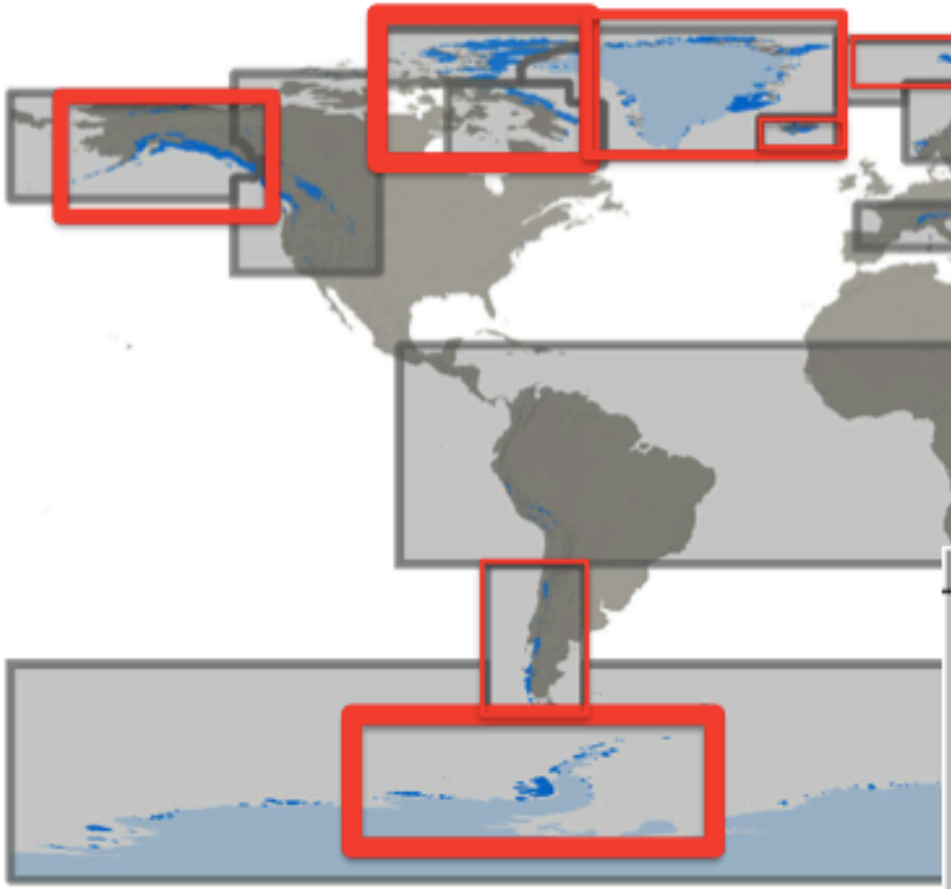
Potentially important regions for SLR



Region	mm SLE
Arctic Canada	199 ± 30
Antarctica	147 ± 64
Alaska	68 ± 8
Greenland	44 ± 7
Russian Arctic	44 ± 11
High Mountain Asia	31 ± 1
Svalbard	26 ± 2
South America II	20 ± 2
Iceland	12 ± 6
TOTAL	**591 ± 131**
% Gobal	**99%**

Radic & Hock (2010)

$$\delta V / \delta \alpha = M_a - M_m - M_c \pm M_b$$

Regional overview of mass changes : Canadian Arctic

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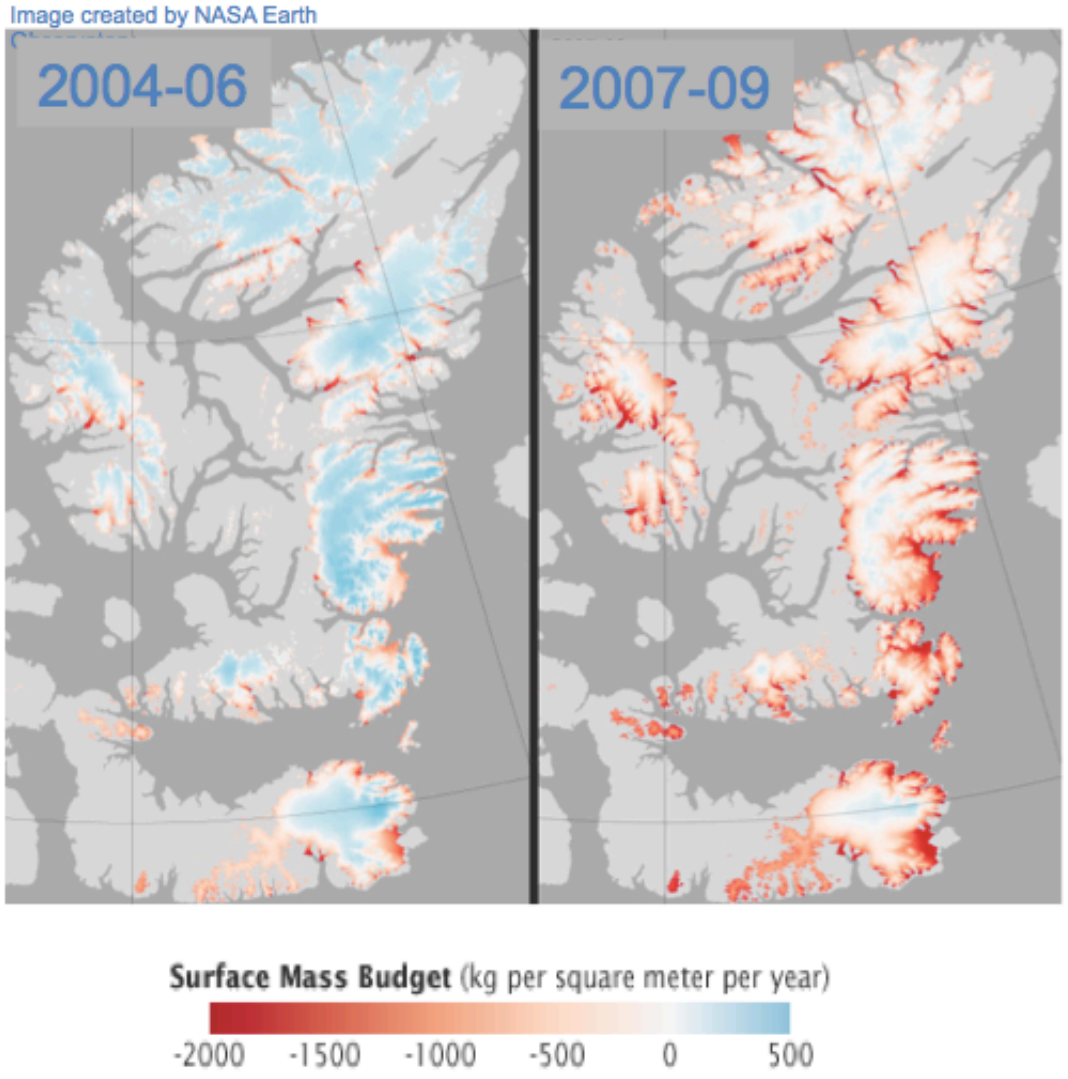

- SMB model constrained by observations
- Increasingly –ve mass balance since ~2006

Gardner et al (2011)

Regional overview of mass changes : Canadian Arctic

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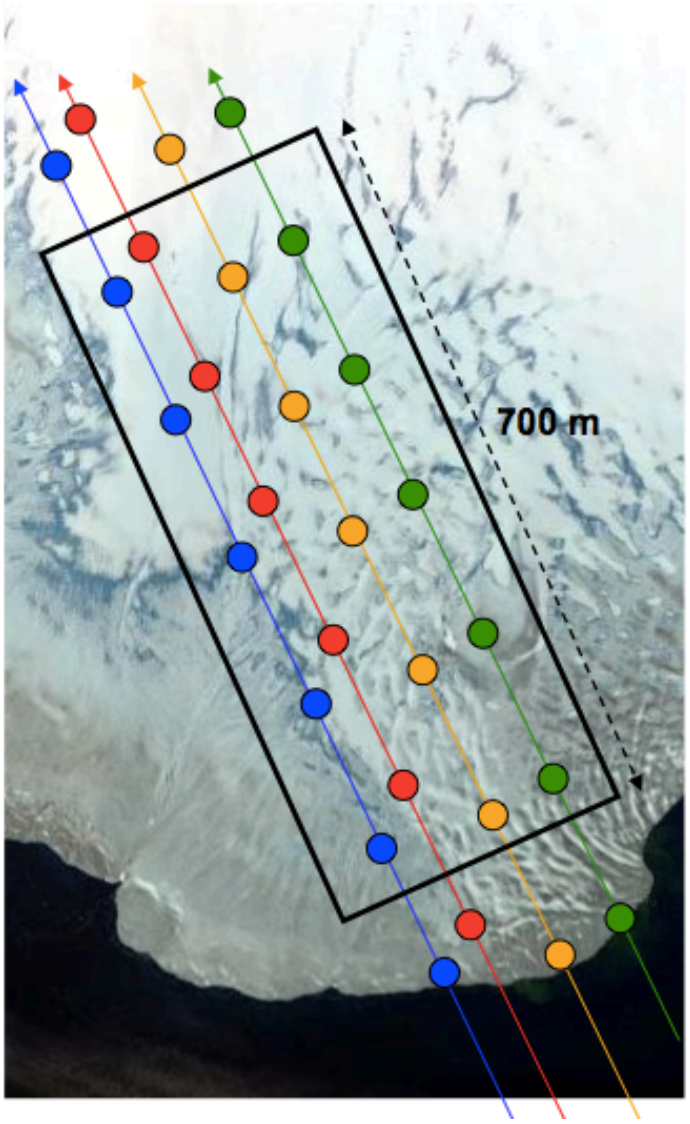
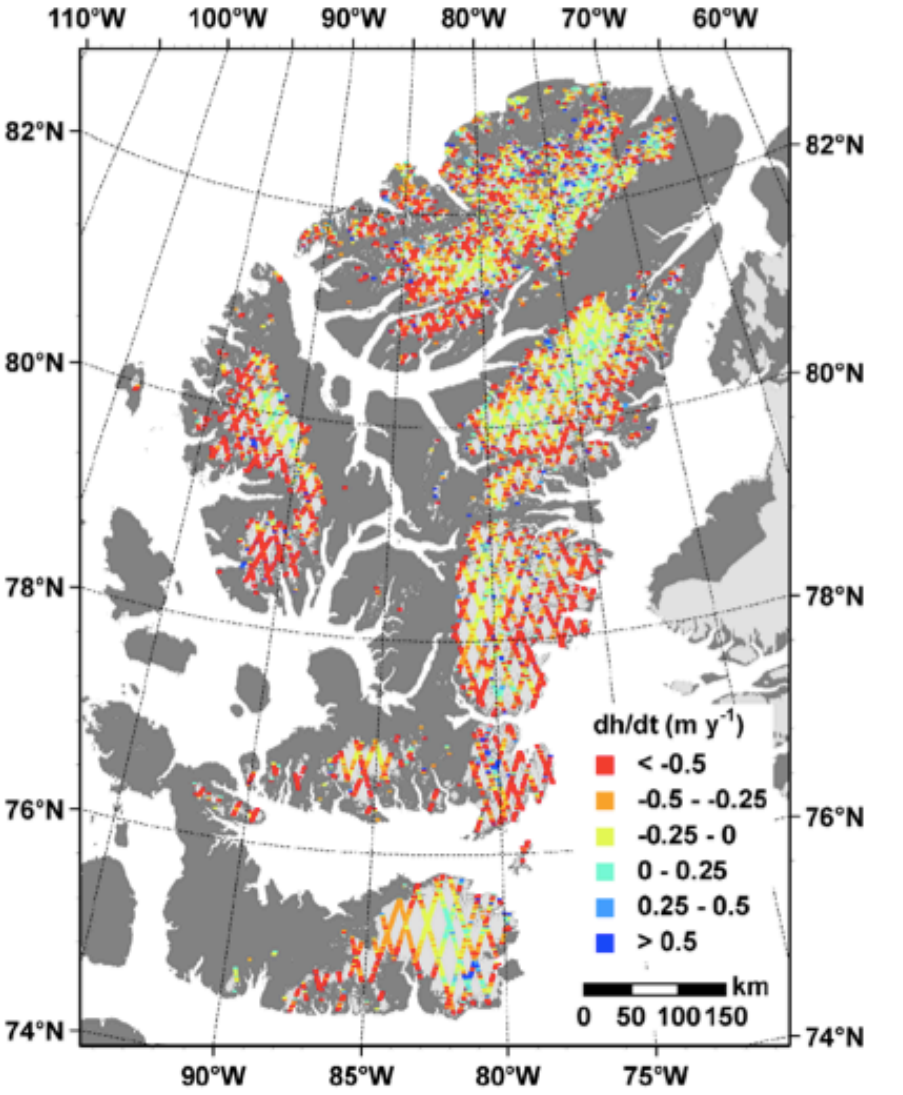
Gardner et al (2011)





Regional overview of mass changes : Canadian Arctic

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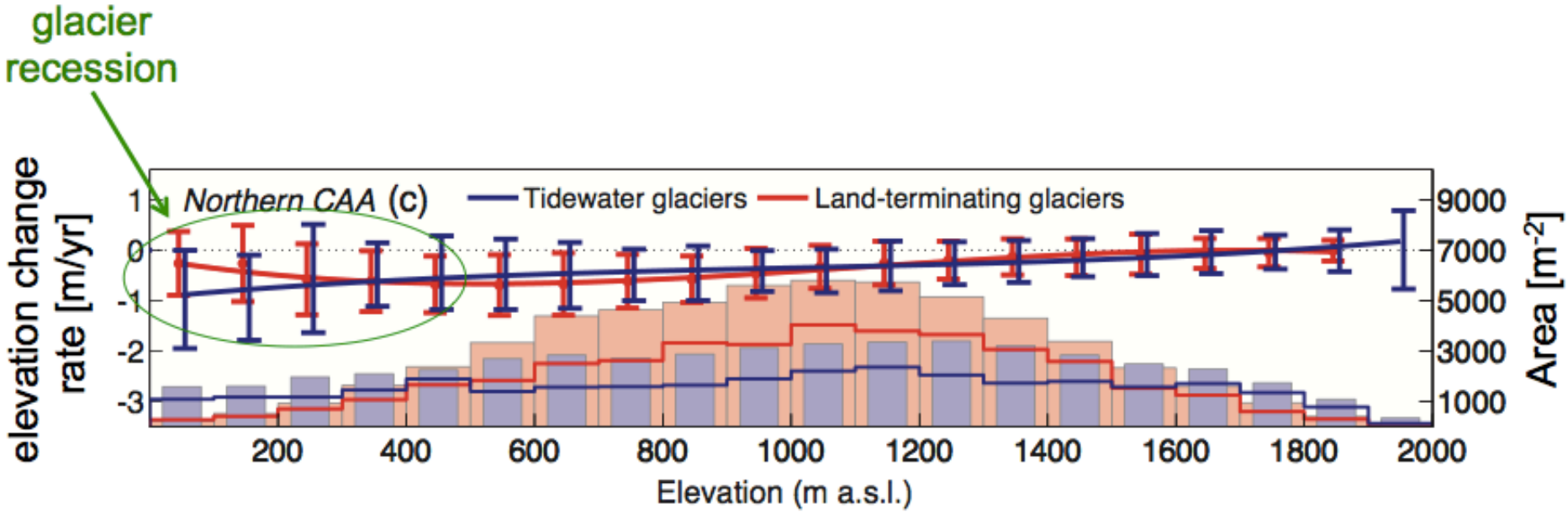

Image: A. Gardner

Regional overview of mass changes : Canadian Arctic

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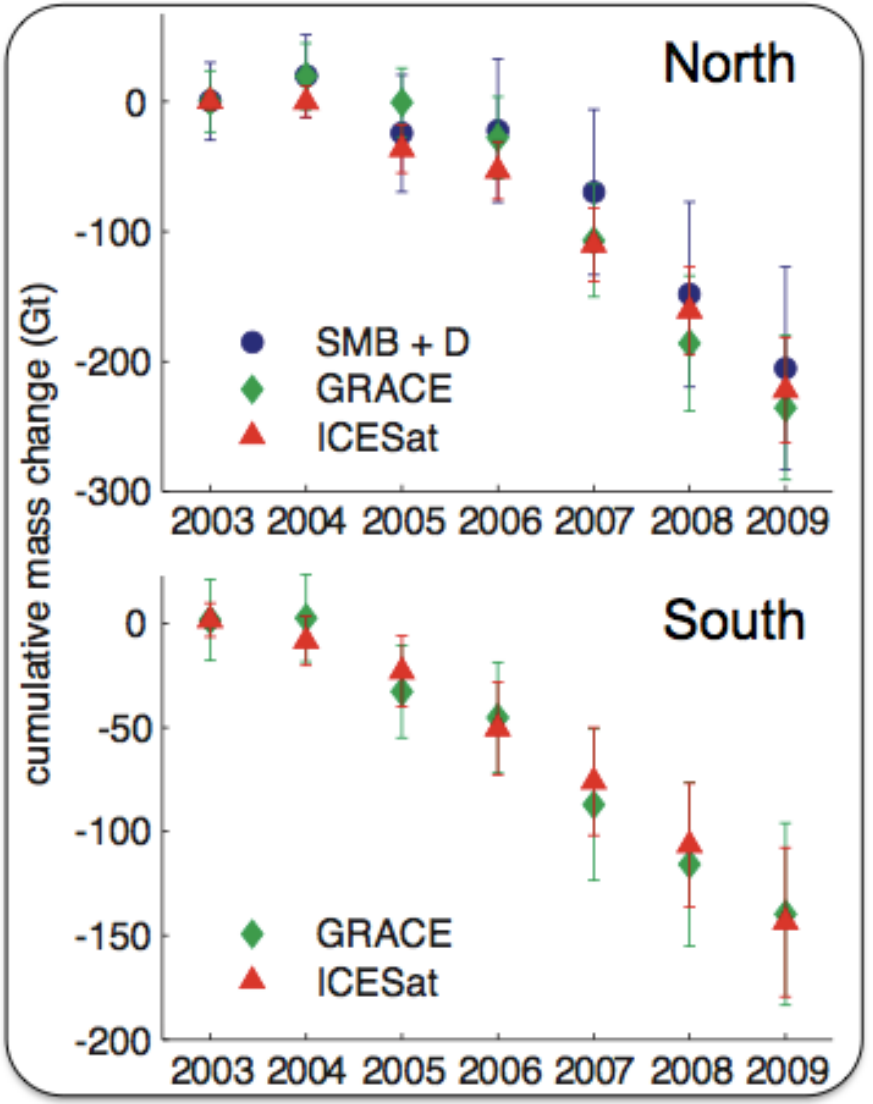
methods agree

- 04-06 : −31 ± 8 Gt yr^{-1}
- 07-09 : −92 ± 8 Gt yr^{-1}

ice loss from increased ablation resulting from warmer summer temp

- −64 ± 14 Gt yr^{-1} K^{-1}



Gardner et al (2011)

Regional overview of mass changes : Gulf of Alaska

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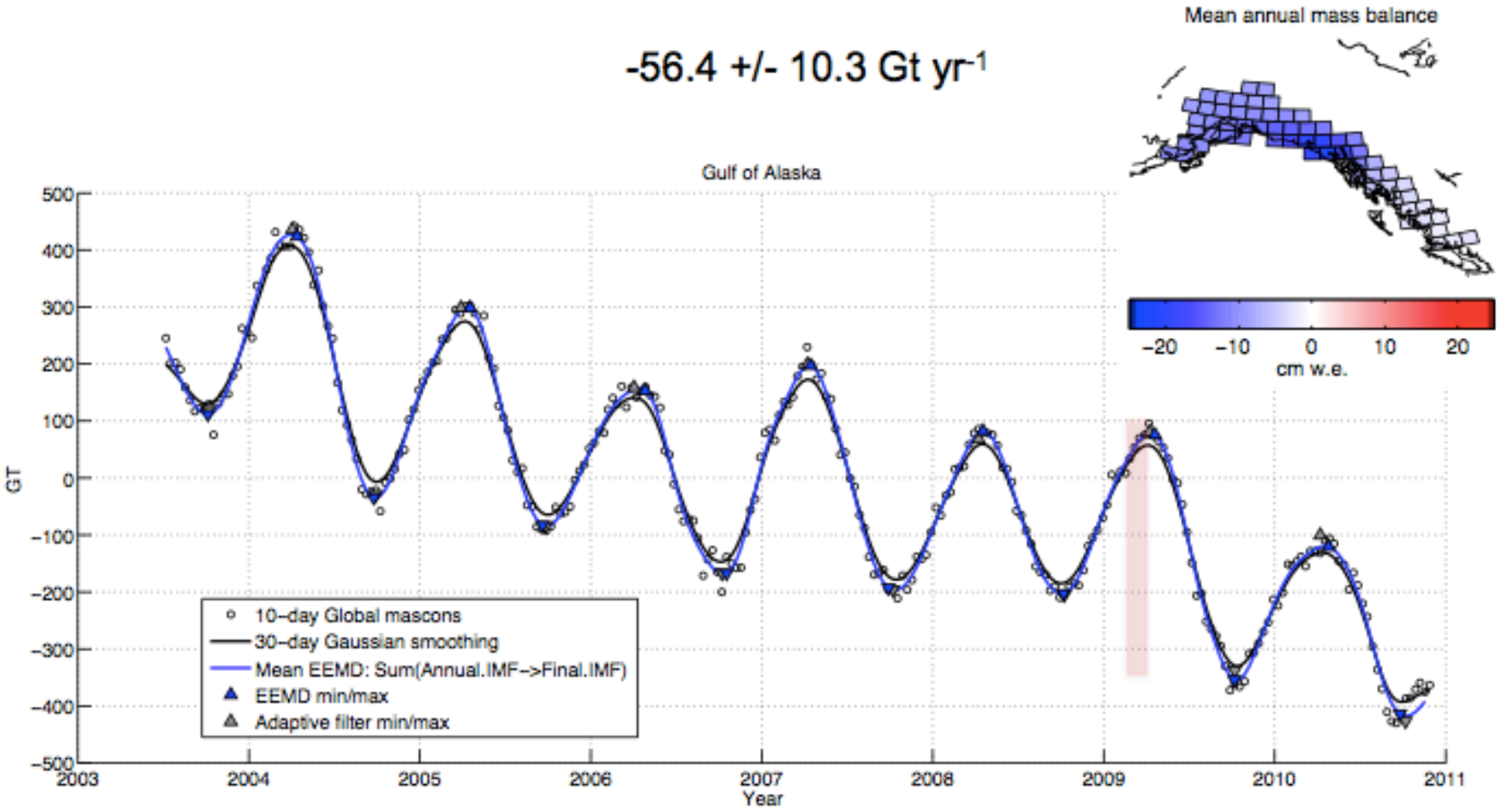

