

DTU Space  
National Space Institute

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**DTU** Technical University of Denmark

[www.space.dtu.dk](http://www.space.dtu.dk)

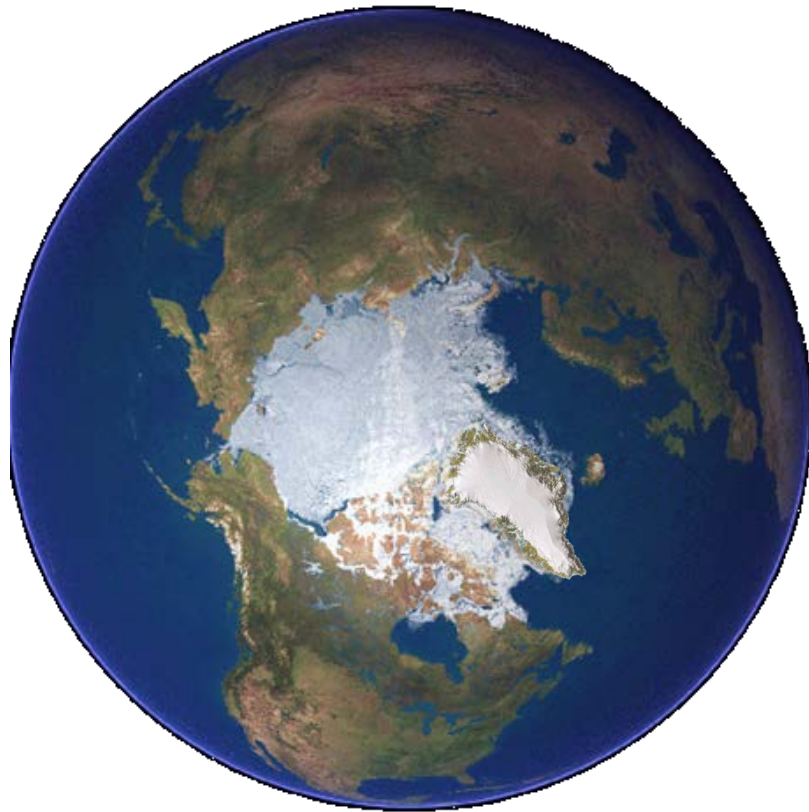
# The Shrinking Ice Sheets

Rene Forsberg, DTU-Space, Denmark  
Andrew Shepherd, University of Leeds, UK  
and the IMBIE-team



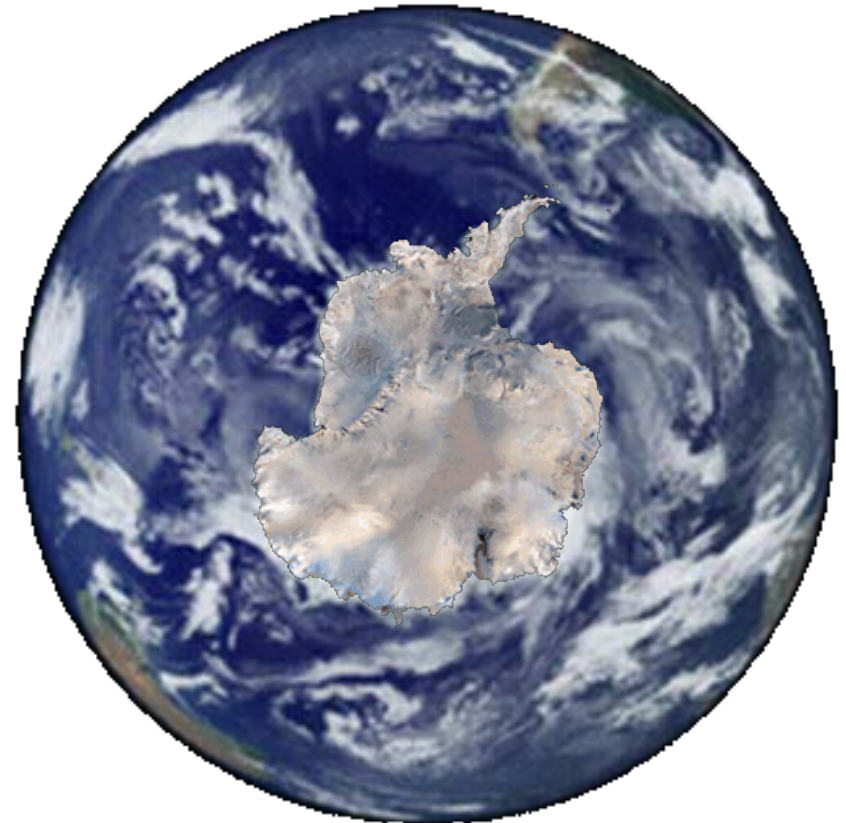
*Antarctic Peninsula, DTU Jan 2010*

## The ice sheets



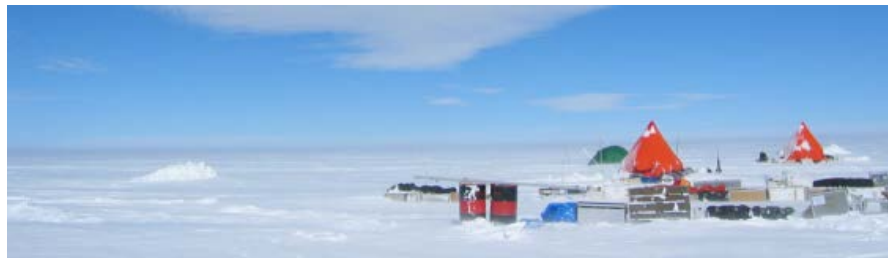
Greenland

7 metres sea level equivalent



Antarctica

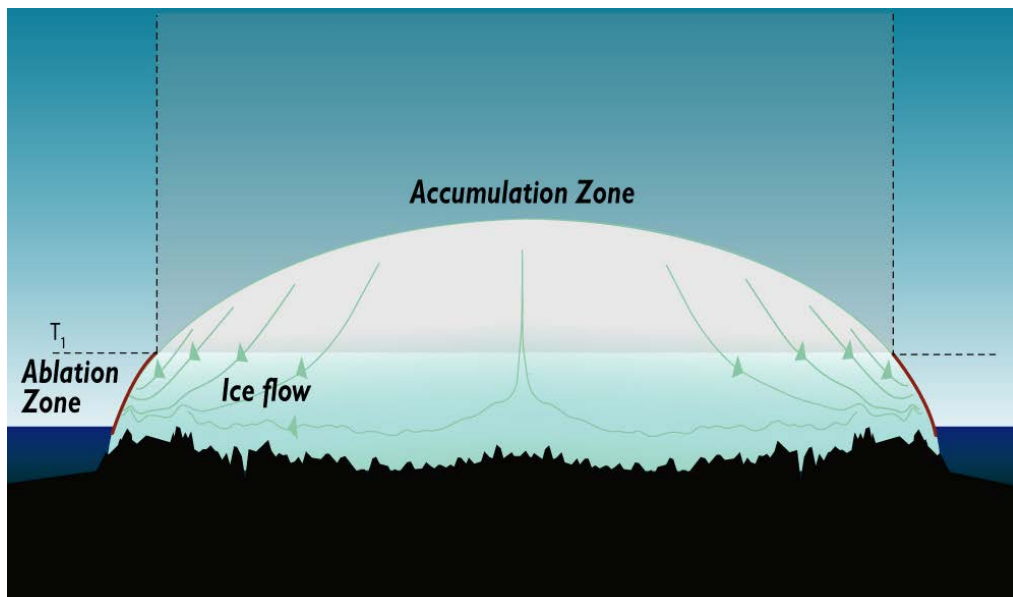
57 metres sea level equivalent



## Ice sheets are in dynamic balance

- Snow accumulate on top
- Turns into ice at depths of 20-40 m
- Flows to coastal area and melt or breaks off as icebergs
- Large outlet glaciers move up to 30 m/day

*Greenland case: yearly mass exchange ~ 650 GT*  
*Yearly mass loss at present ~ 240 GT*



*Ablation zone: snow and ice melt every summer*

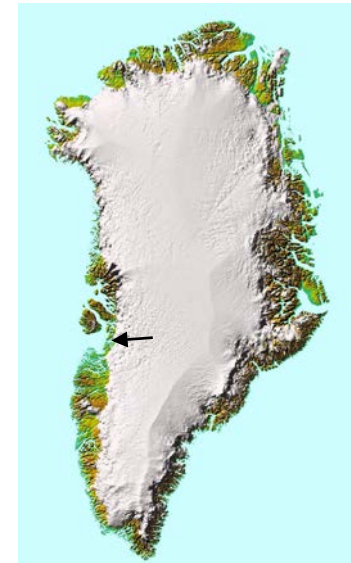


# The Greenland ice sheet

- Ice area > 2 mio km<sup>2</sup>
- Largest height 3300 m at summit  
(Gunnbjørn Fjeld on East Coast 3700 m)
- Ice up to 3500 m thick (below sea level in center)

*Greenland society interest in ice changes:*

- Iceberg production, new mining opportunities ..
- **Sea ice** changes much more important locally ..