Luthcke et al (2008)

Regional overview of mass changes : Gulf of Alaska

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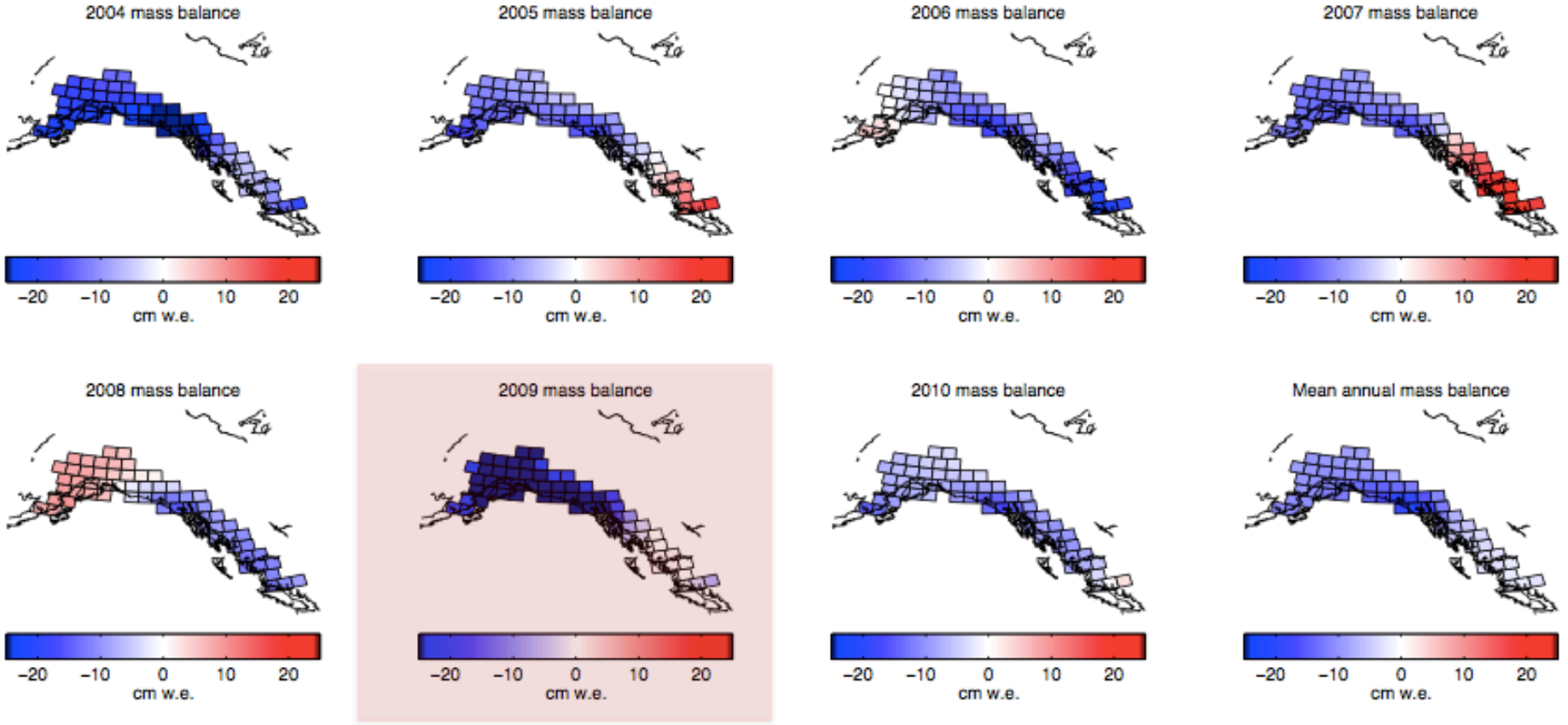

Luthcke et al (2008), courtesy A. Arendt

Regional overview of mass changes : Patagonia

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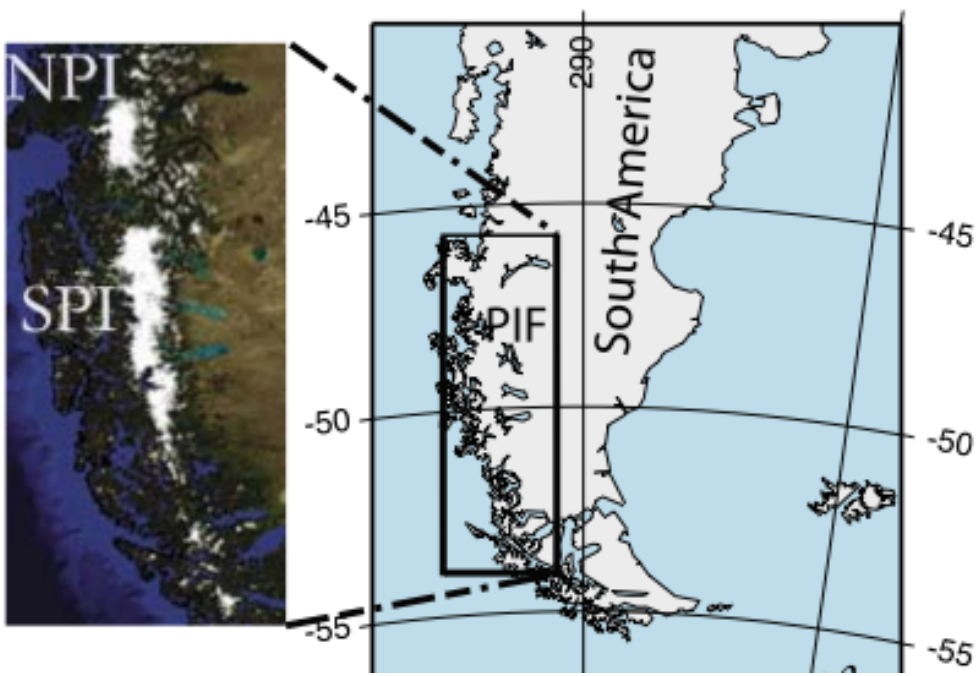

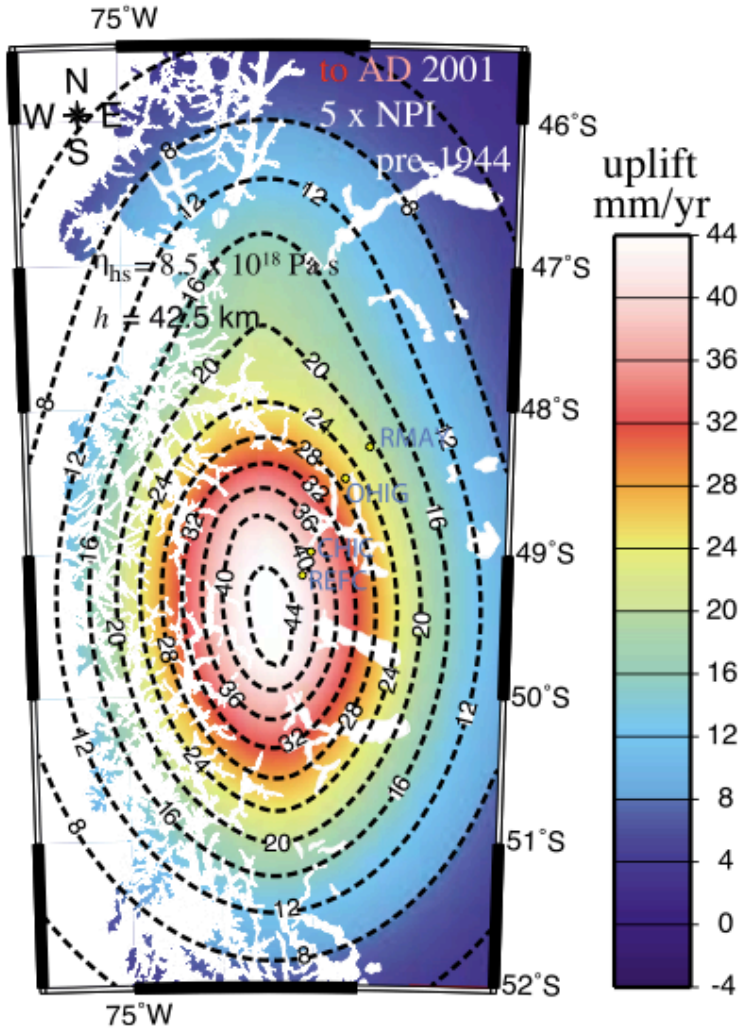

- 2003-2009 -26 Gt yr^{-1}
- GIA = ~+9 Gt yr^{-1}

Ivins et al (2011)

Regional overview of mass changes : Russian Arctic

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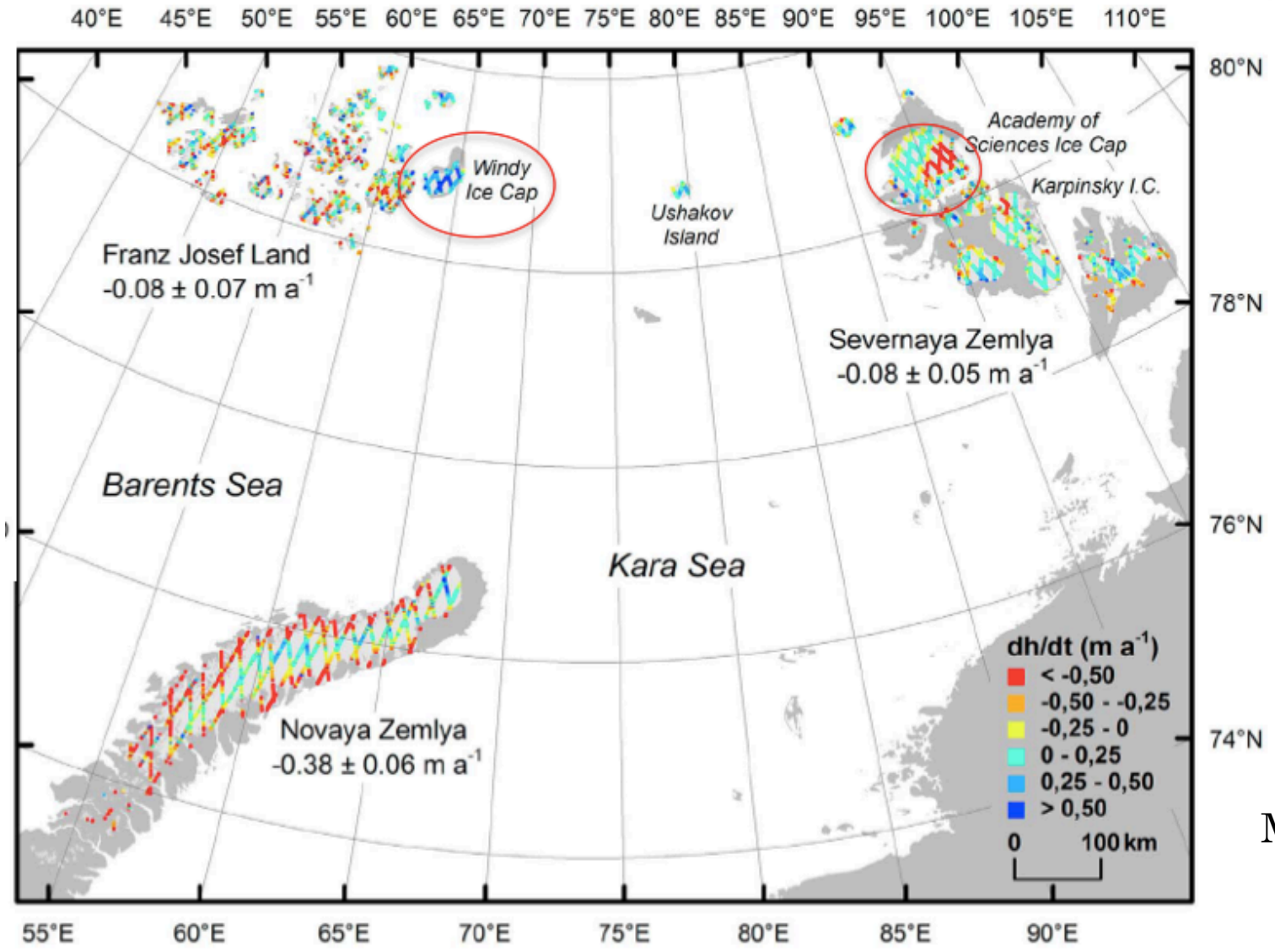
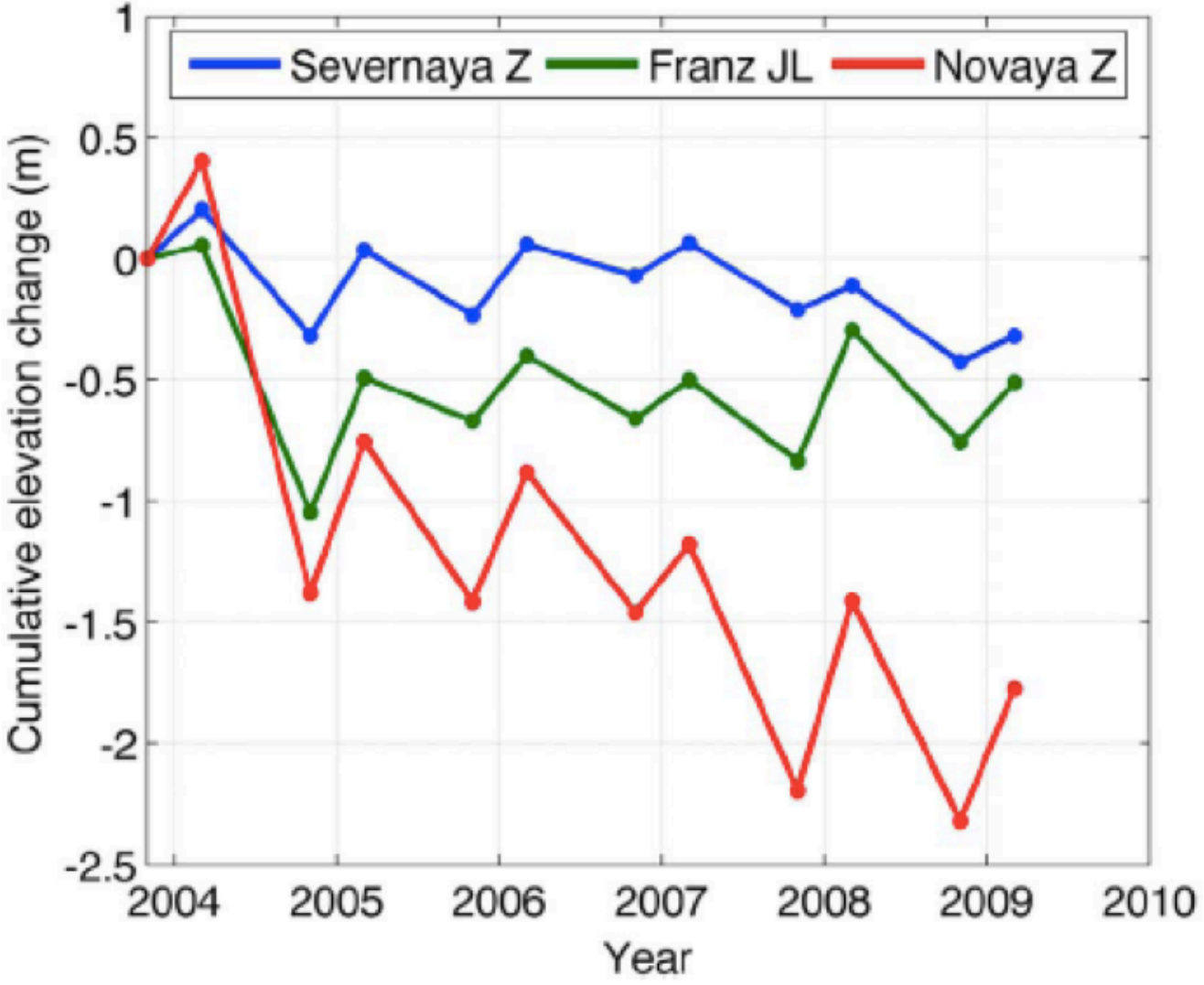


Moholdt et al (2012)



- 2003-2009 -9.1 Gt yr^{-1}
- 80% from Novaya Zemlya
- 20% from FJL & SZ

Moholdt et al (2012)

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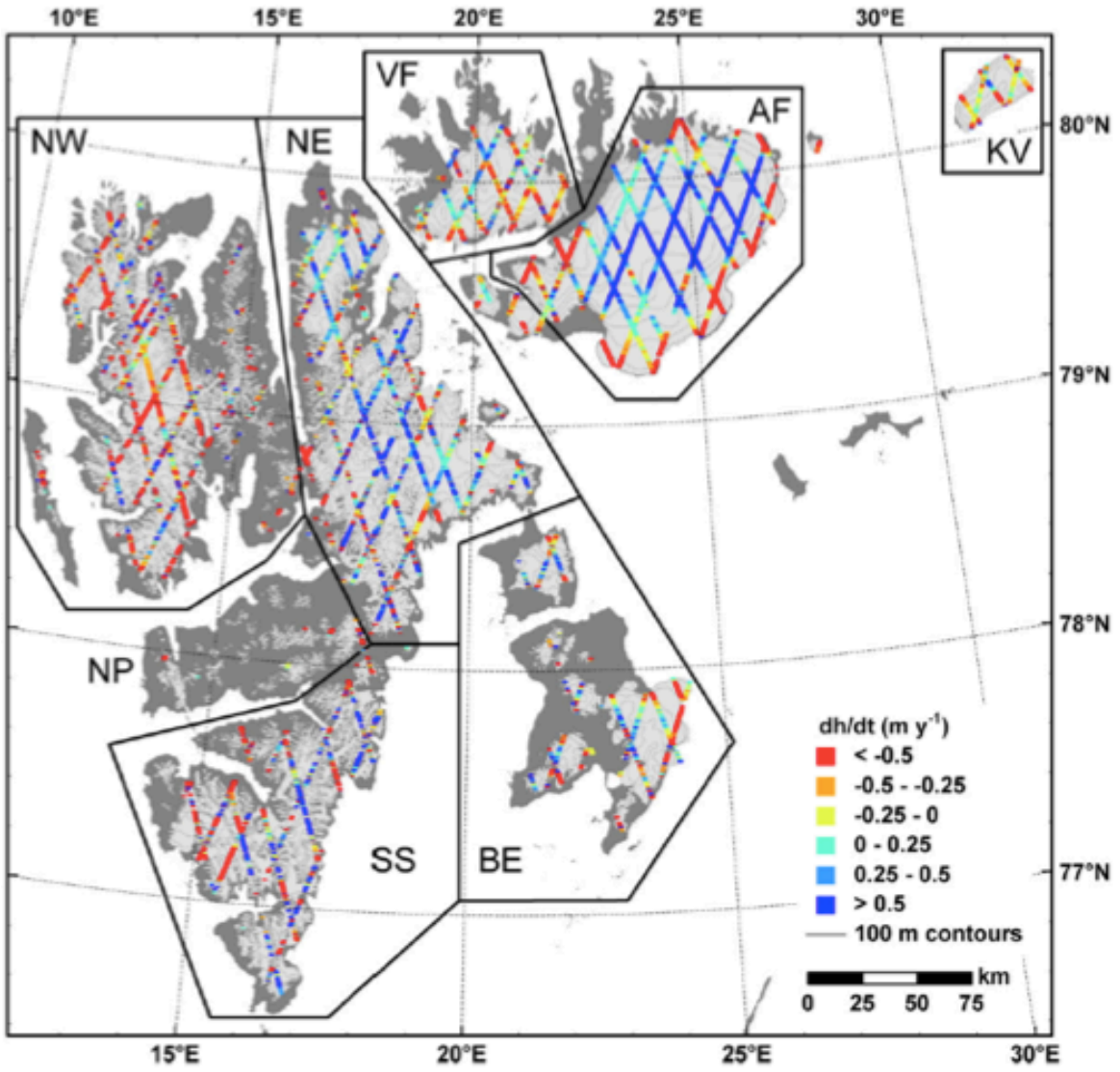
Regional overview of mass changes : Svalbard

- Low elevation thinning
- High elevation thickening
- -4.3 Gt yr^{-1}
- 20% from FJL & SZ
- NE Spitzbergen & Austfonna gaining mass



Moholdt et al (2010) RSE

Global glaciers

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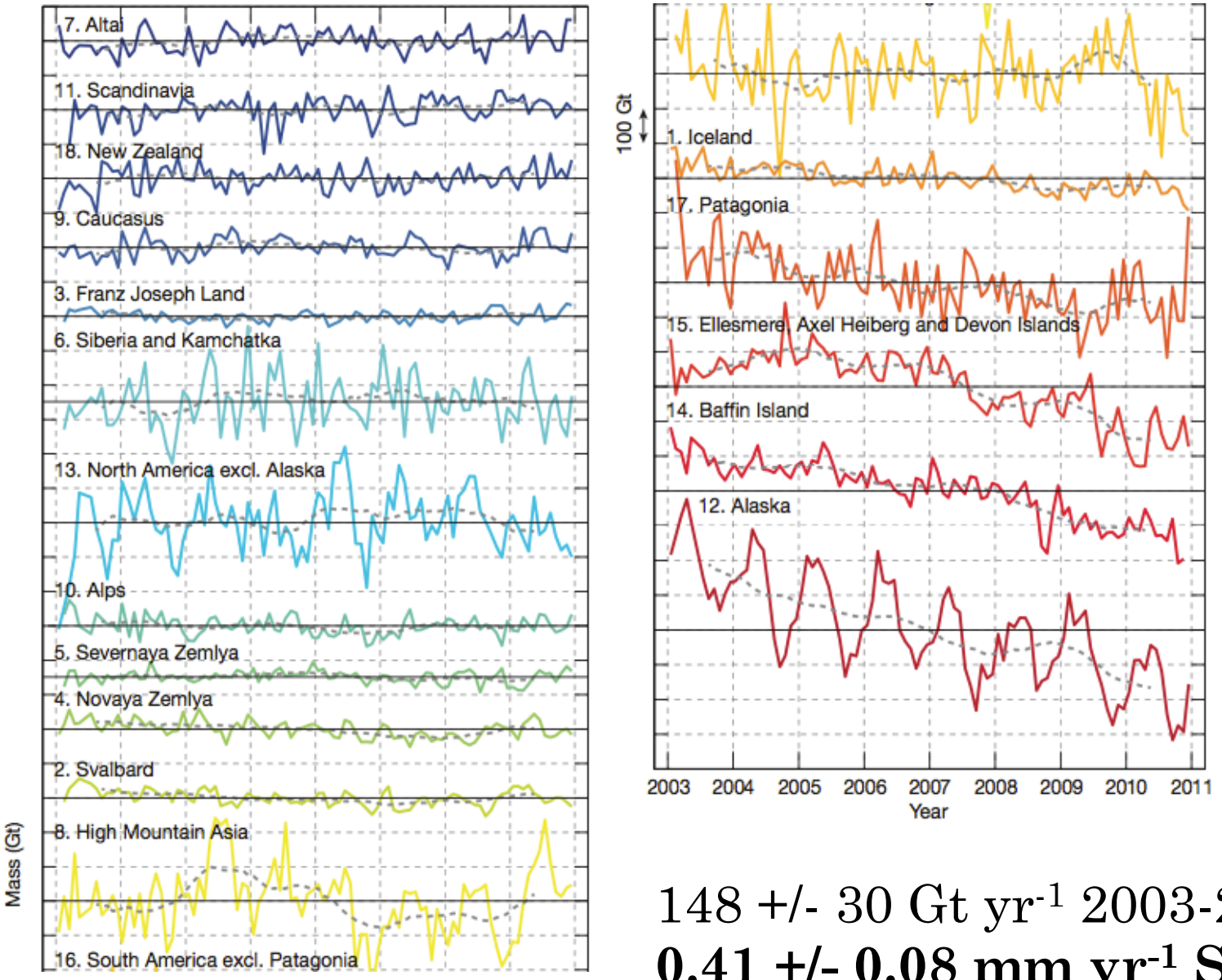

Jacob et al. (2012)

148 +/- 30 Gt yr^{-1} 2003-2010

0.41 +/- 0.08 mm yr^{-1} SLR

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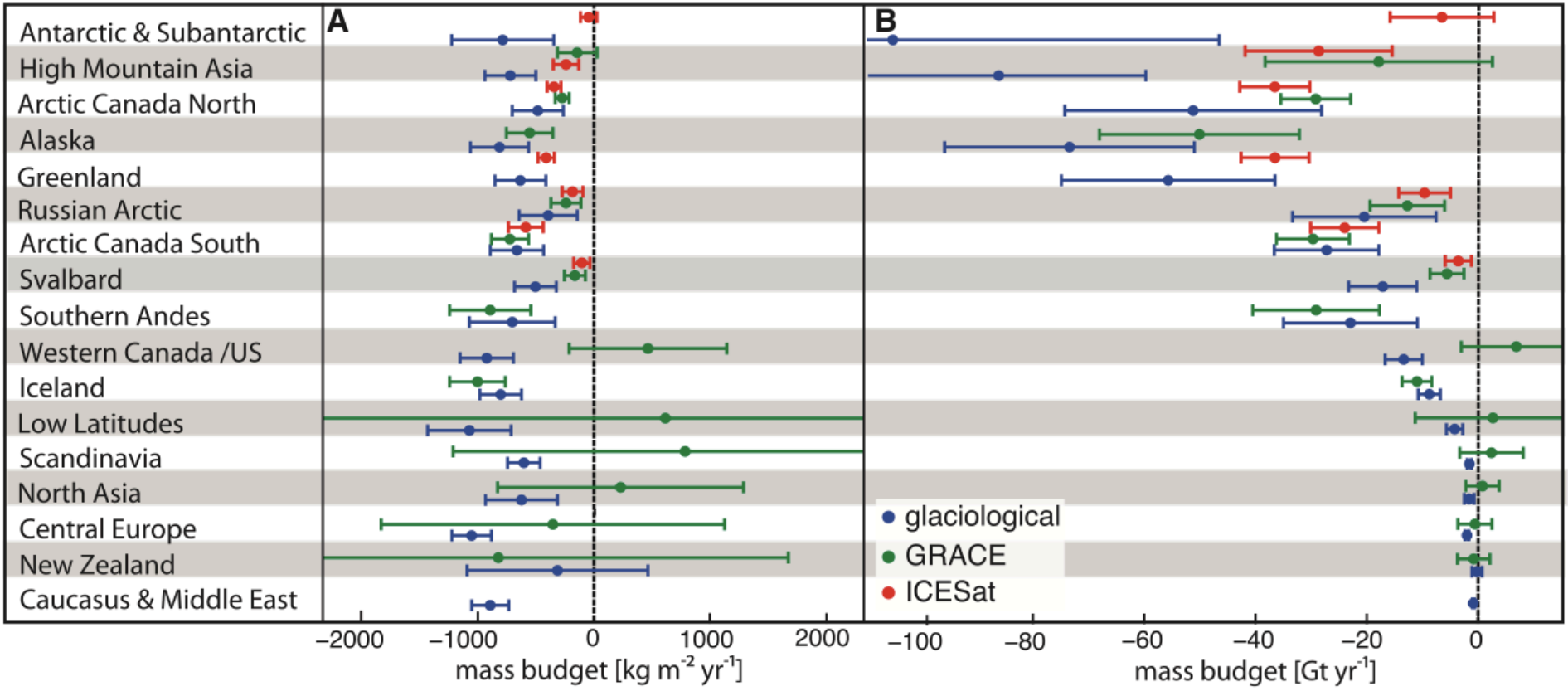
Global glacier mass changes



- 2003-2009 : Global mass budget : -259 ± 28 Gt yr^{-1}
- 2003-2009 : **0.71 ± 0.08 mm SLE yr^{-1}**

Gardner et al (2013) *Science*

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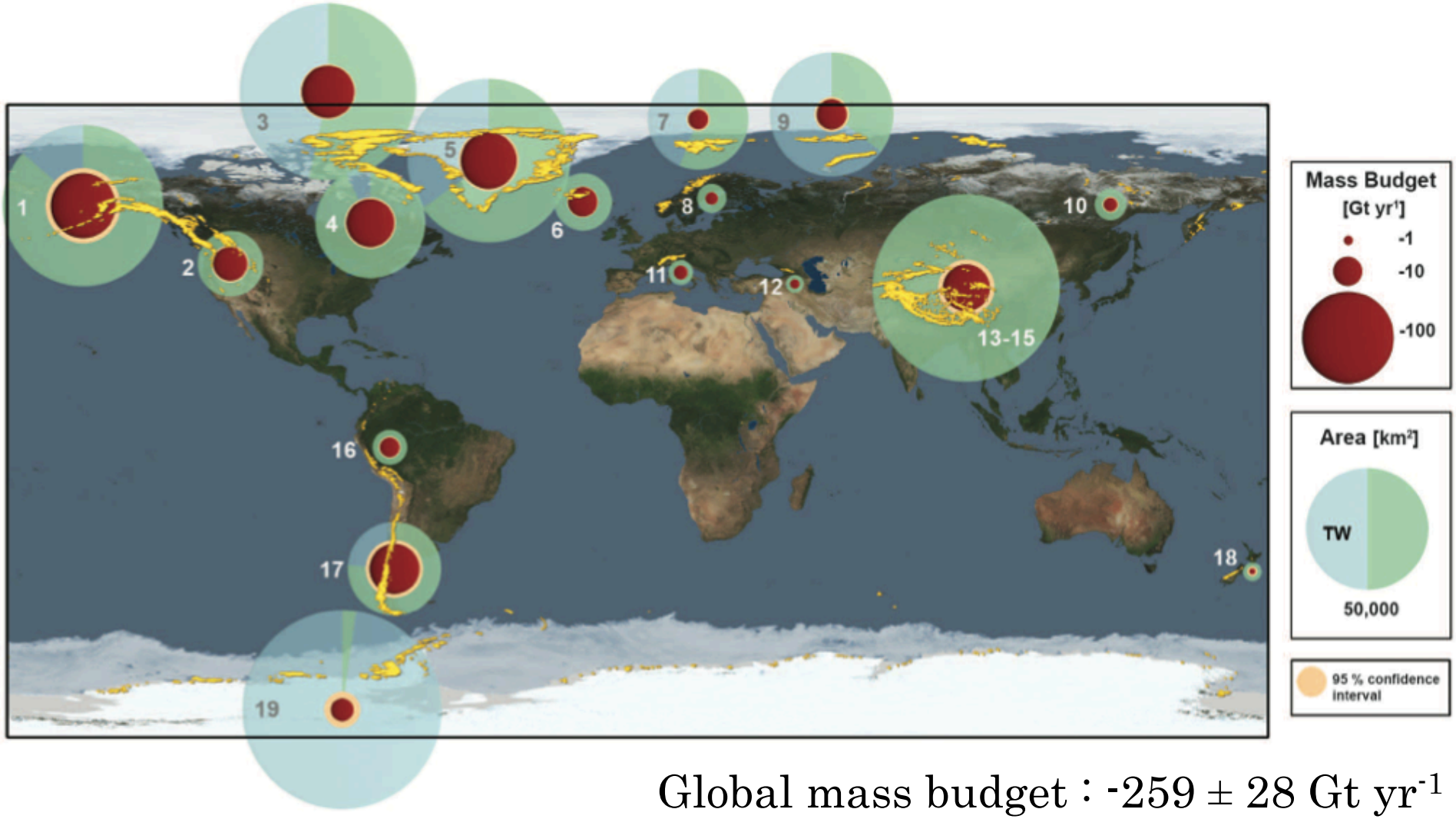
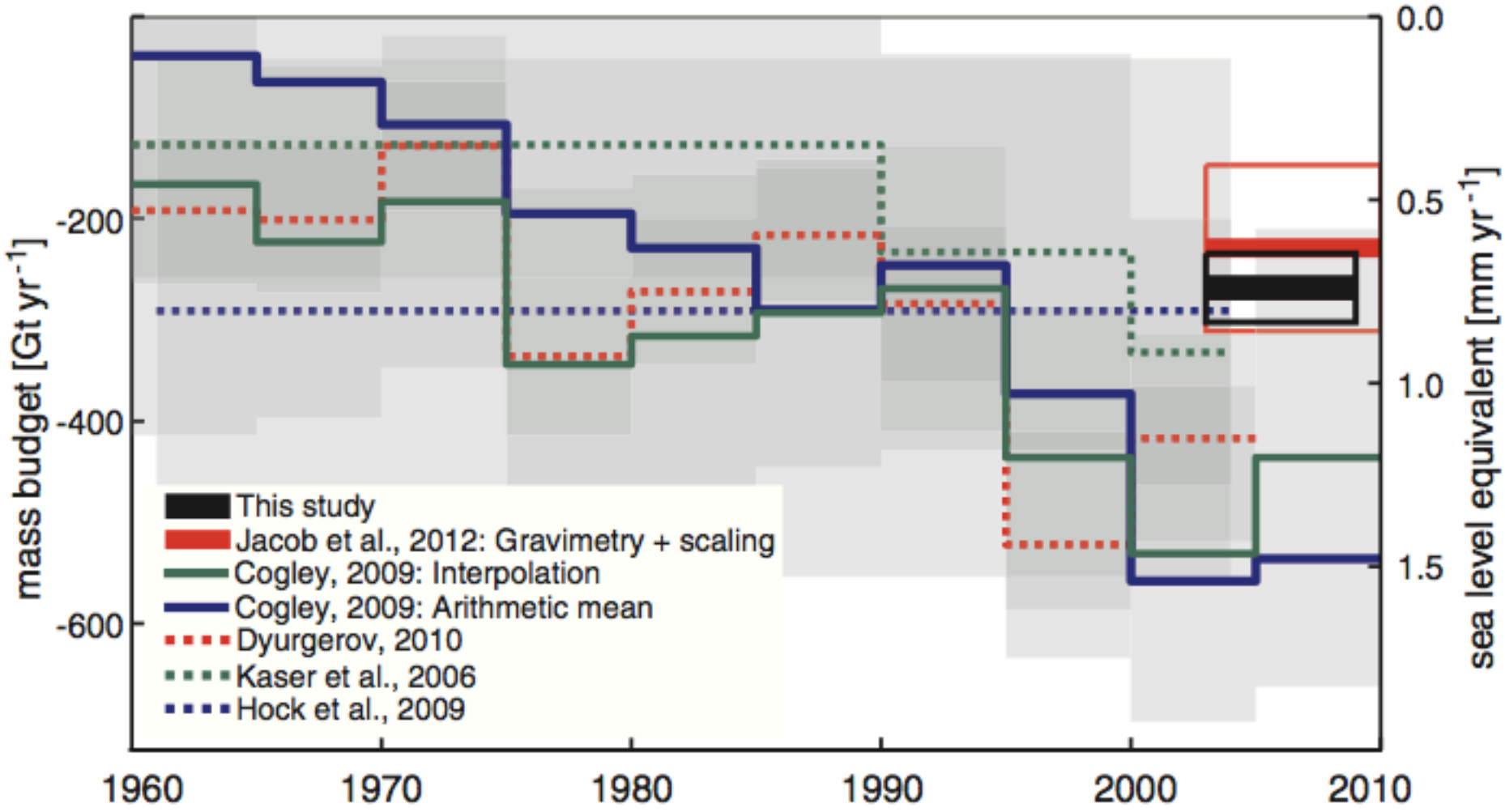
Global glacier mass changes



Global mass budget : -259 ± 28 Gt yr^{-1}

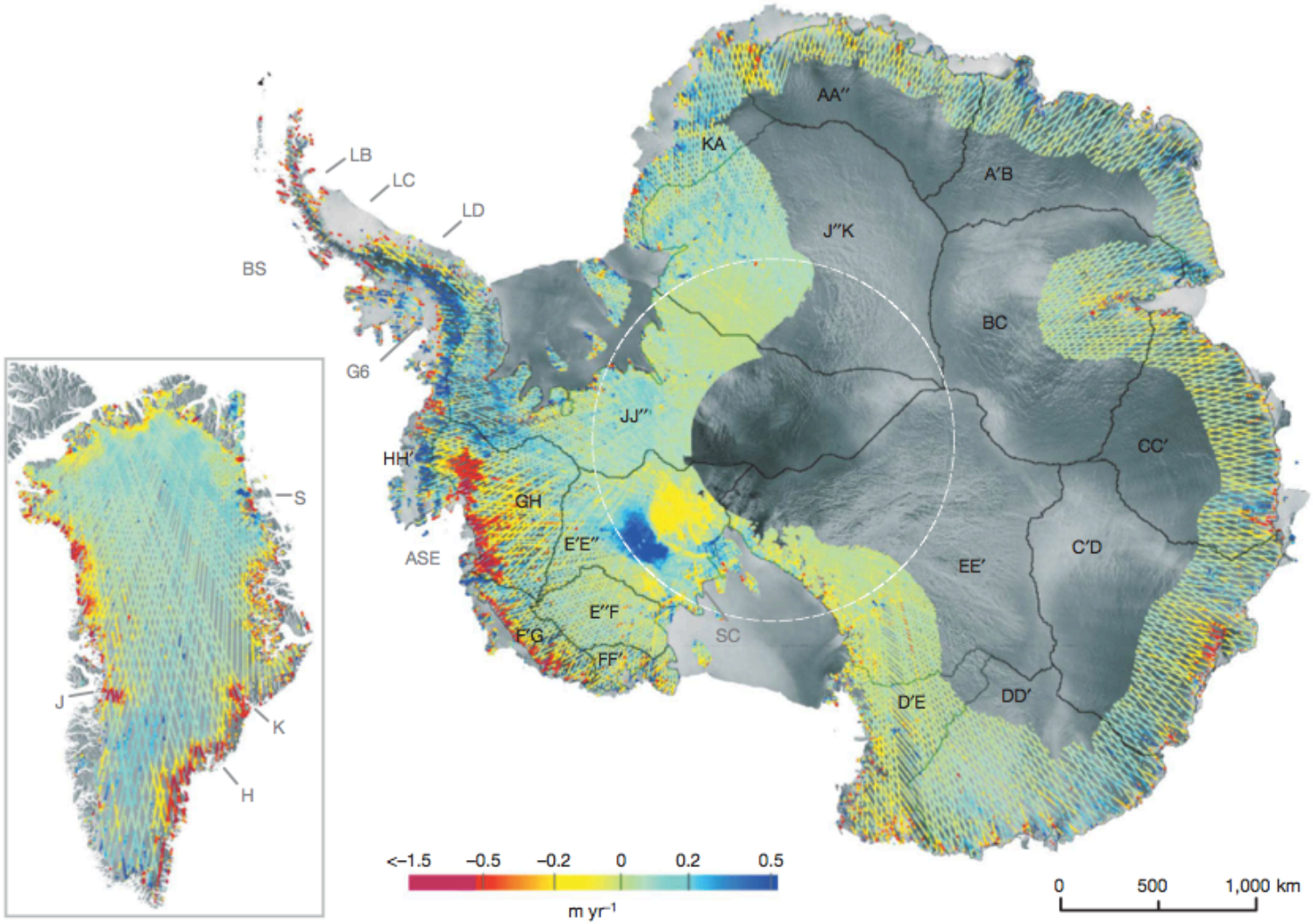
0.71 ± 0.08 mm SLE yr^{-1}

Gardner et al (2013) *Science*



Gardner et al (2013) *Science*

Greenland and Antarctica?