*Jakobshavn glacier retreat*

## Example:

- Malmbjerget Molybdenum prospect

Discovered in 1954

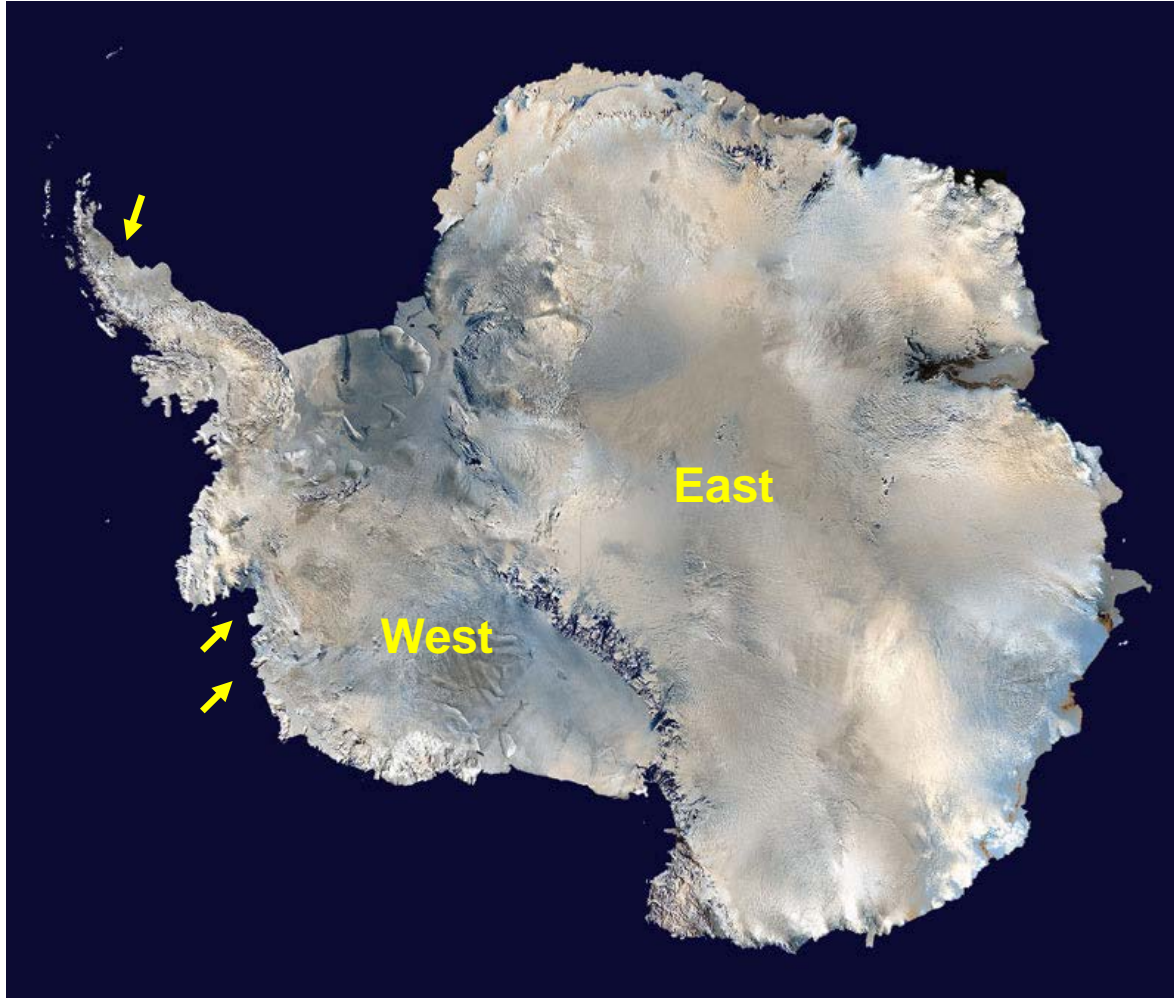
Mine plans:

- 50,000 t ore per day
- 20 years
- Open pit
- 500 - 600 employees





## Antarctica ice sheets



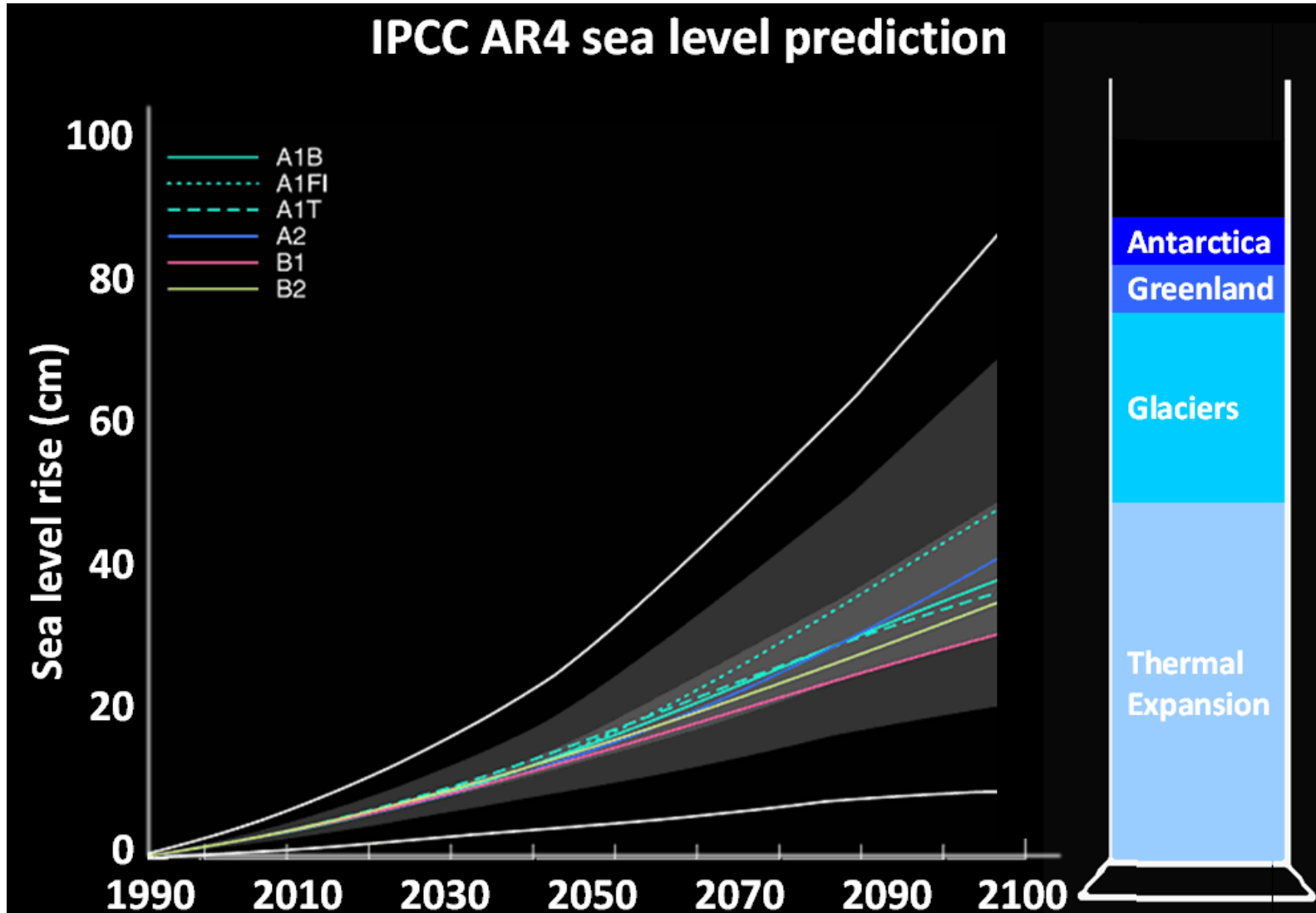
- Much larger than Greenland
- Ice up to 4.5 km thick
- Essentially no summer melt
- Floating ice shelves