Pritchard et al. (2009)

Ice Sheets

Ice Sheet Mass Balance Intercomparison Exercise (IMBIE)

IMBIE

- 30+ estimates since 1989
- Lack of clarity in estimates
- Allow for combined ice sheet SL contribution between 0.2 mm yr^{-1} **fall** and 1.9 mm yr^{-1} **rise**

Altimetry : changes in ice sheet shape

InSAR : changes in ice sheet flow

Gravimetry : changes in ice sheet weight

Past estimates of GIS mass balance

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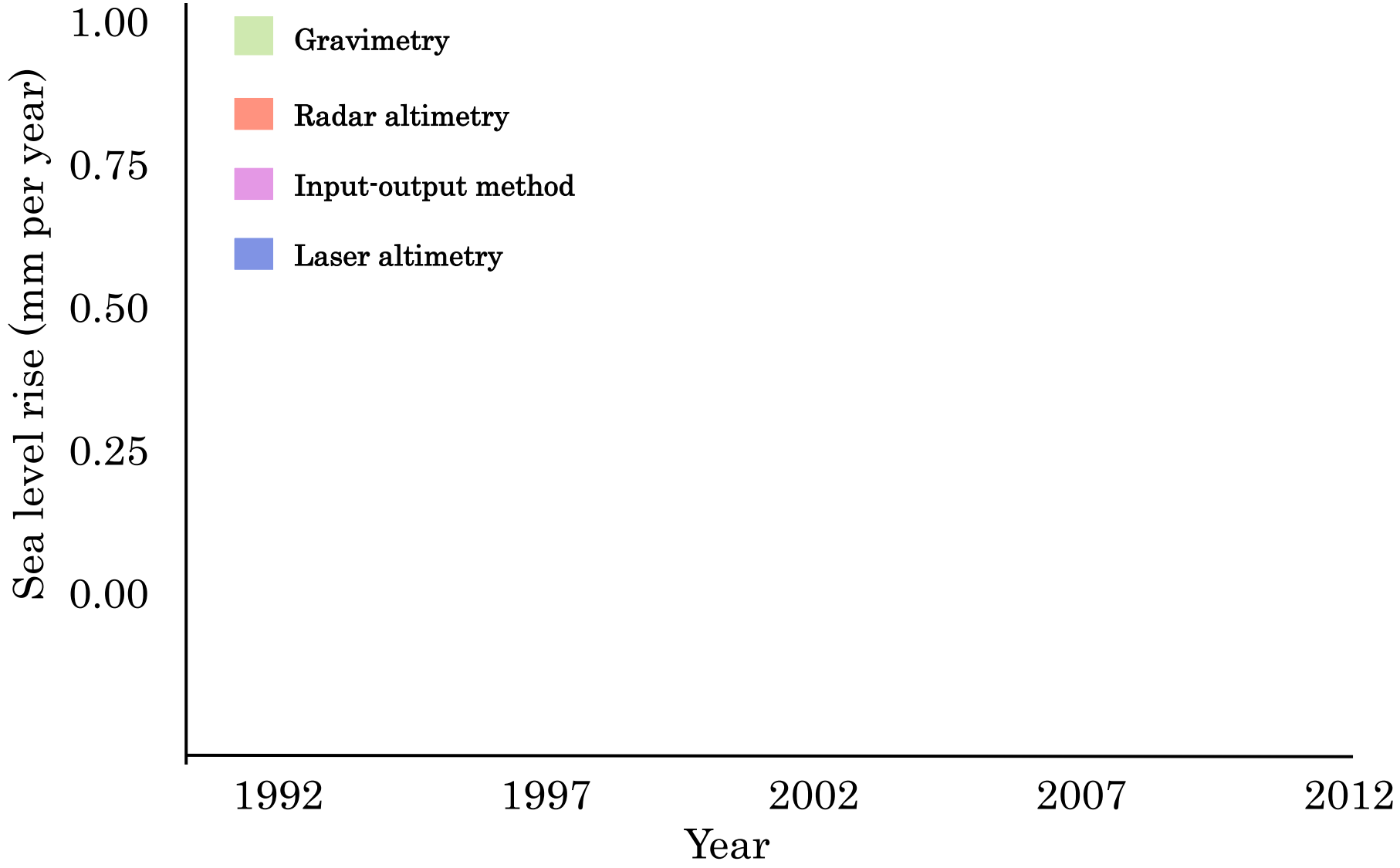

Past estimates of GIS mass balance

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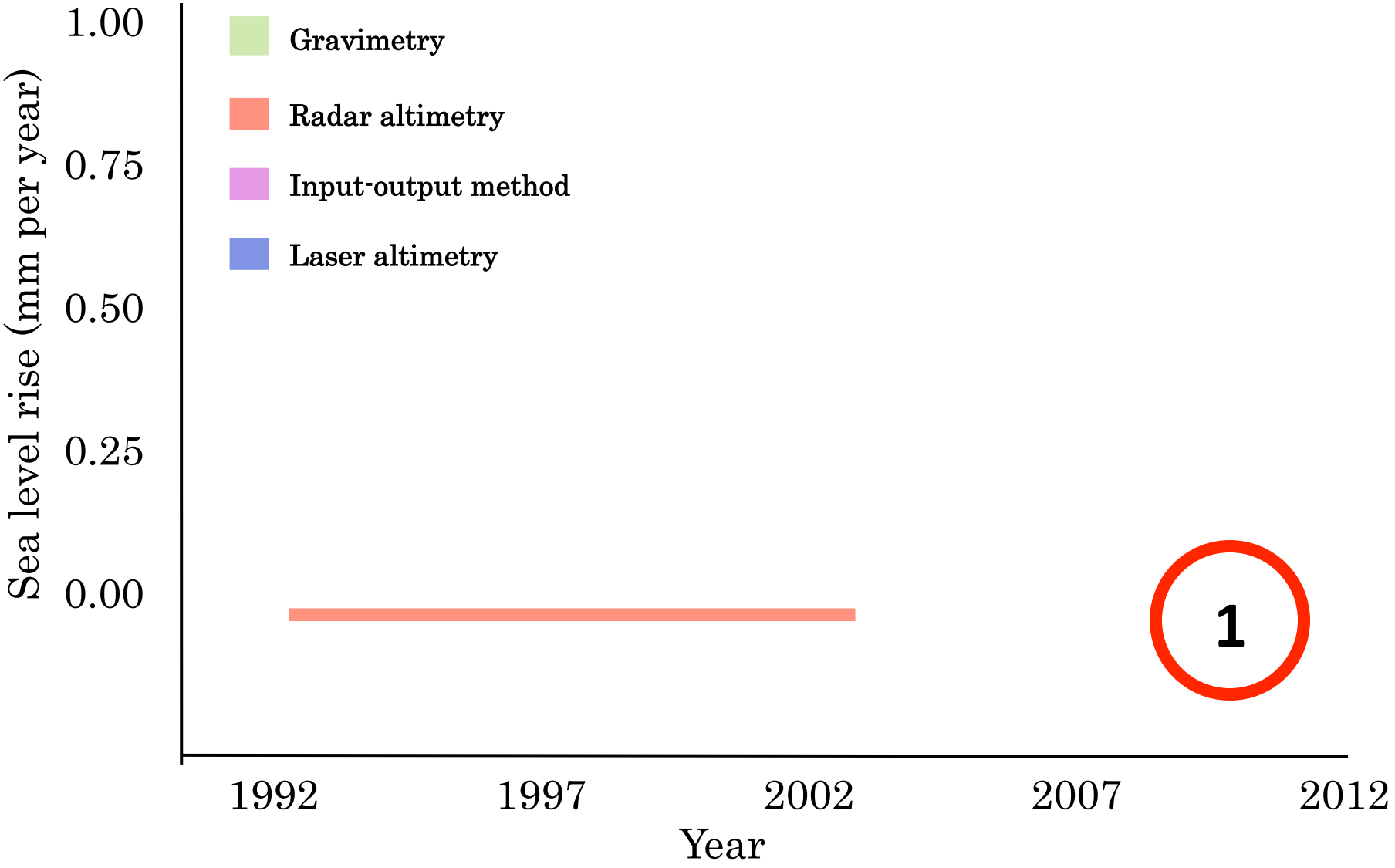

Past estimates of GIS mass balance

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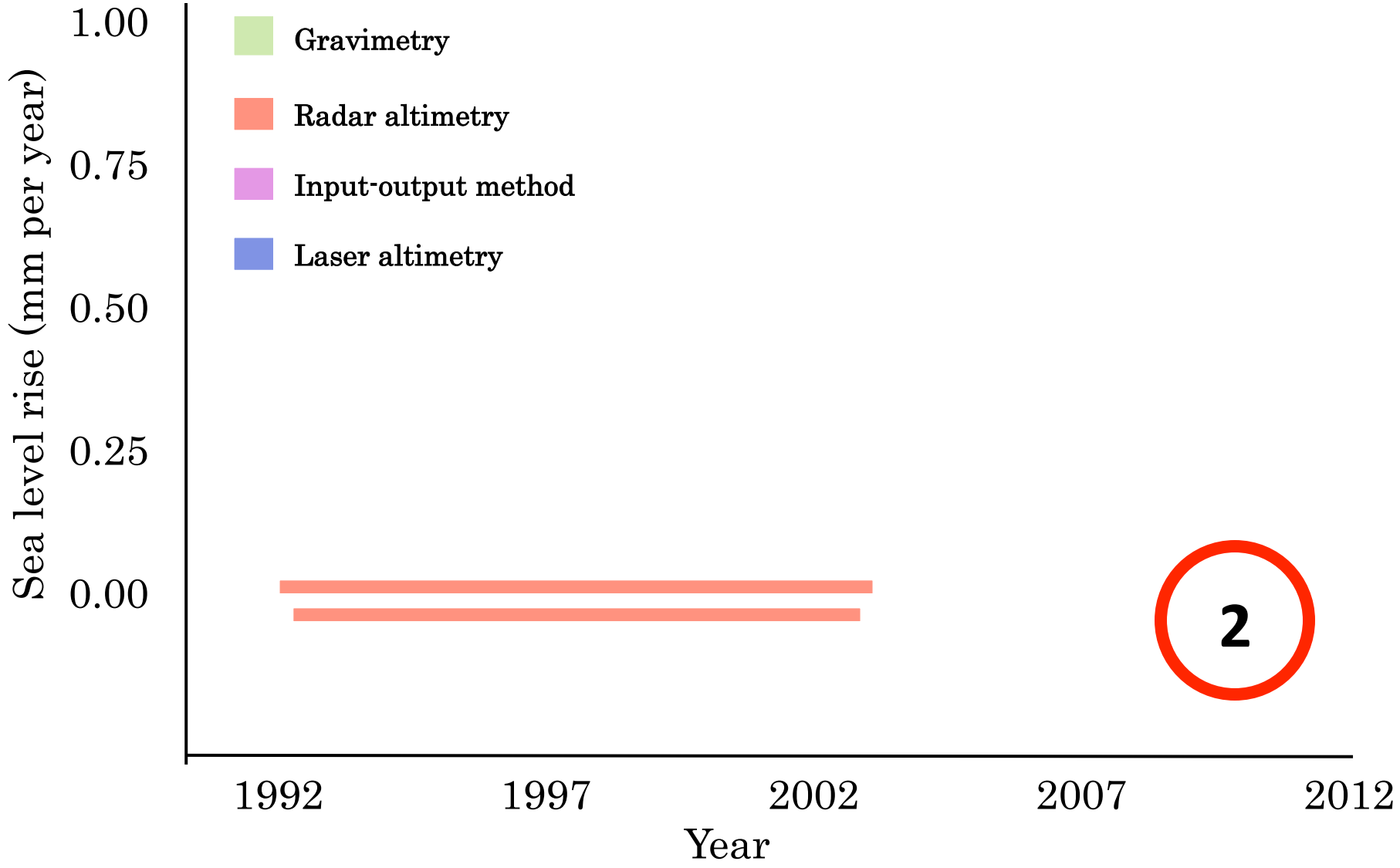

Past estimates of GIS mass balance

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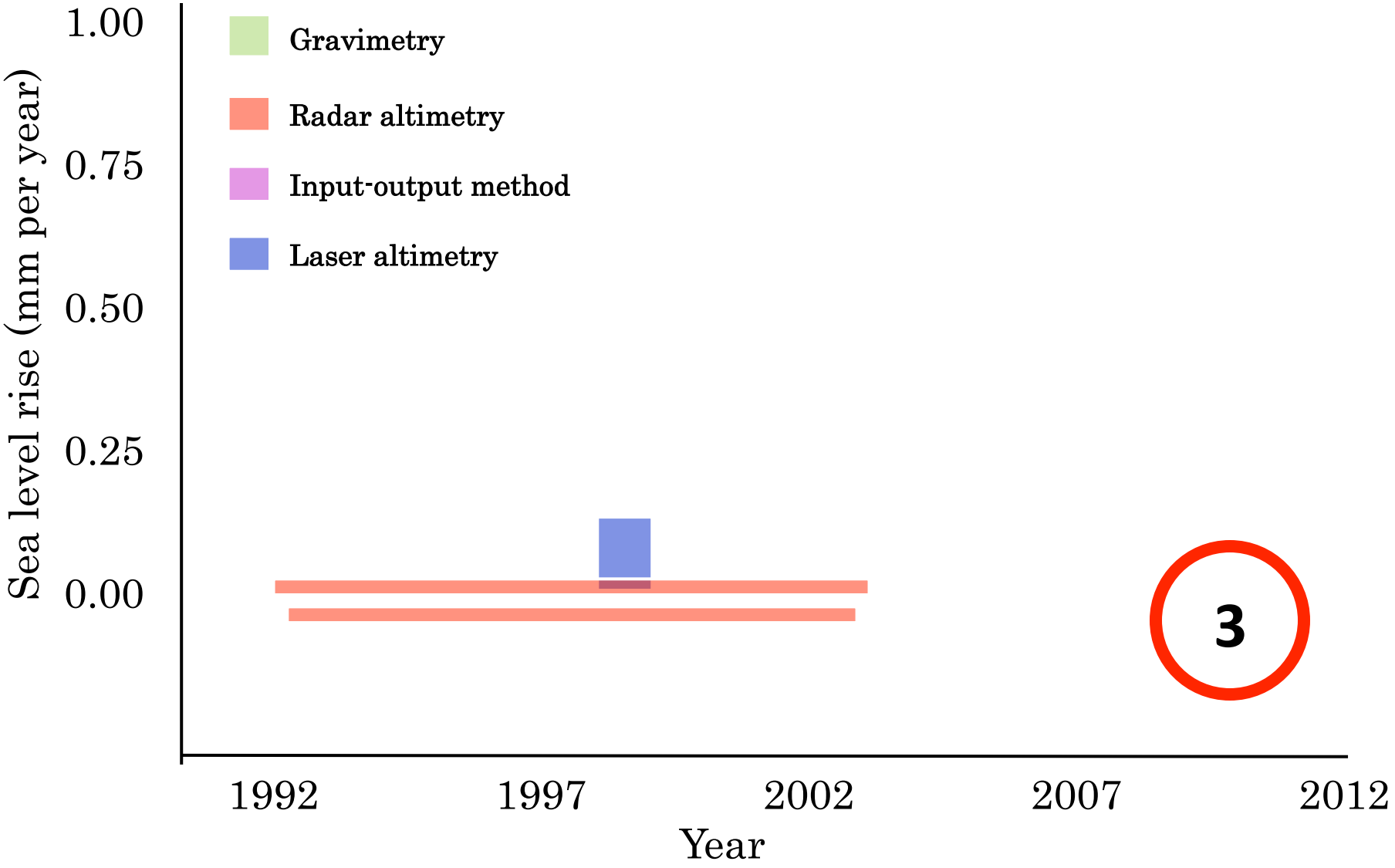

Past estimates of GIS mass balance

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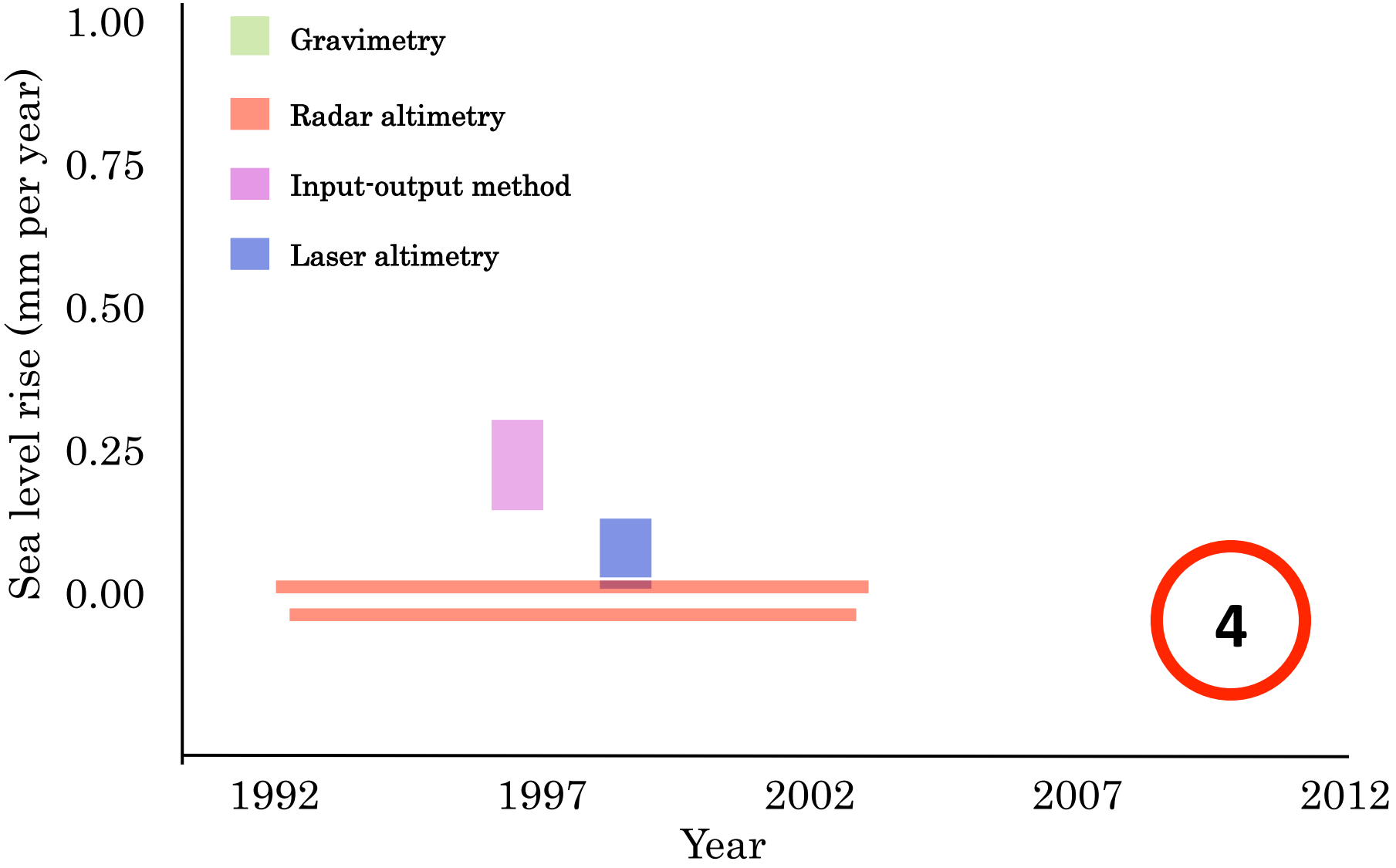

Past estimates of GIS mass balance

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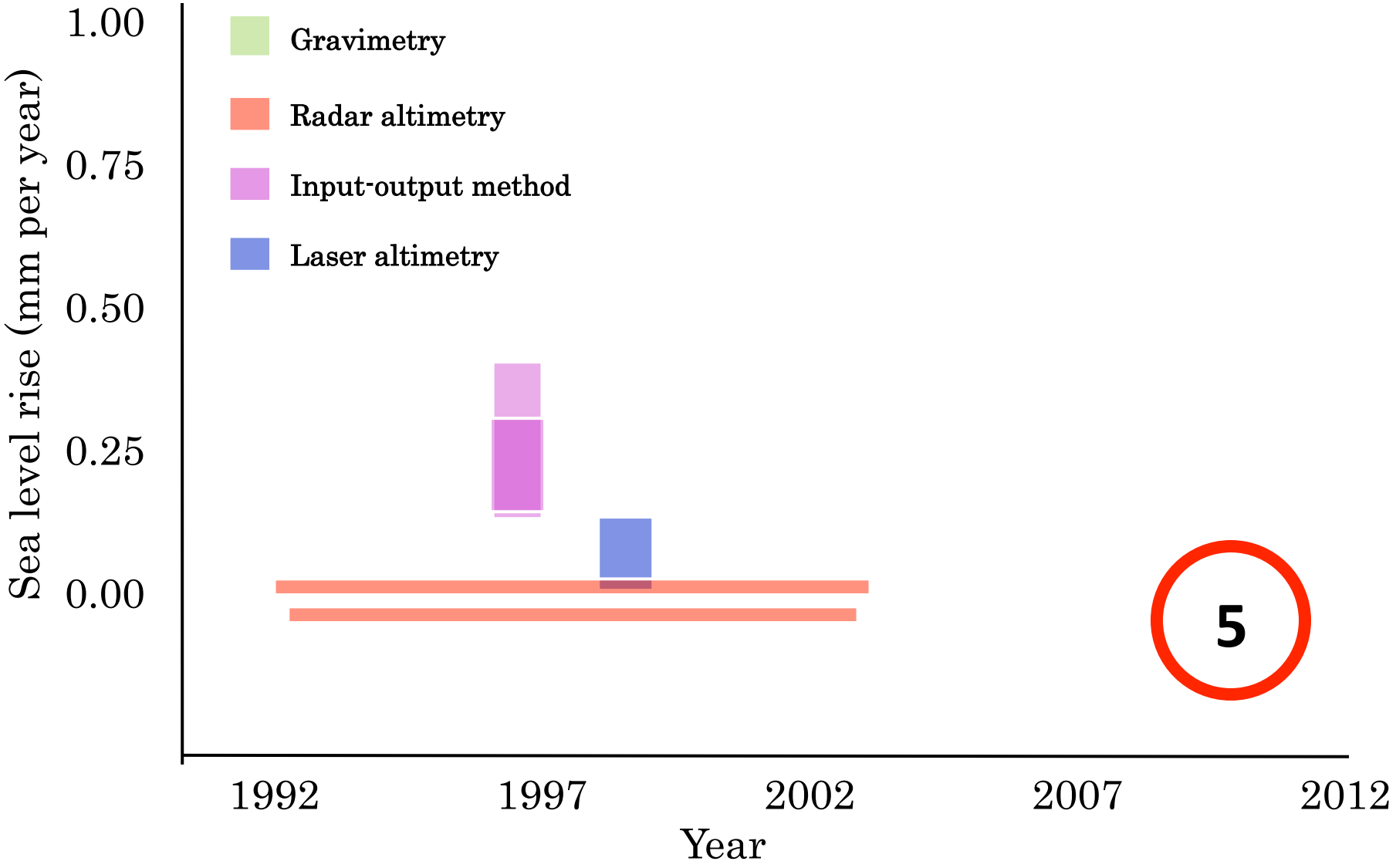