### *Major changes:*

- *West Antarctica thinning (Pine Island Glacier)*
- *Ice shelf loss (Antarctic peninsula)*



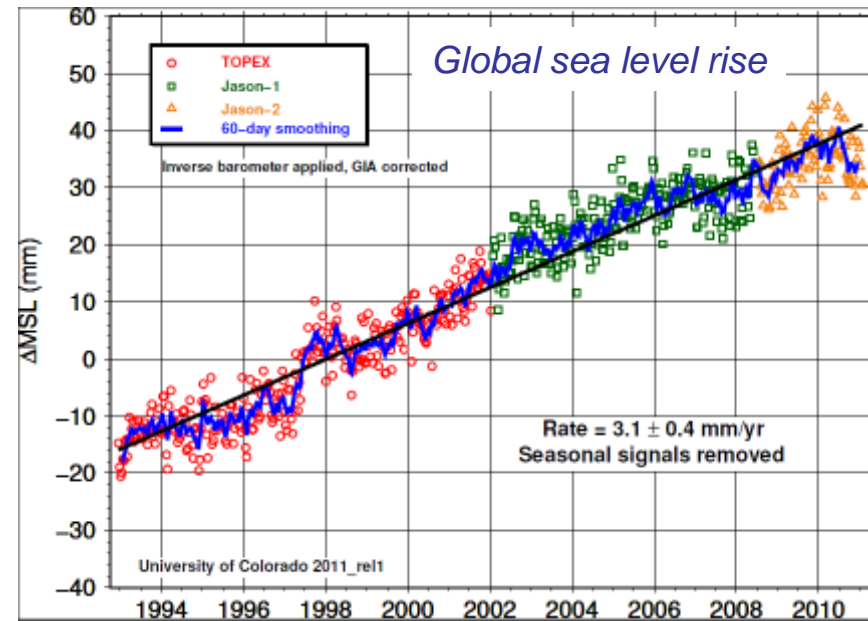
# Sea level rise: future melt of the ice sheets



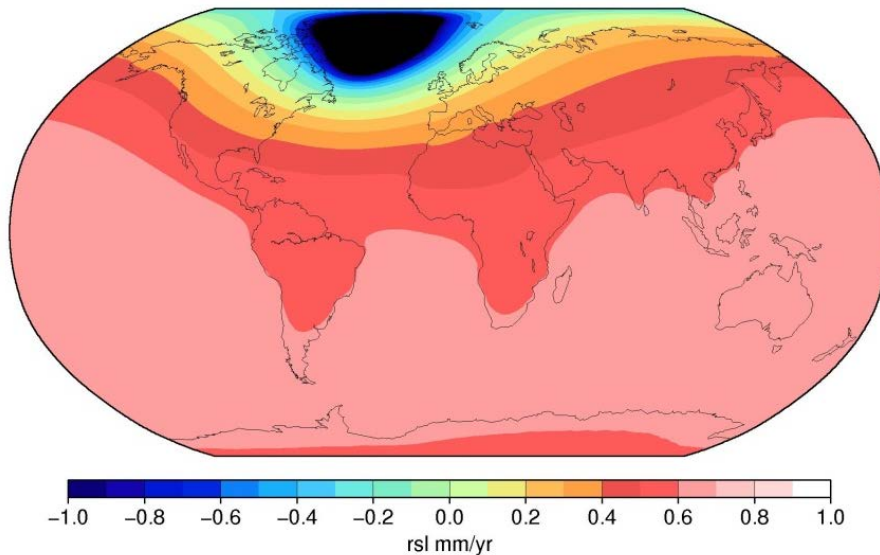
# Ice sheet melting concerns ...

- Freshwater input to ocean  
... may change ocean circulation
- Global sea level rise  
... sea-level rise not uniform across oceans  
*Antarctica change European sea level!*

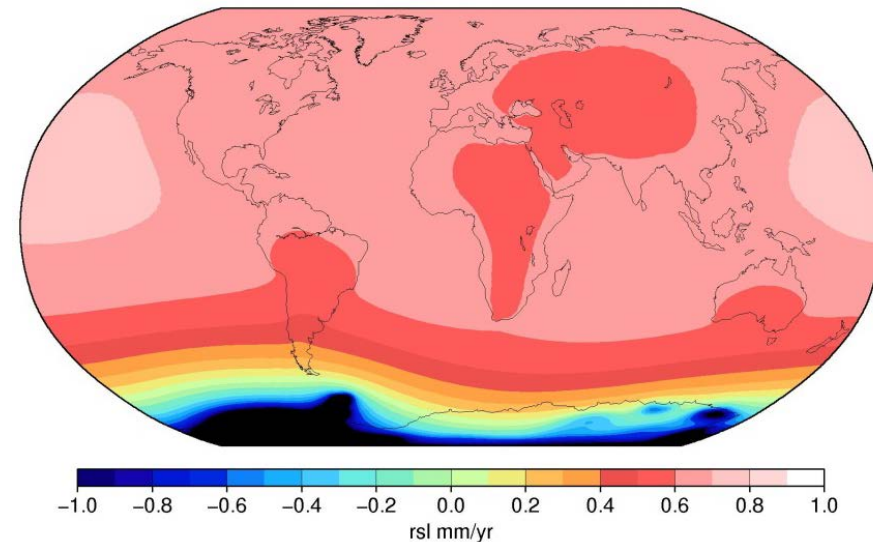
**Current rate ~ 0.7 mm/yr for Greenland,  
~ 0.3 mm/yr for Antarctica**



*Sea-level change due to current Greenland melt*



*Sea-level change due to Antarctica melt*





# Measurement of ice sheet mass loss from space

## "The geodetic methods"

### Height measurements:

- Radar altimetry (ERS-1, ERS-2, EnviSat, CryoSat ..)
- Laser altimetry (NASA IceSat..)

*Provide ice height changes ...*

### Mass change measurements:

- Satellite-to-satellite ranging (NASA/DLR GRACE 2002- ..)

*Direct estimate of mass-changes ...*

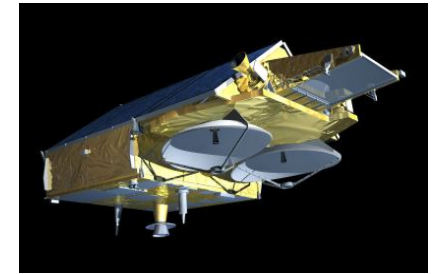
### Velocity measurements:

- SAR interferometry (ERS, EnviSat ++ .. )

*Glacier velocities must be combined with snow fall and thickness information ..*

**Do methods agree?**

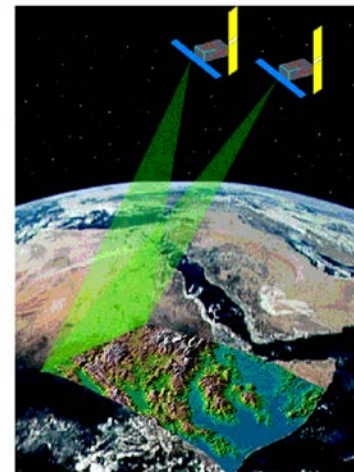
**NASA-ESA IMBIE study 2011-12**



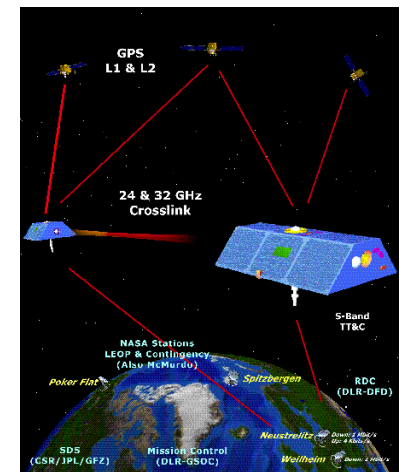
ESA Cryosat-2 (2010- ..)



NASA IceSat (2003-9)