Past estimates of GIS mass balance

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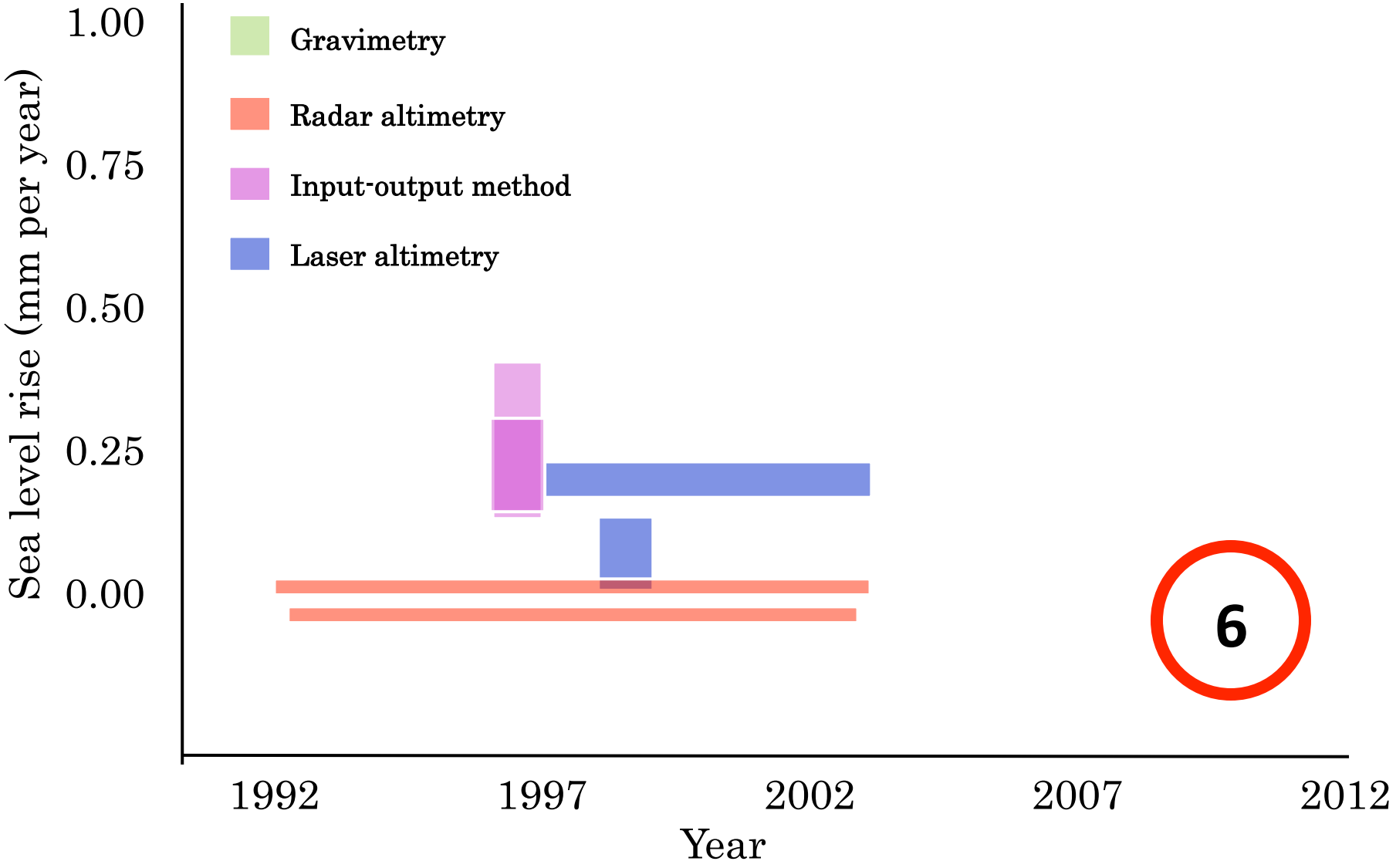

Past estimates of GIS mass balance

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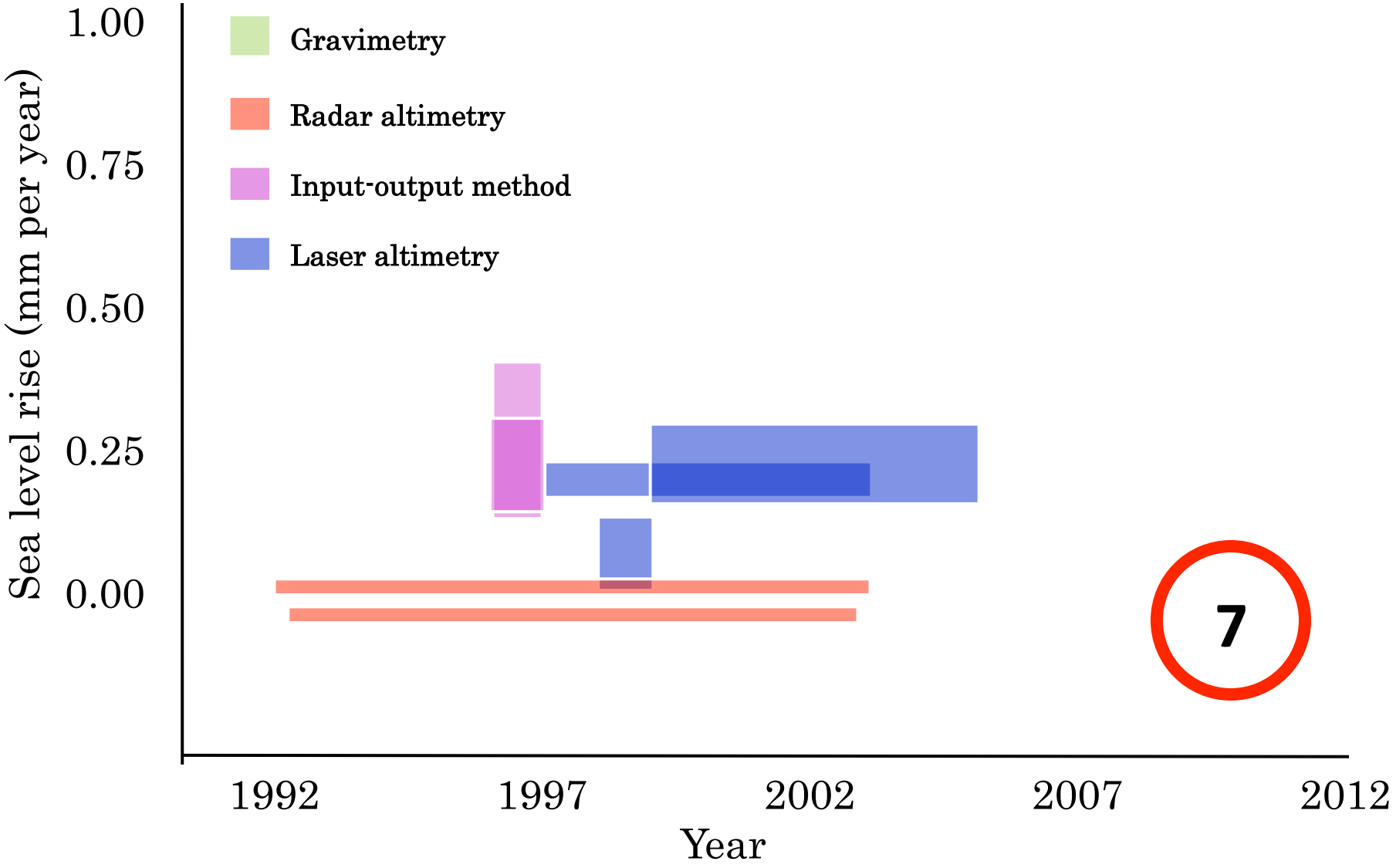

Past estimates of GIS mass balance

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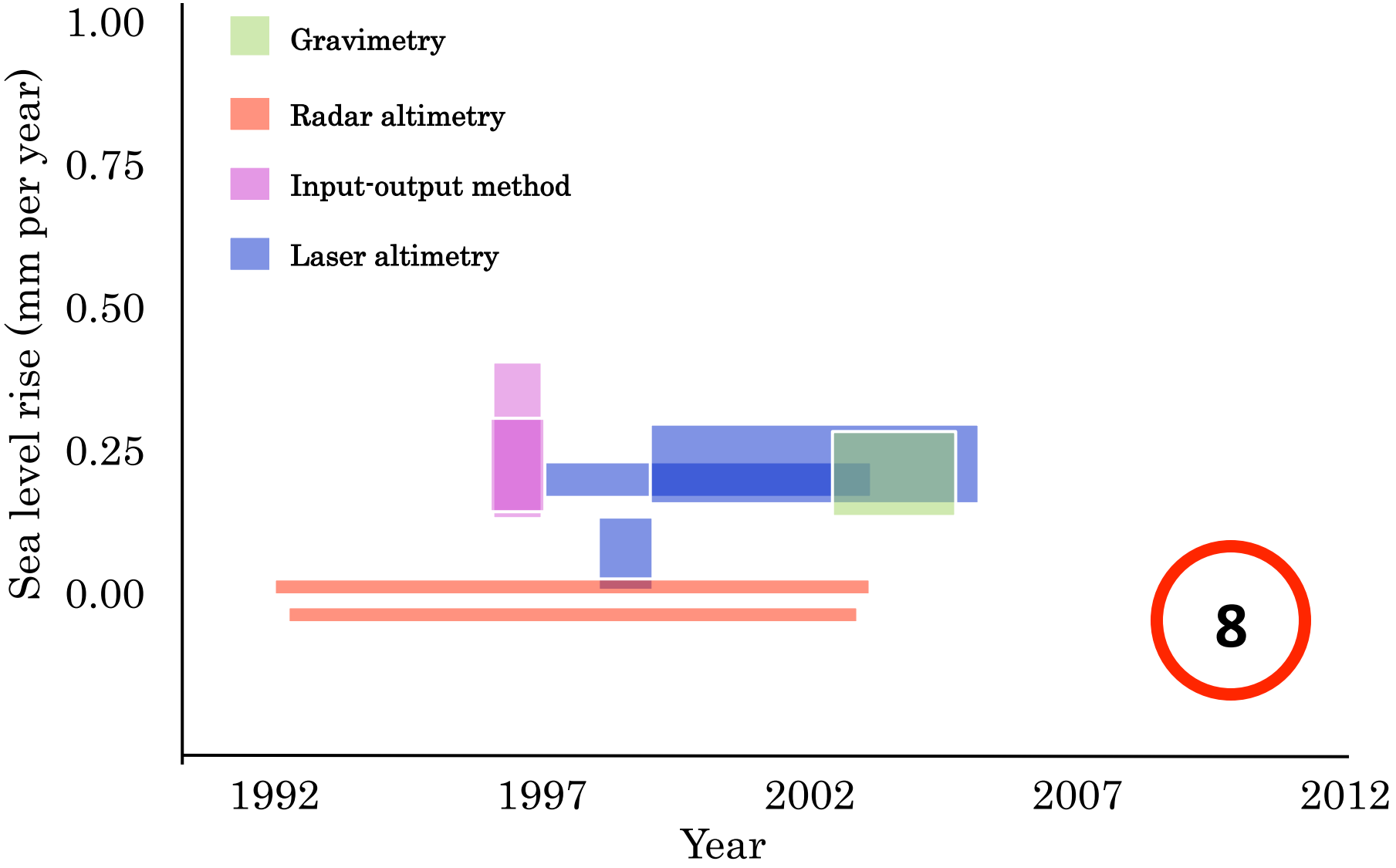

Past estimates of GIS mass balance

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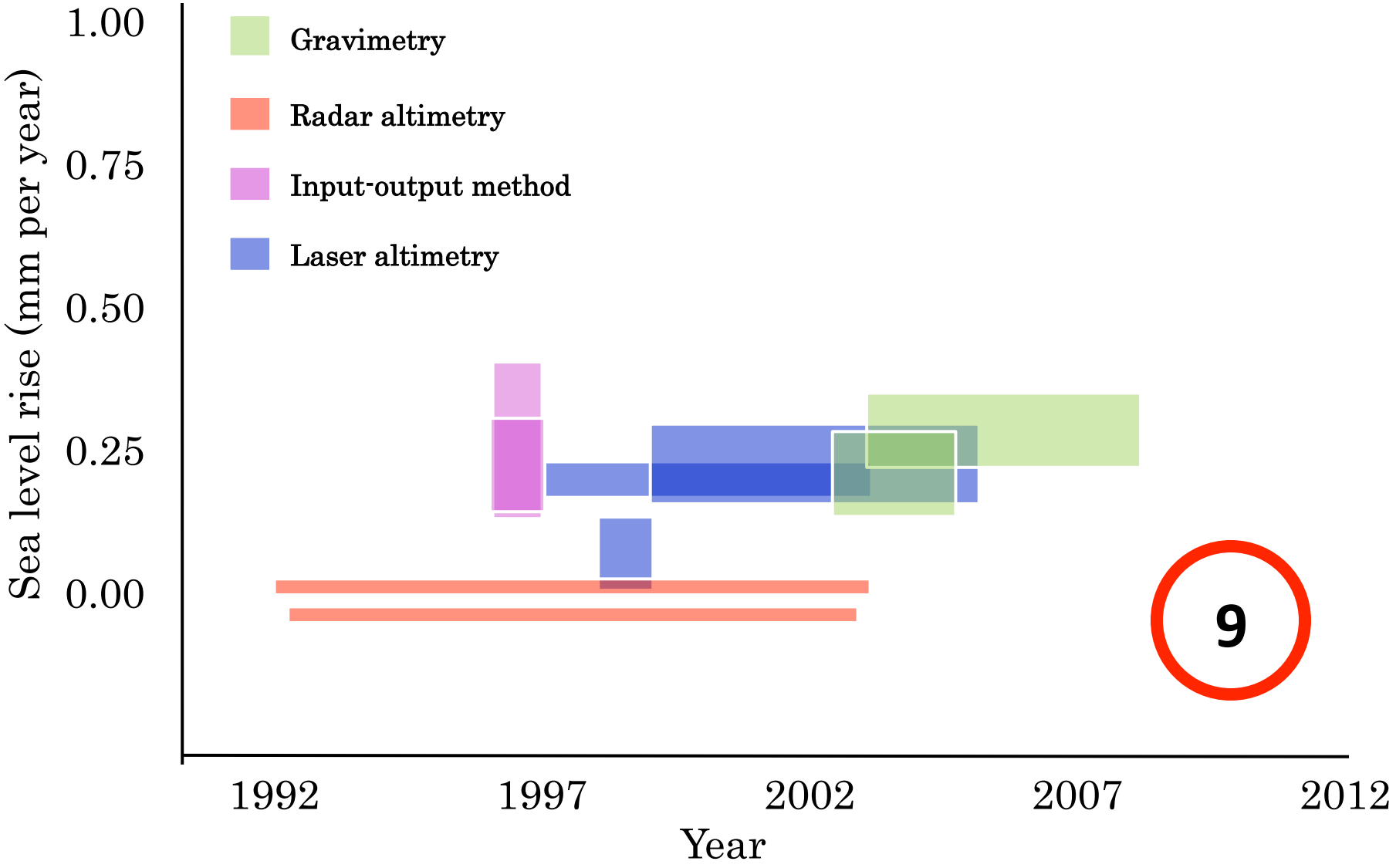

Past estimates of GIS mass balance

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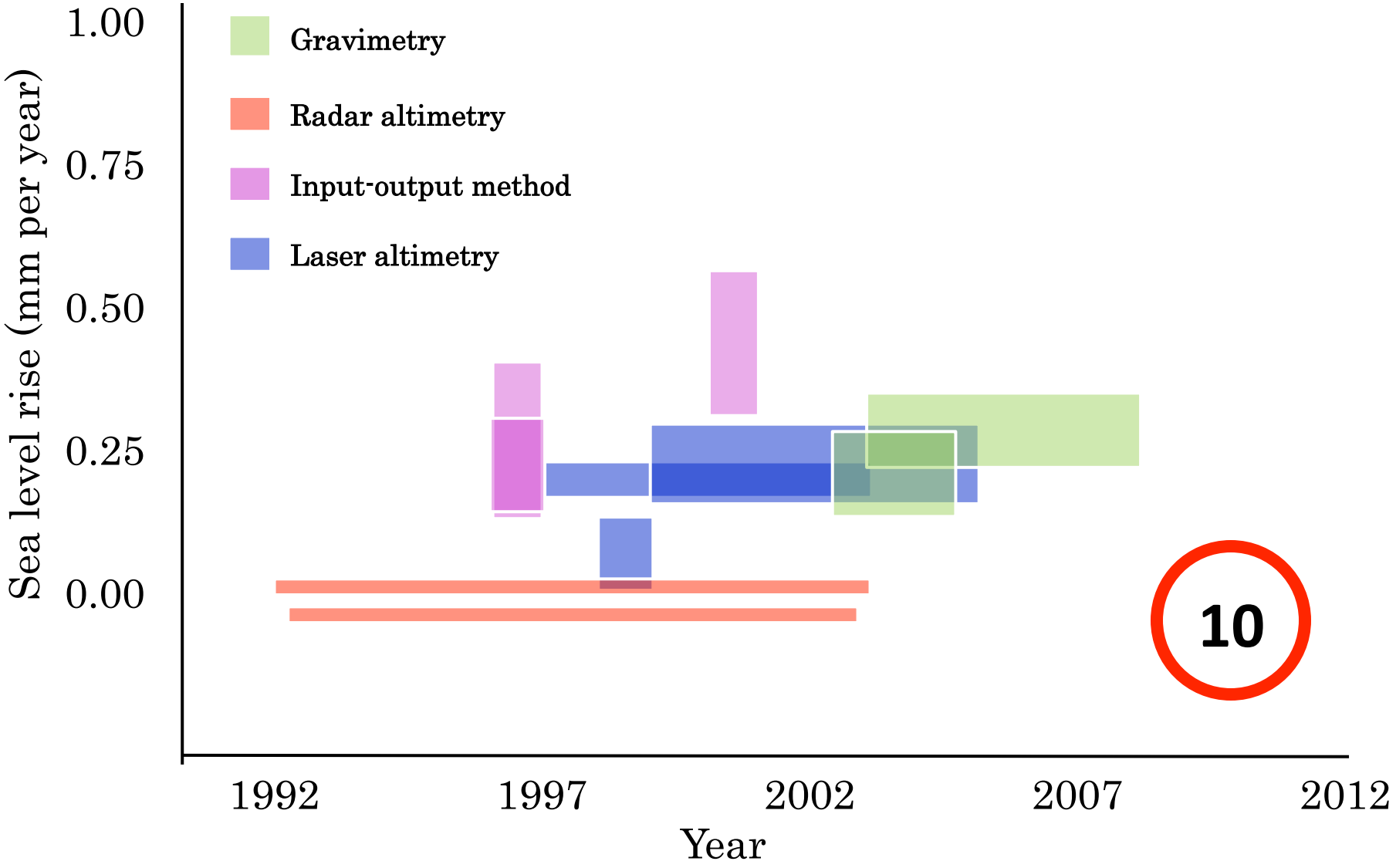