SAR interferometry

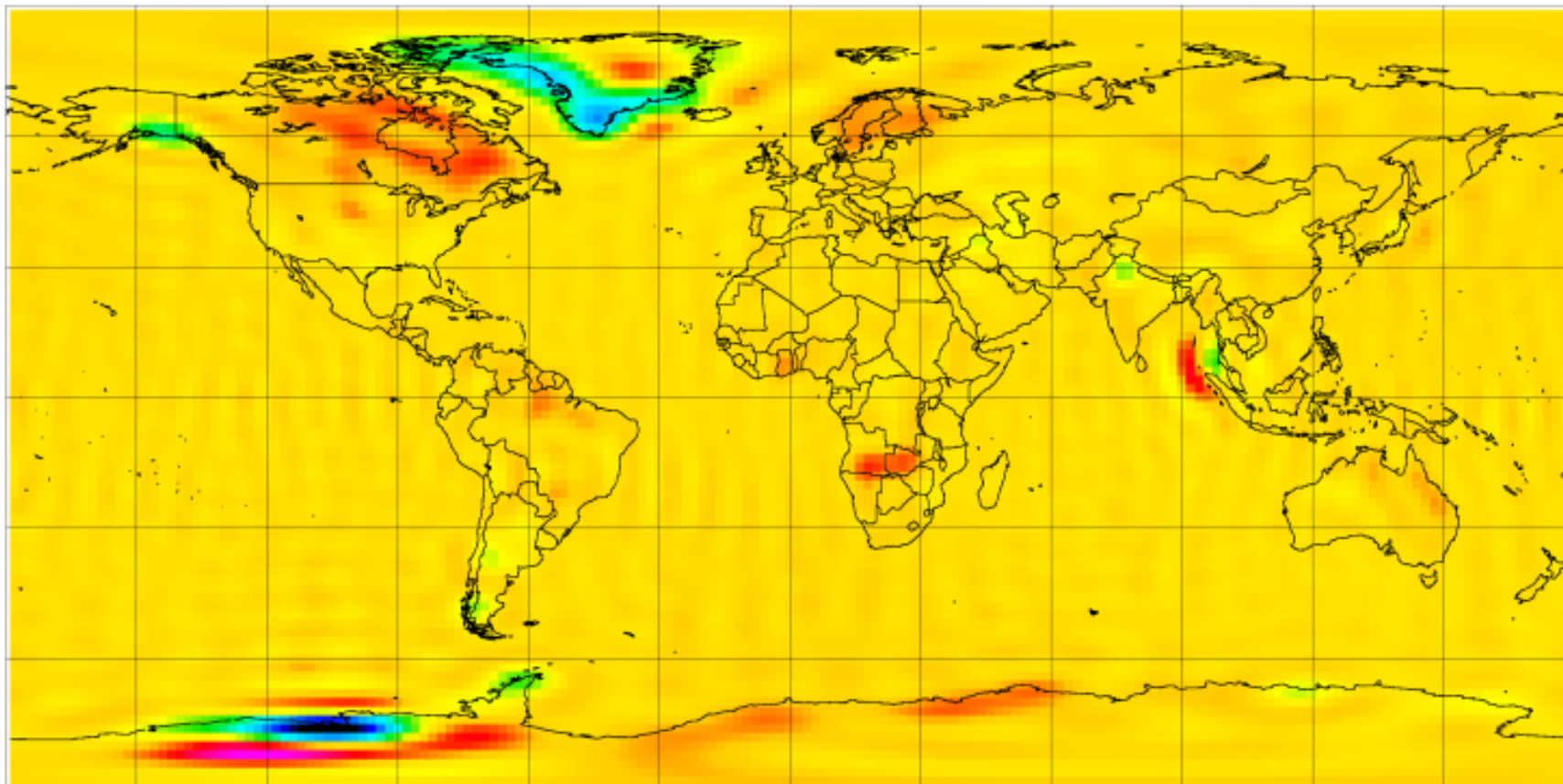
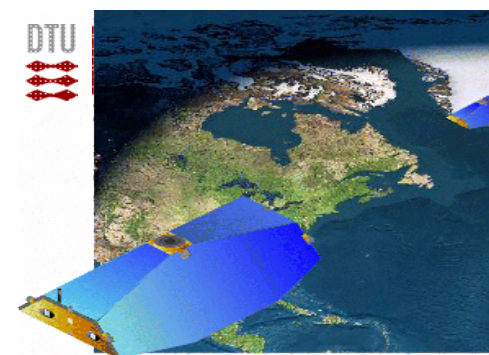


NASA/DLR GRACE (2002-..)

# Examples of space results

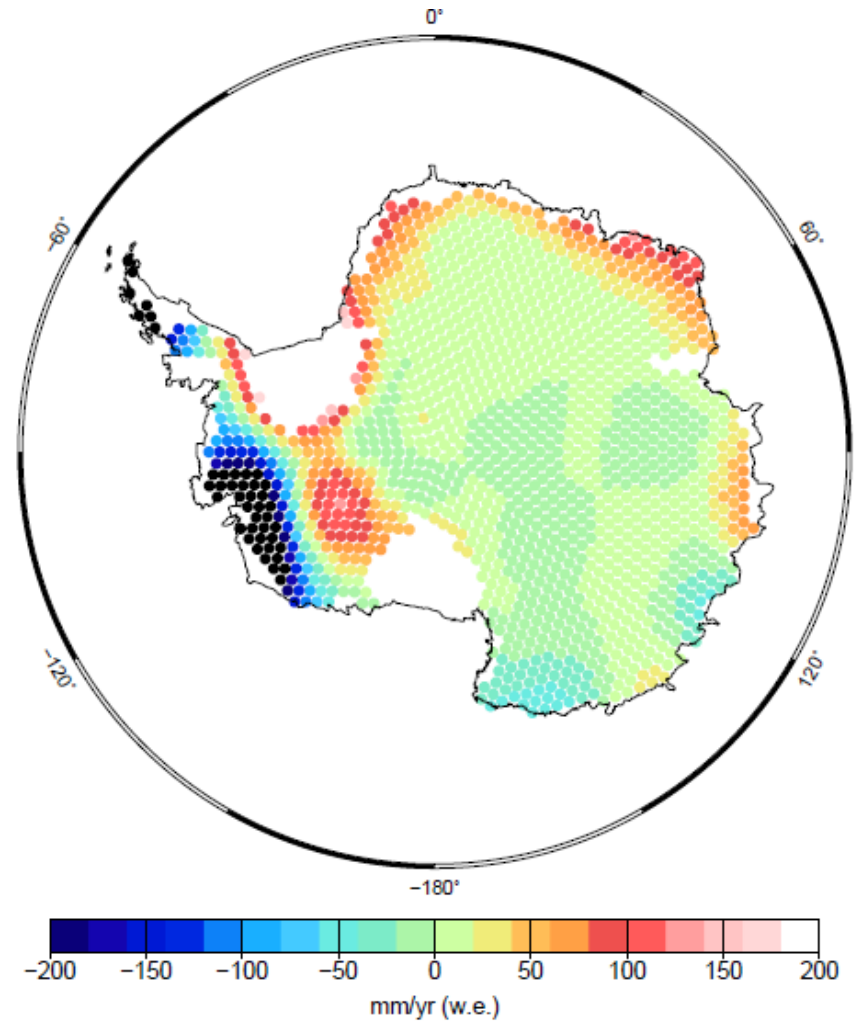
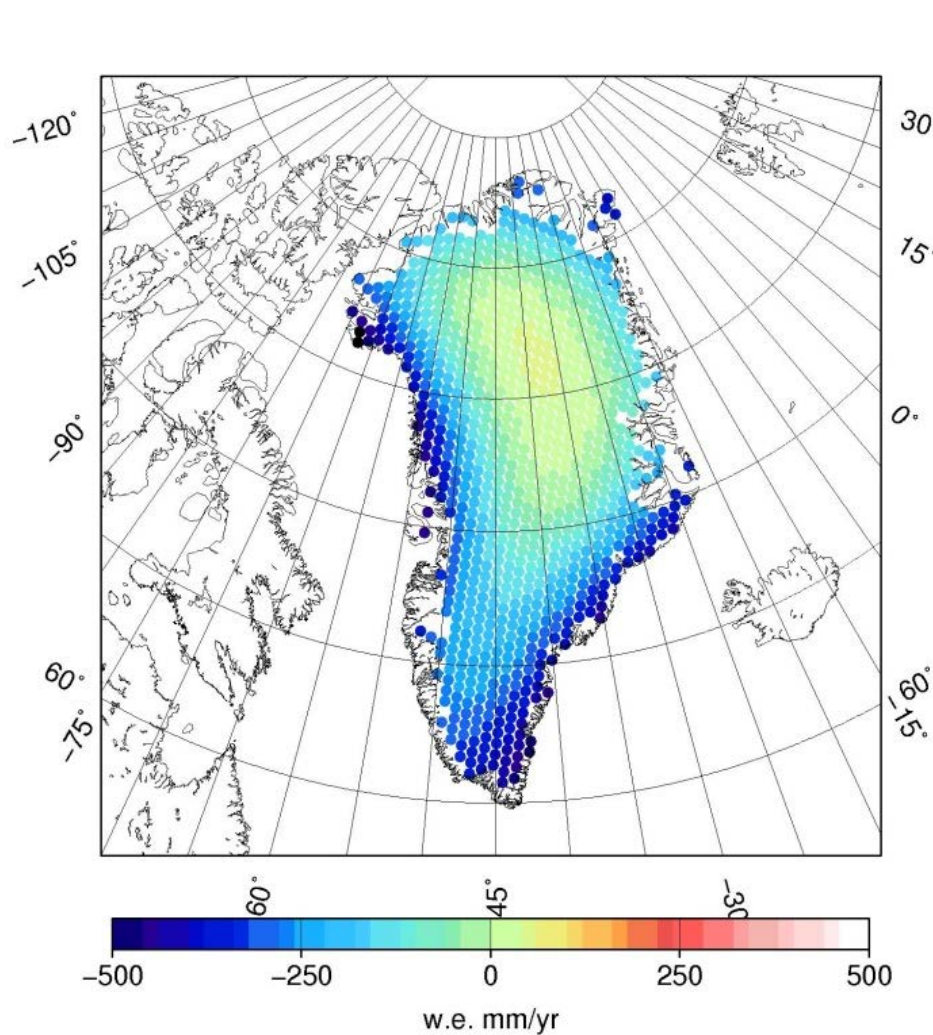
## Gravity measurements from space (GRACE)

Trend in gravity @ 480 km elev 2003-12 (DTU)