Past estimates of GIS mass balance

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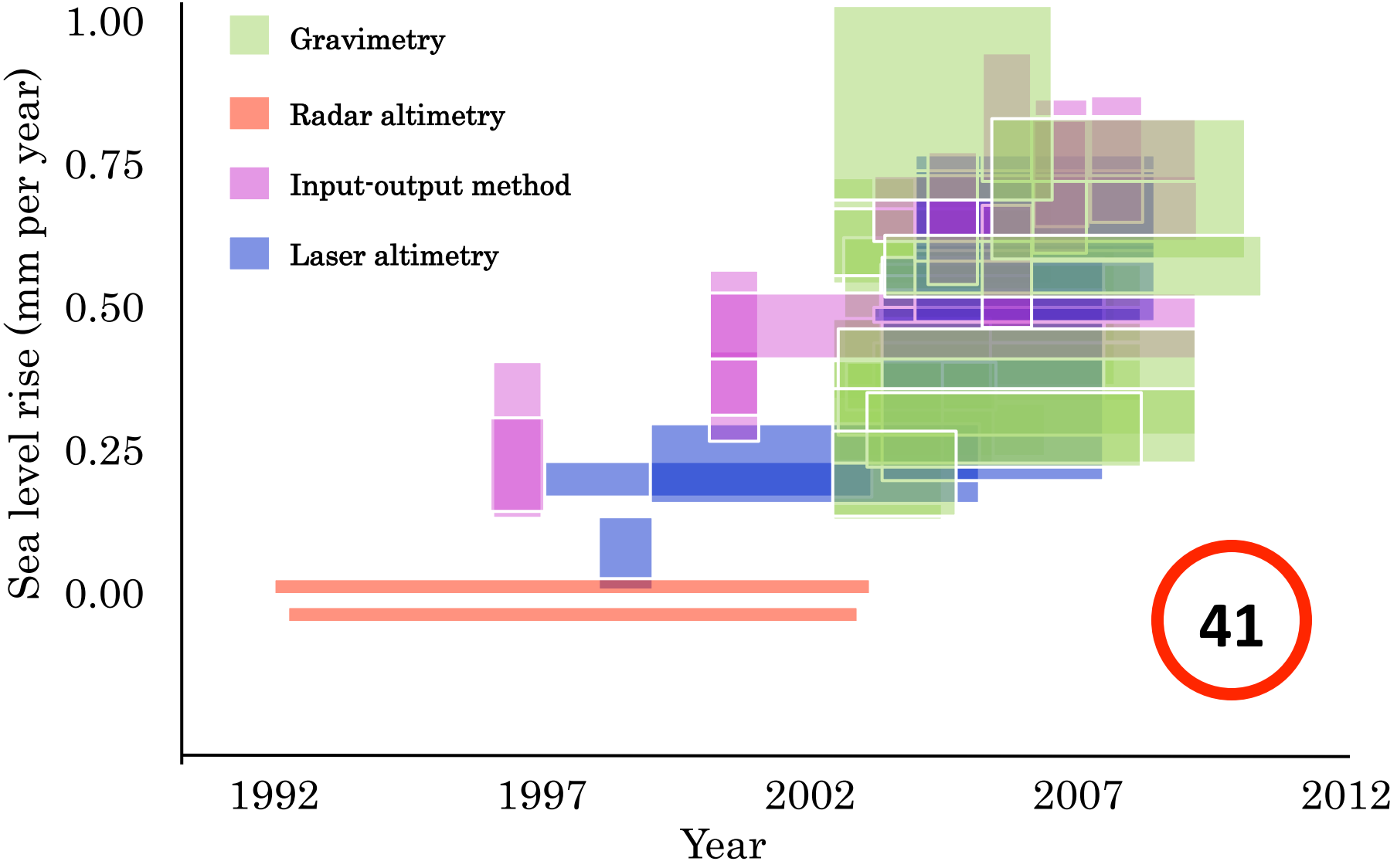

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Reconciling the estimates

- Community assessment
- Supported by ESA and NASA
- 47 participants, 26 research groups
- 10 satellites, 54 total years of data

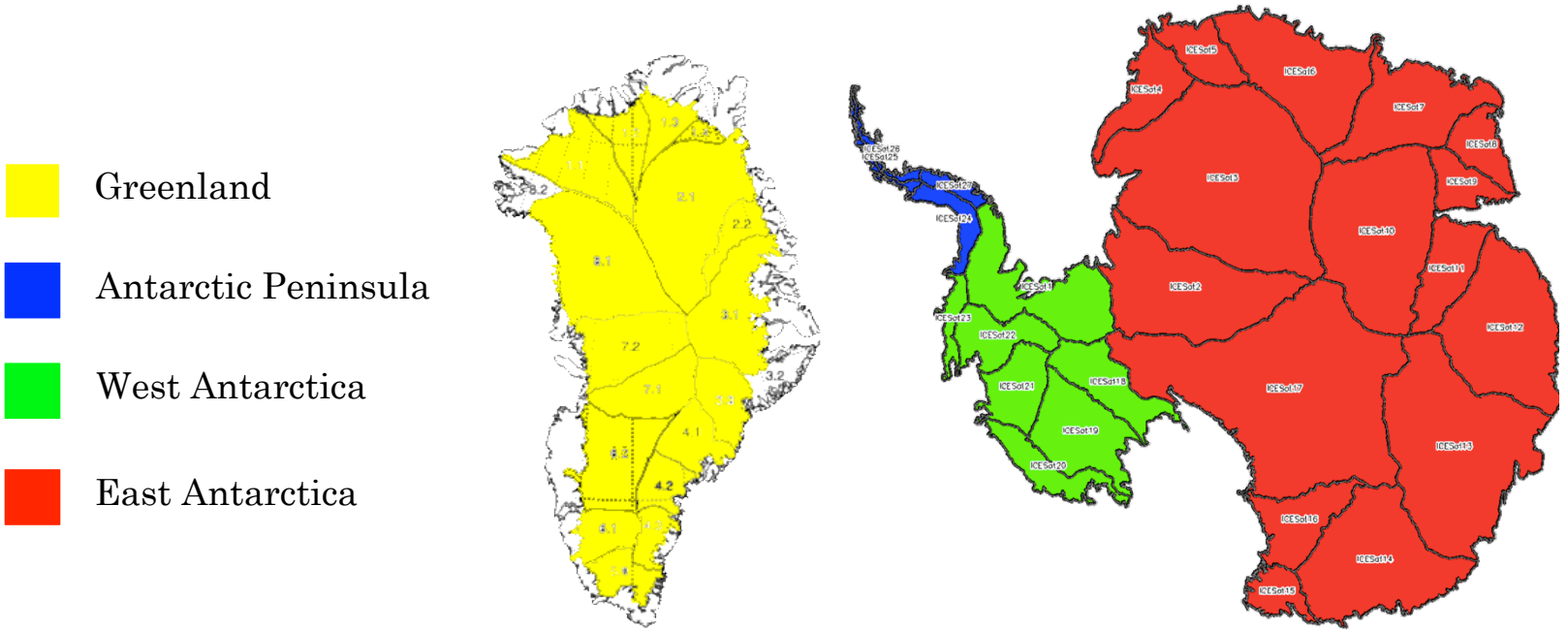

Image: A. Shepherd

IMBIE – define common periods

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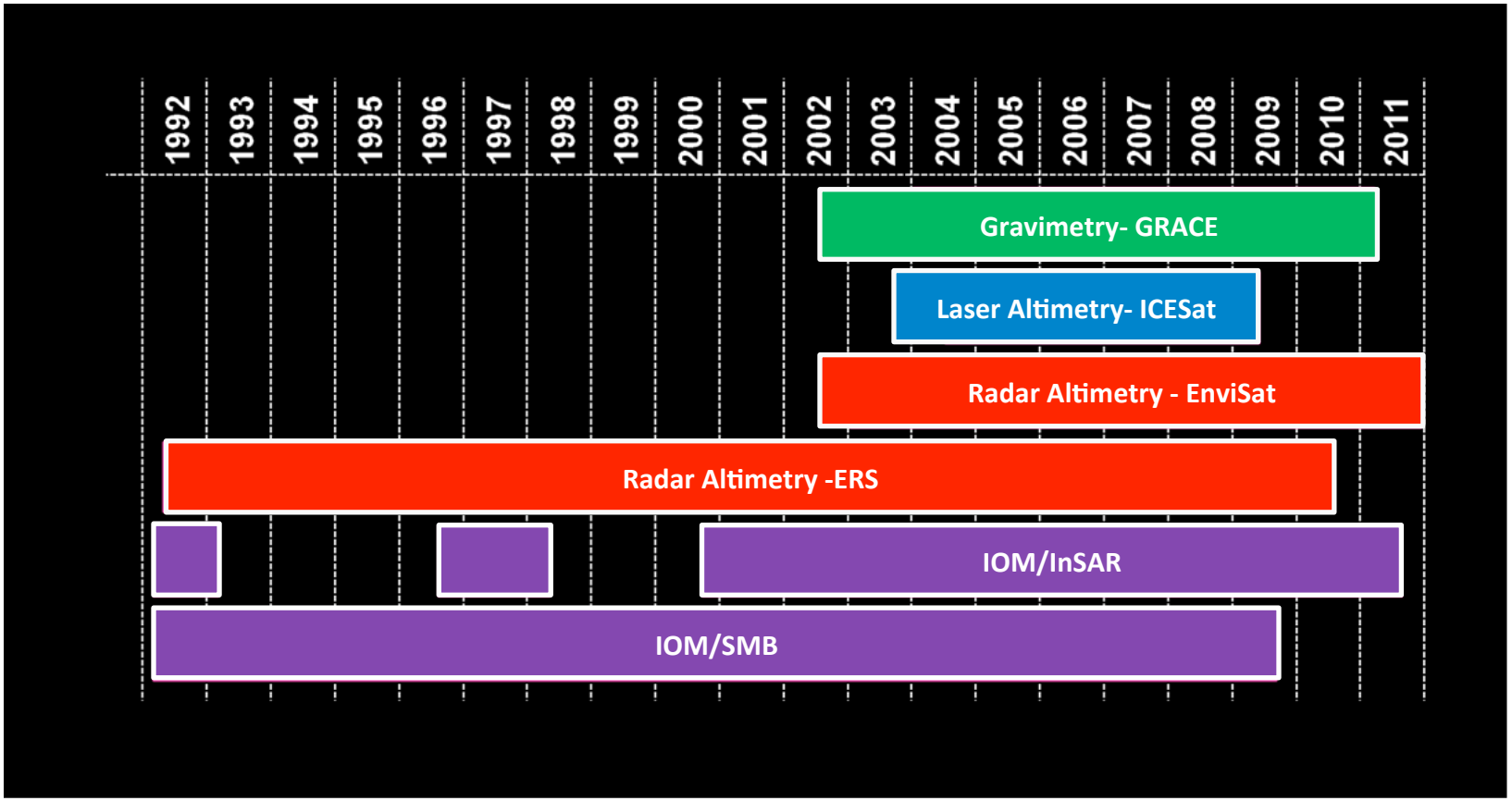

Image: A. Shepherd

IMBIE – define common periods

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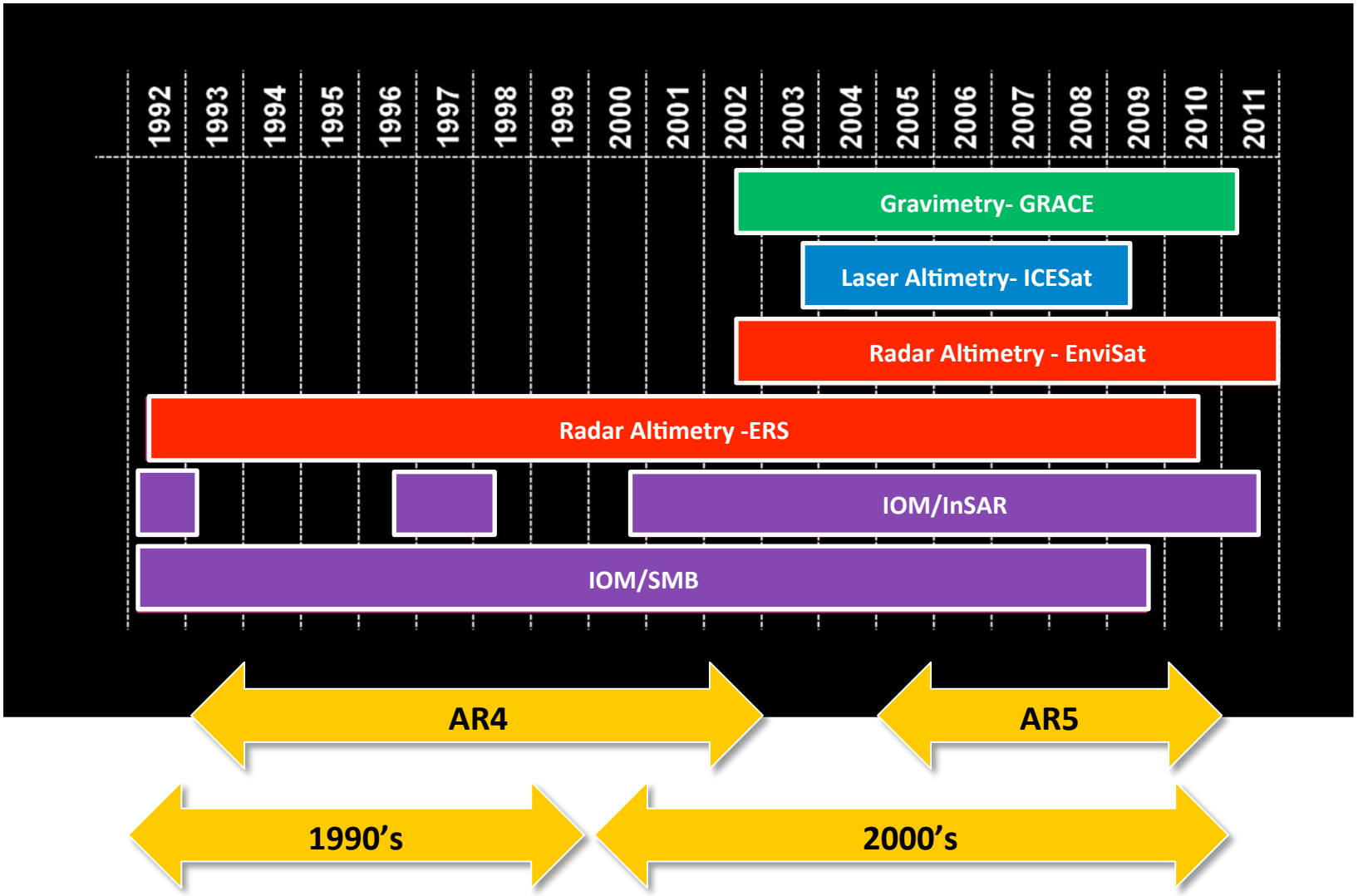

Image: A. Shepherd

IMBIE – define common periods

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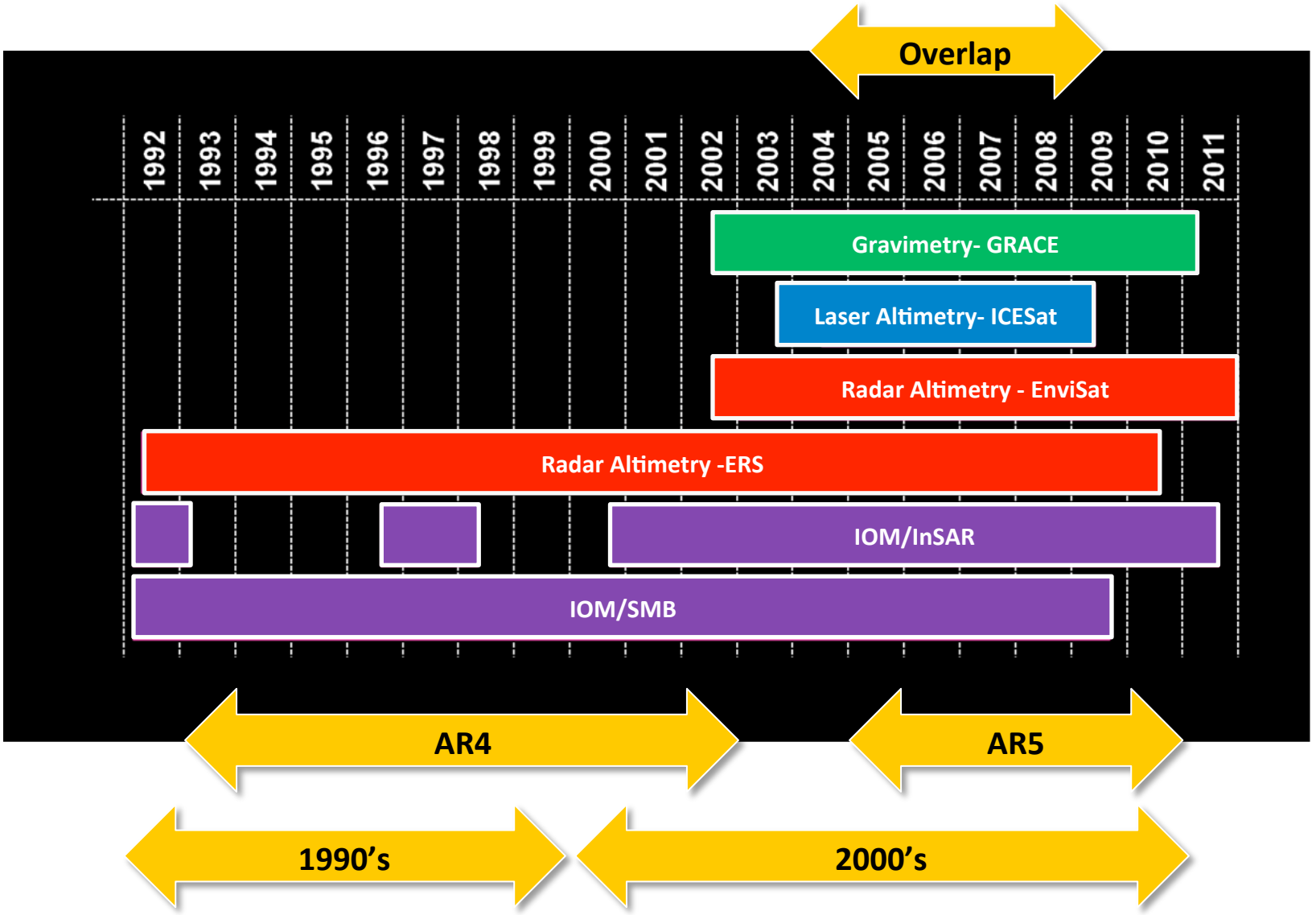

Image: A. Shepherd

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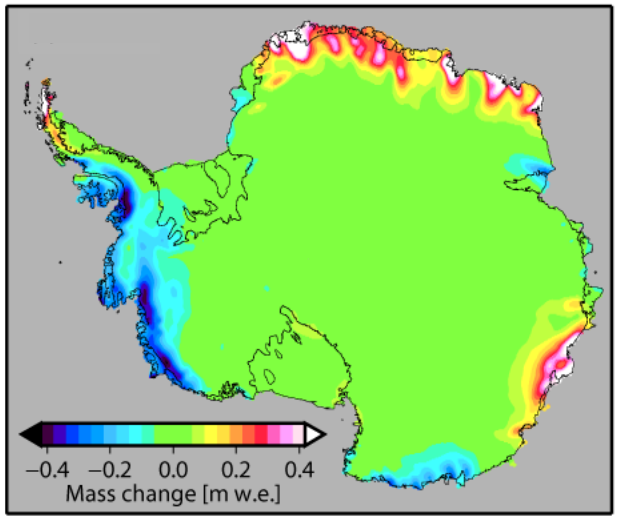
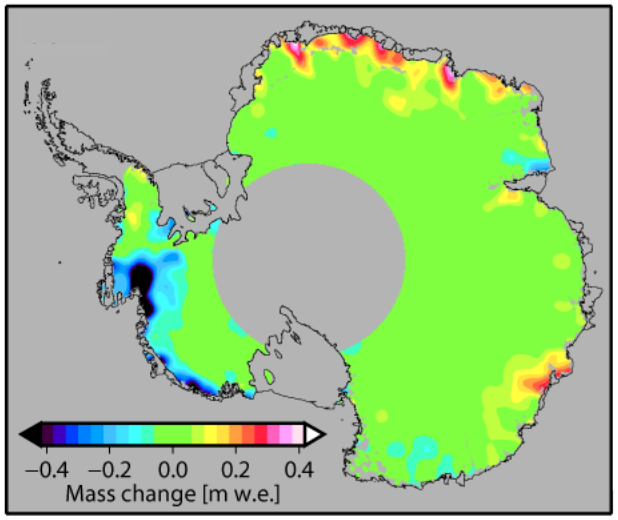
IMBIE : patterns of imbalance

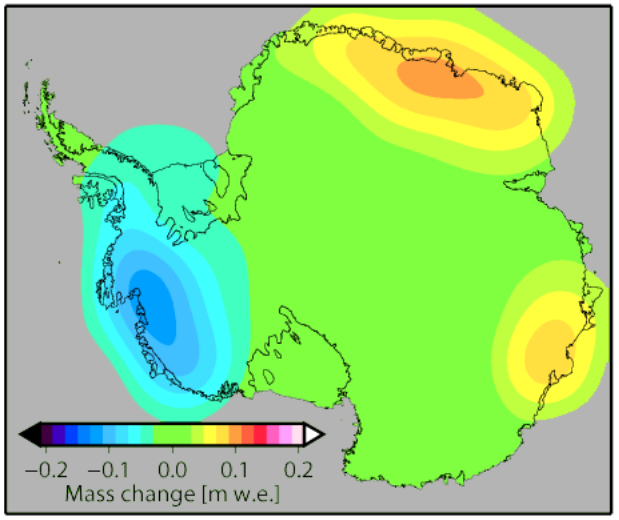
InSAR



Altimetry



Gravimetry



Shepherd et al (2012) *Science*

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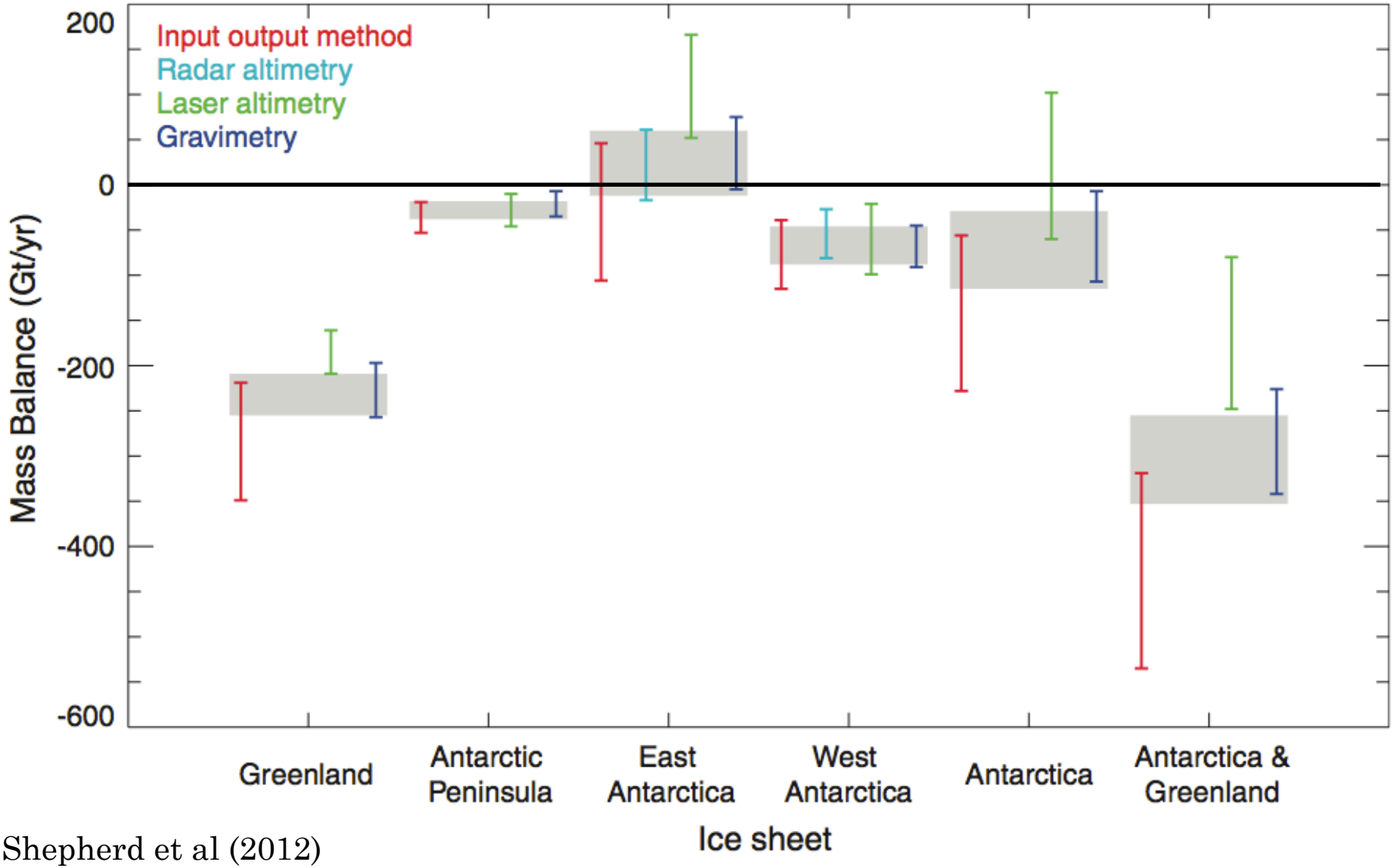
IMBIE : patterns of imbalance



Shepherd et al (2012)

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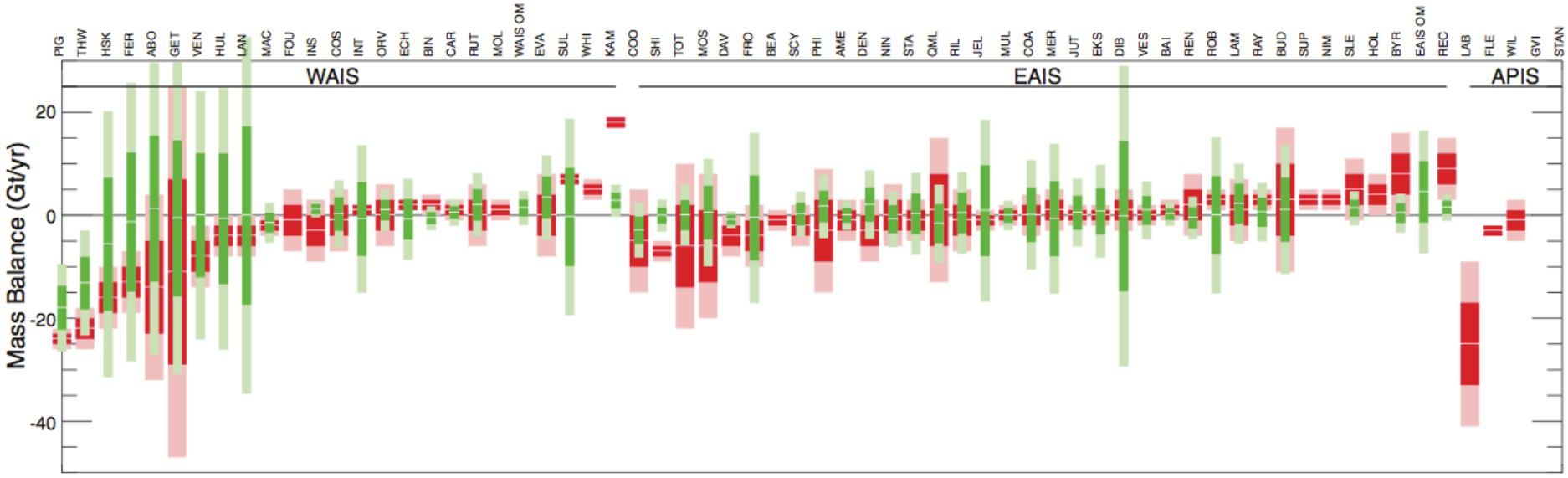
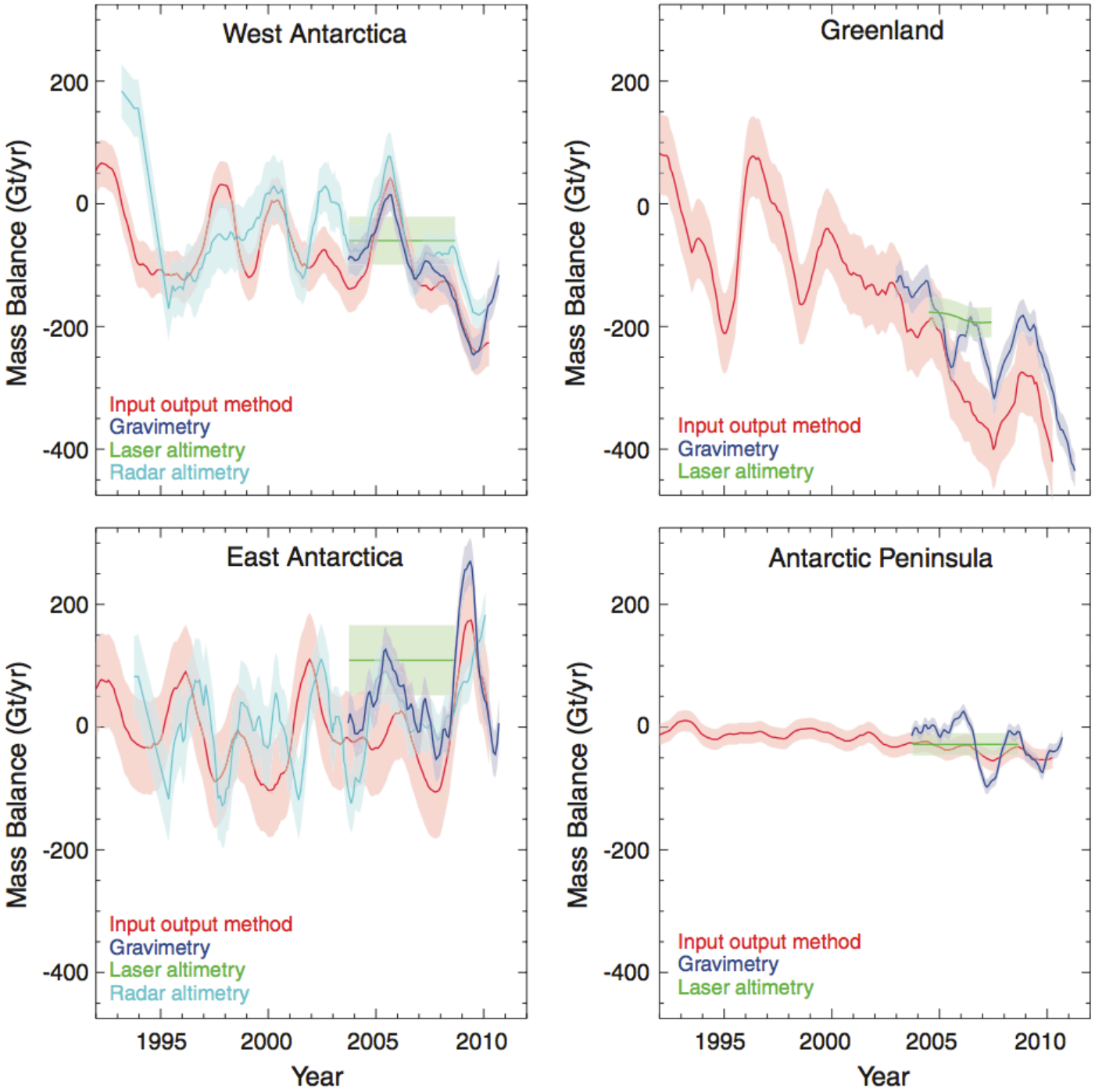
IMBIE : basin mass loss



Radar altimetry – green
Budget / IOM - red

Shepherd et al (2012)



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Shepherd et al (2012)

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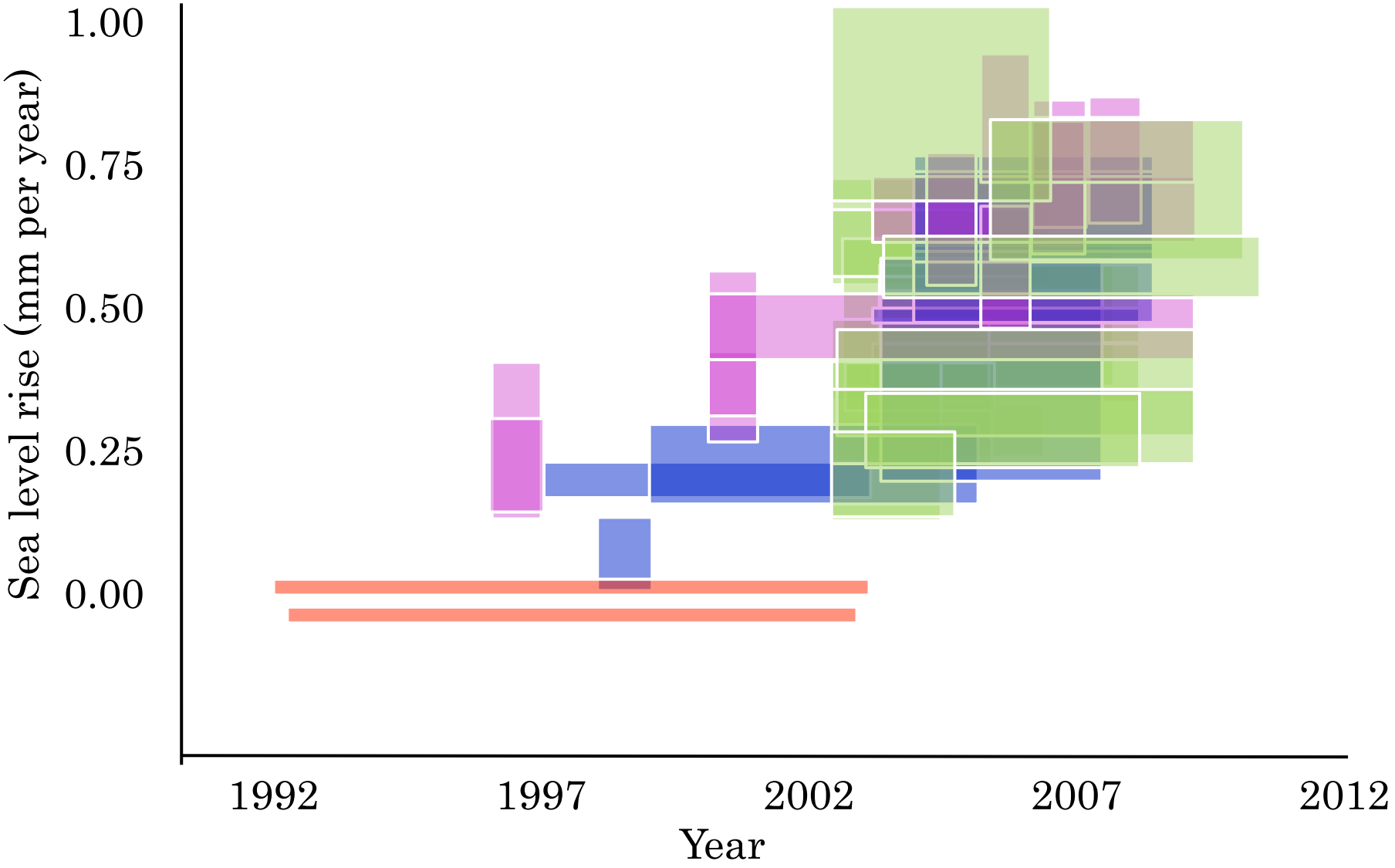
IMBIE : no more box plots



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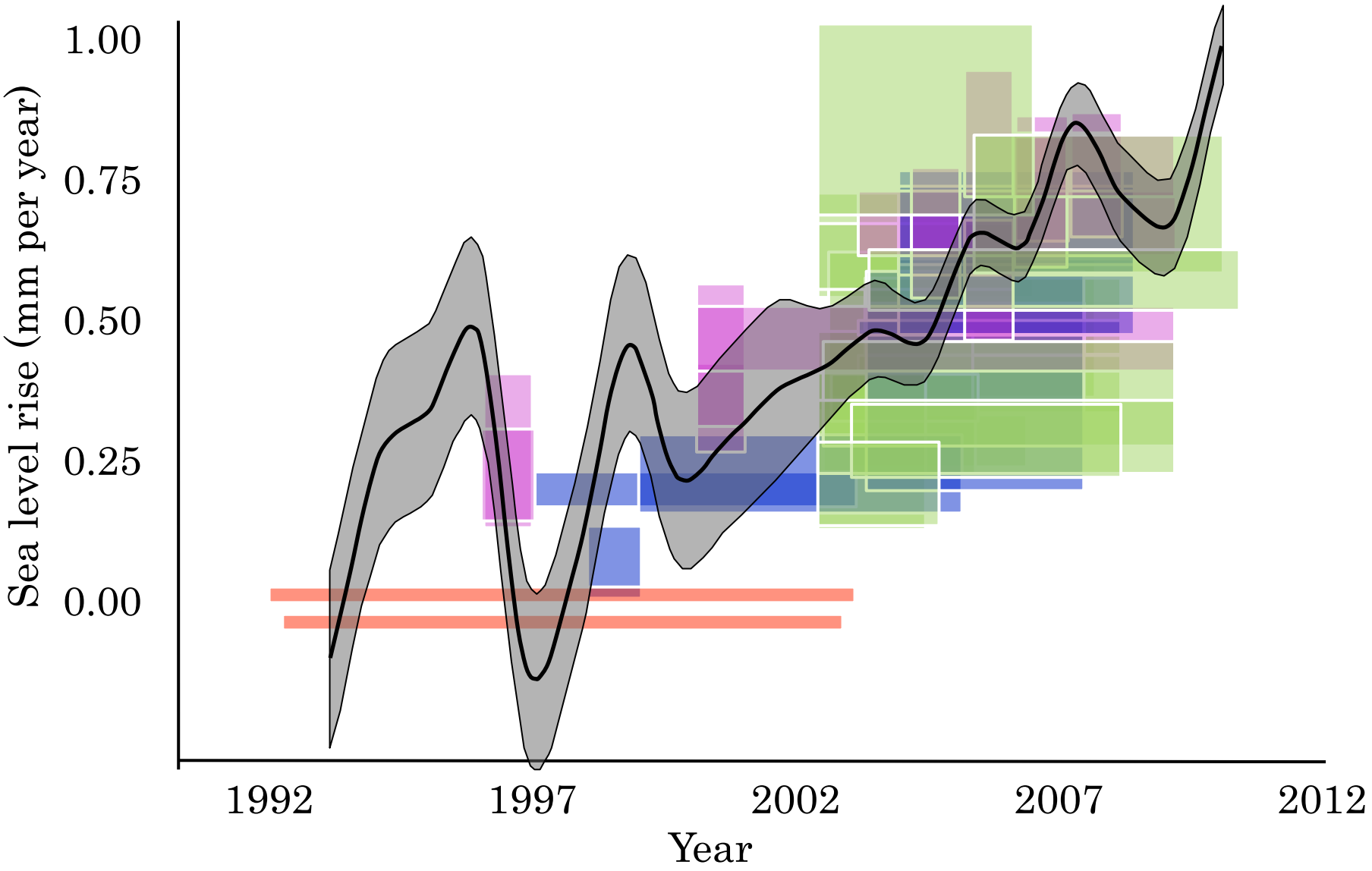
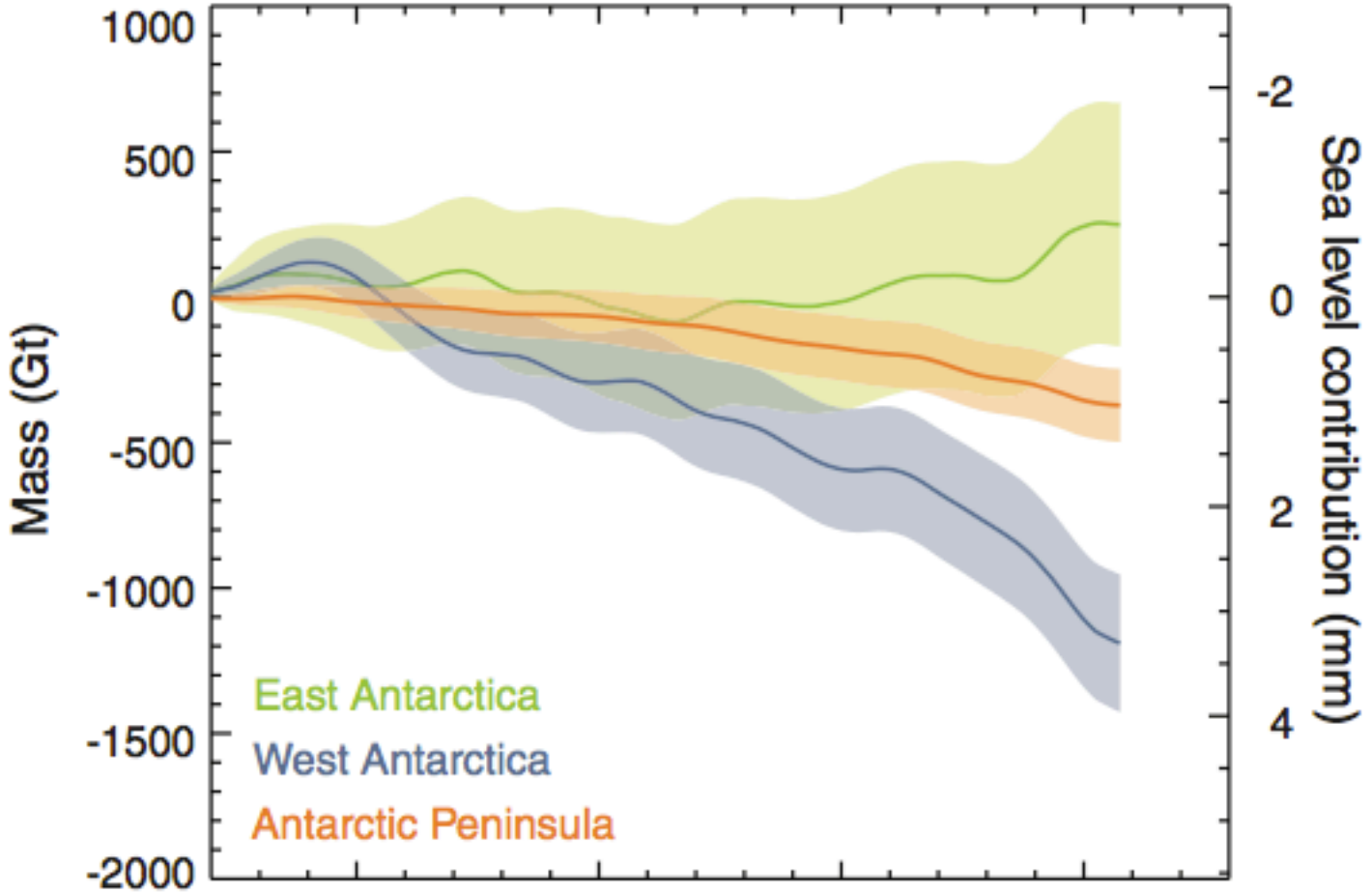
IMBIE : no more box plots



Antarctic sea-level curves



Shepherd et al (2012)

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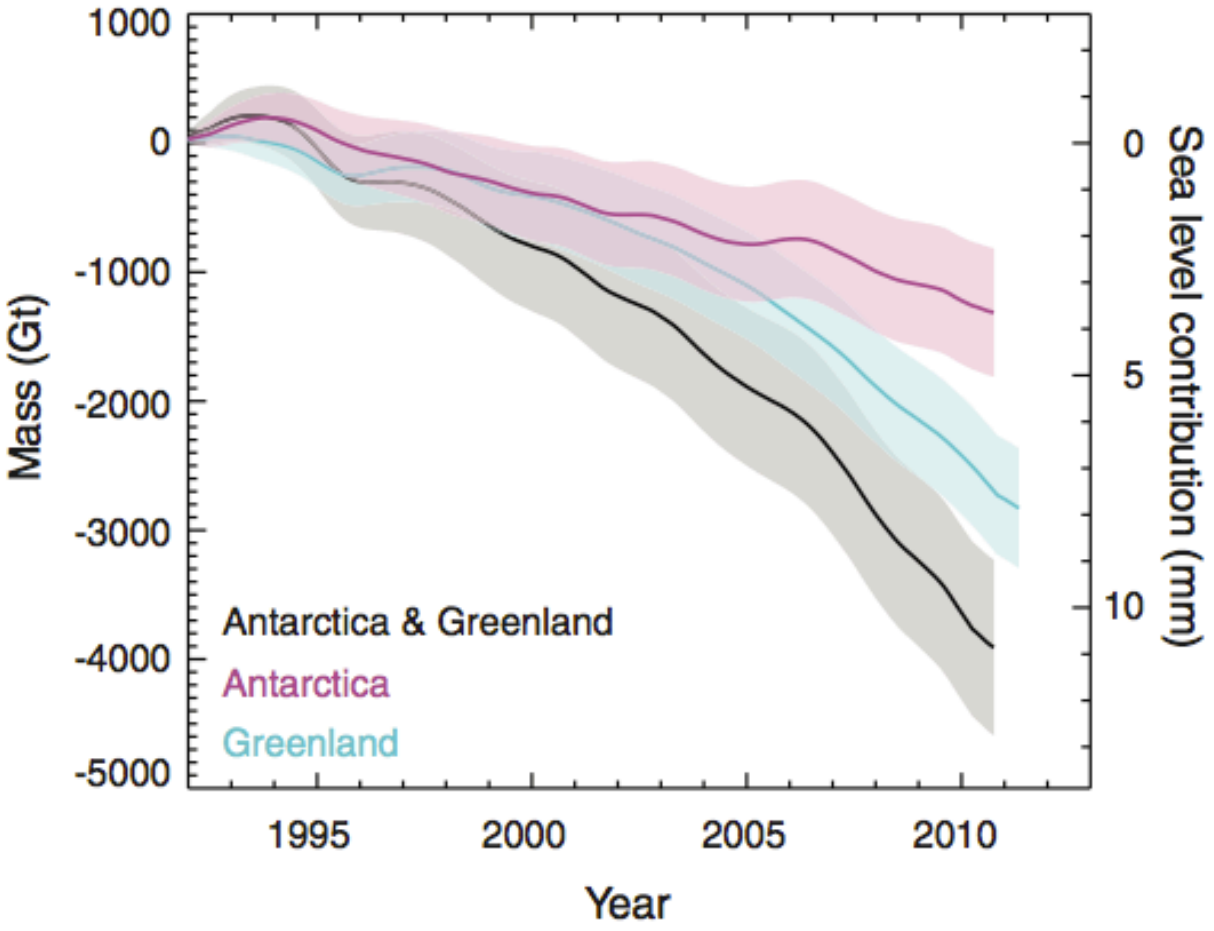
Ice sheet sea-level curves



- 11.1 +/- 3.8 mm SLR since 1992
- 20% of global SLR trend
- 2/3 from Greenland Ice Sheet
- Greenland now losing 5 x as in 1990s

Shepherd et al (2012)

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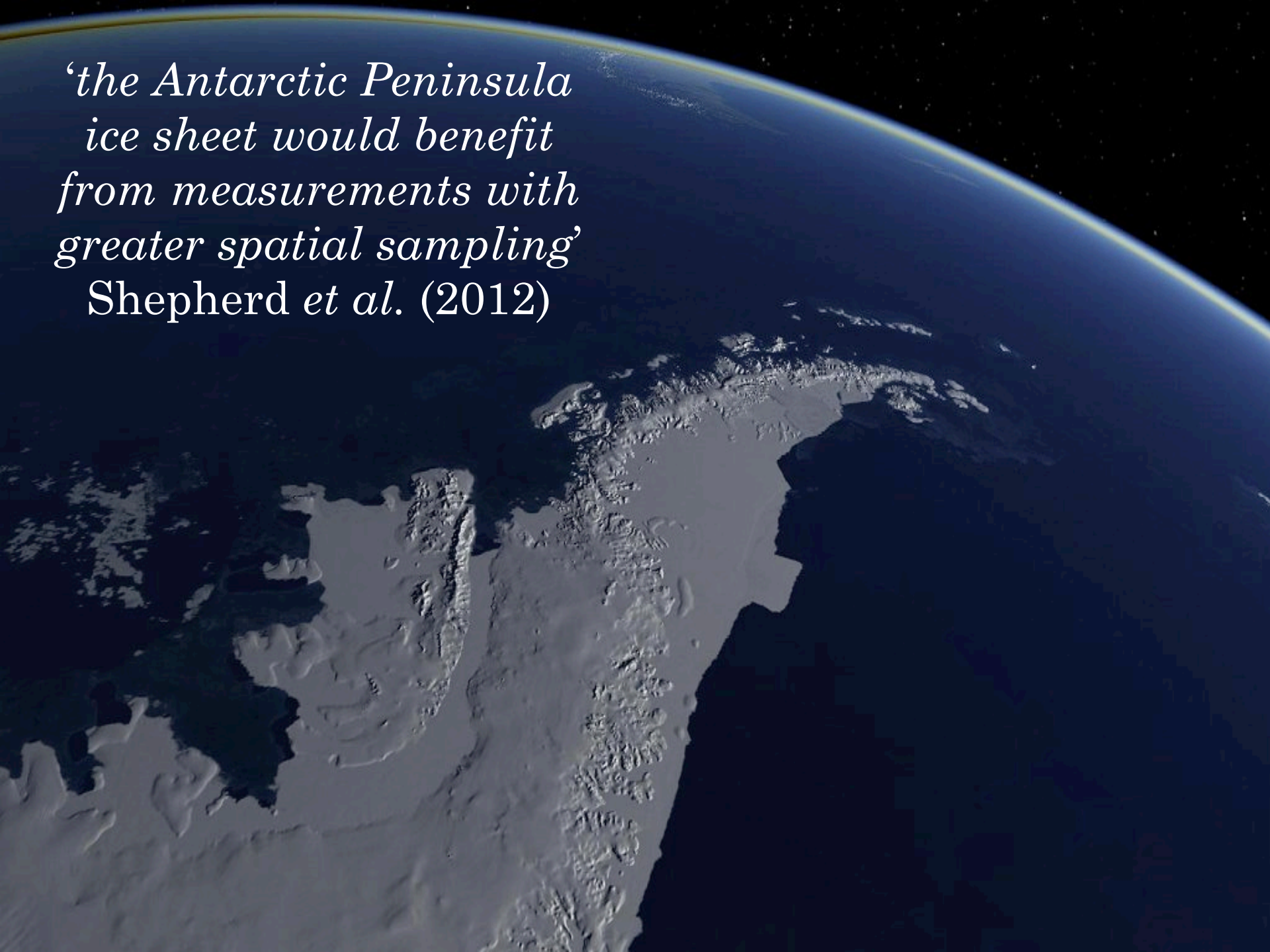
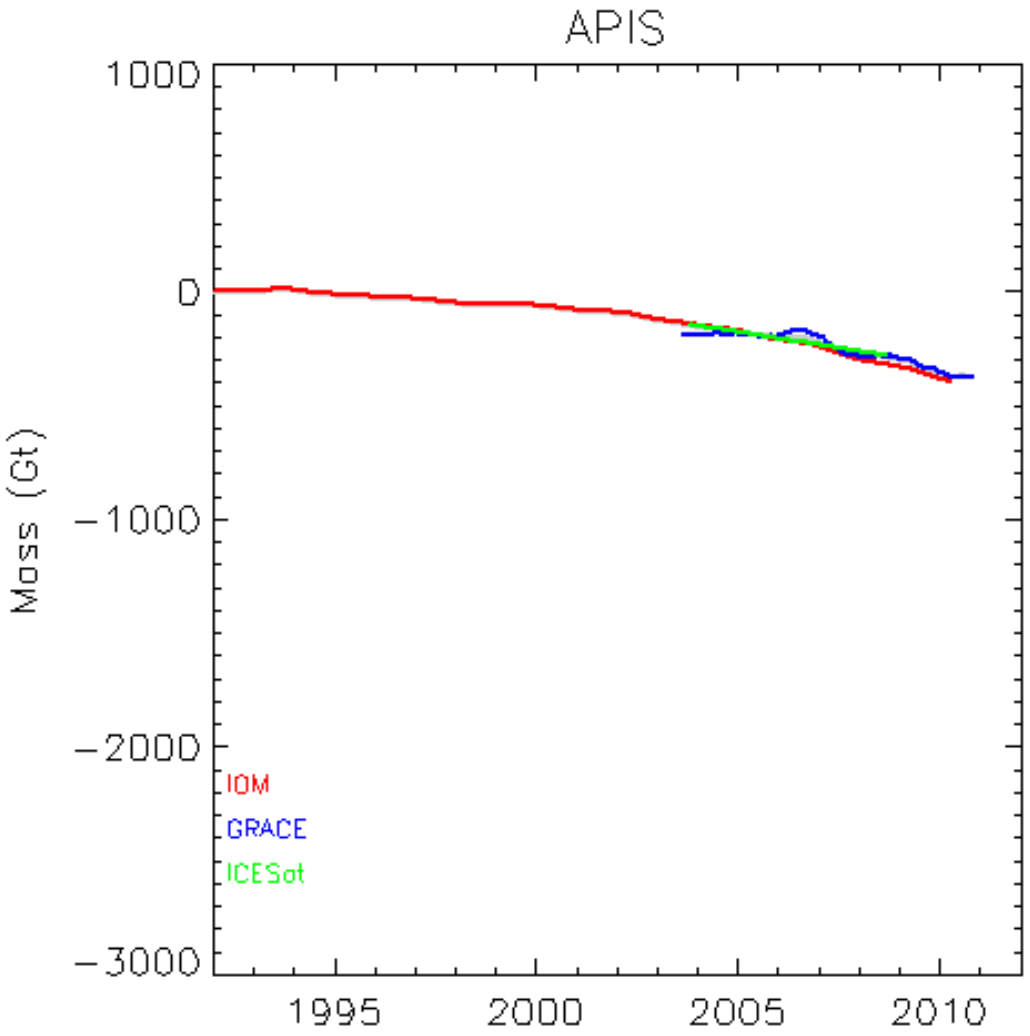
Antarctic Peninsula


‘the Antarctic Peninsula ice sheet would benefit from measurements with greater spatial sampling’
Shepherd *et al.* (2012)

AP mass balance

- increased air and ocean temperatures
- Glacier retreat, acceleration, thinning
- more melting
- Ice shelf collapse and inland response



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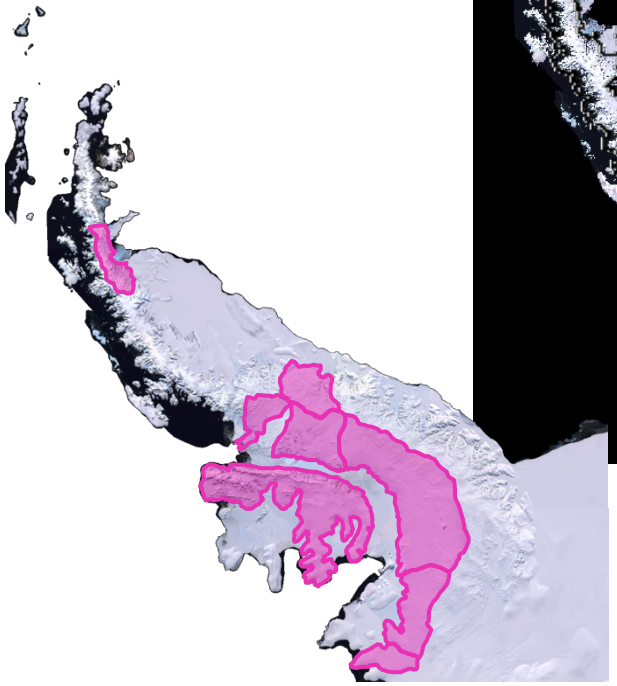
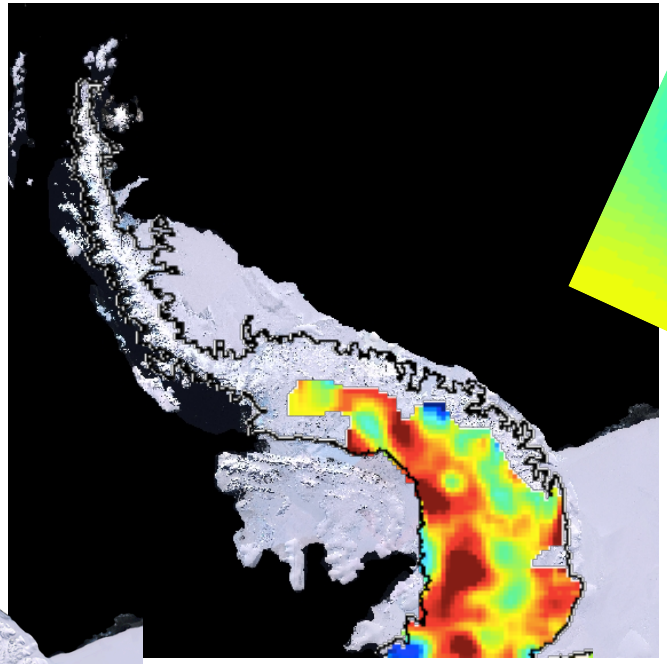
AP mass balance



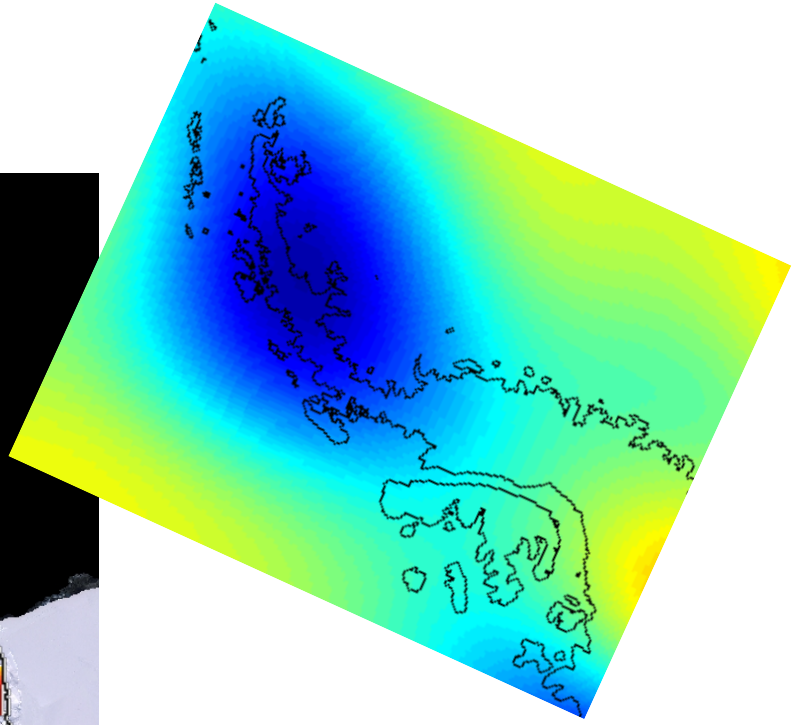
Mass Budget Method

< 50 % coverage



Radar Altimetry (ERS/EnviSat)

< 50 % coverage



Gravimetry

100% coverage

Low spatial resolution

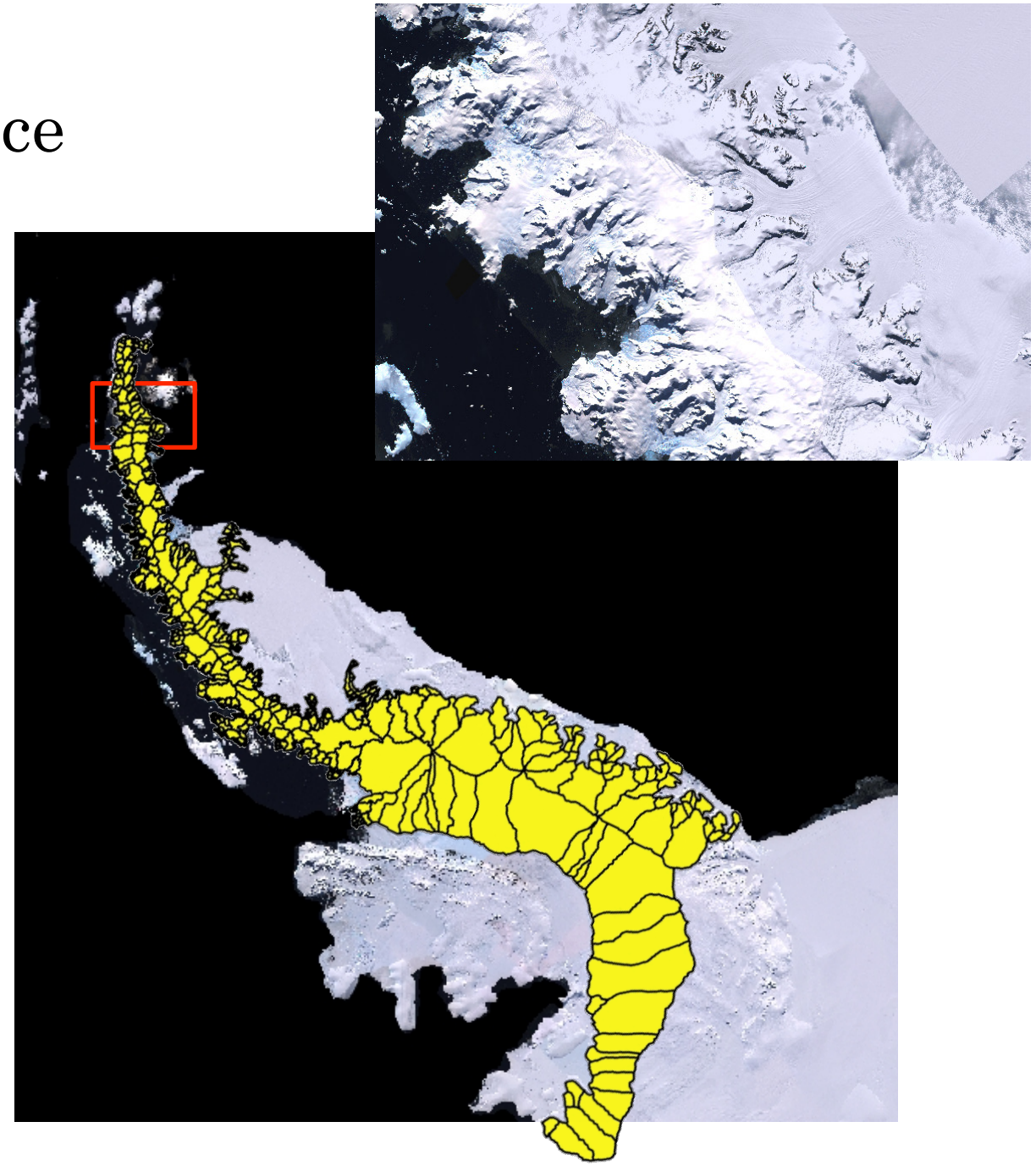
AP mass balance

1000+ basins
Complex terrain

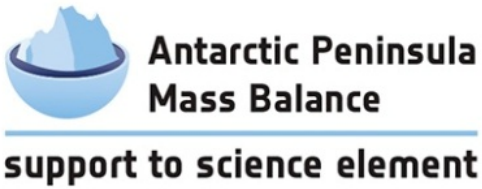
Gaps in data

Large variability in glacier behaviour

Large uncertainty in extrapolation and interpolation



APMB



- 2013 to 2015
- 10 institutions
- dm/dt of APIS
- Altimetry, Gravimetry and Mass Budget methods
- Combine and reconcile techniques
- Maximise data coverage
  - optimise techniques
  - use new datasets (e.g. CryoSat-2)

www.stse-apmb.org/
Antarctic Peninsula
Mass Balance
support to science element
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Summary

- GLACIERS (2003 – 2009)
  0.71 ± 0.08 mm SLE yr^{-1}

- ICE SHEETS (1992 – 2011)
  0.59 ± 0.20 mm SLE yr^{-1}

- ICE SHEETS (2000 – 2011)
  0.82 ± 0.16 mm SLE yr^{-1}