Units:  $10^{-9}g/yr$

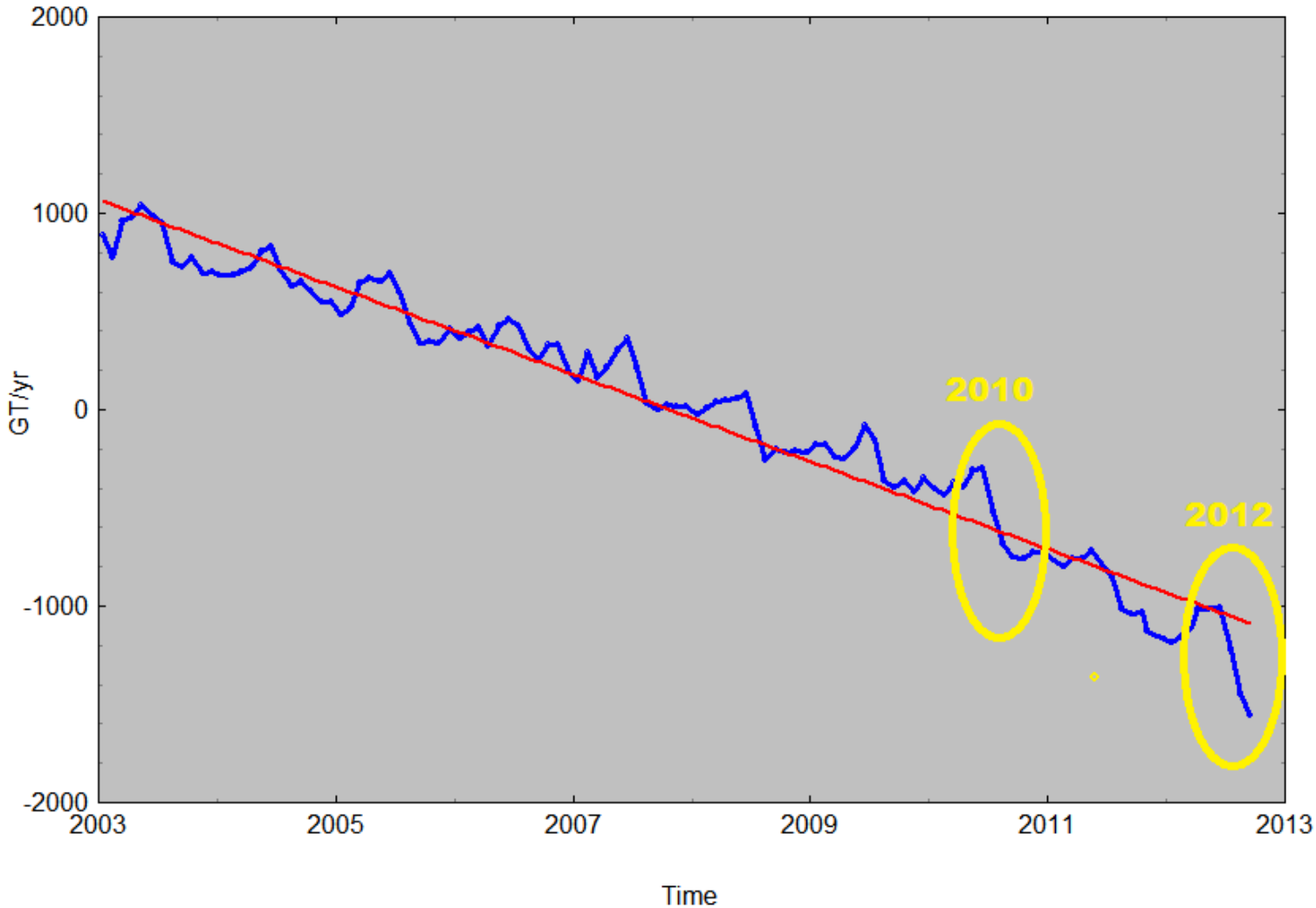
## Greenland and Antarctica mass change regions from GRACE





# Overall Greenland mass trends – yearly mass loss

Greenland mass trend from GRACE



Yearly mass loss  
(differences to previous year)

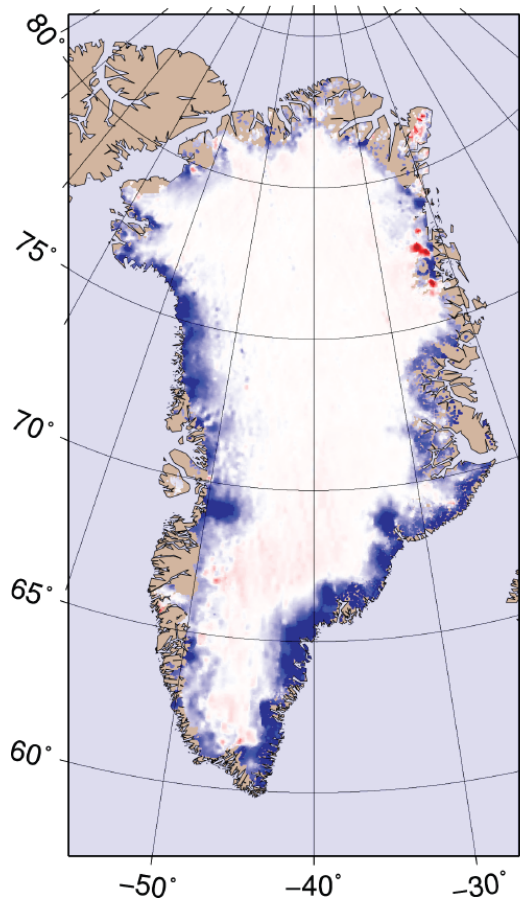
Year	Mass loss (GT)
2003	84
2004	148
2005	201
2006	177
2007	244
2008	282
2009	176
2010	<b>419</b>
2011	291
2012	<b>556</b>

*Best trend estimate 2003-12:  $-244 \pm 20$  GT/yr*

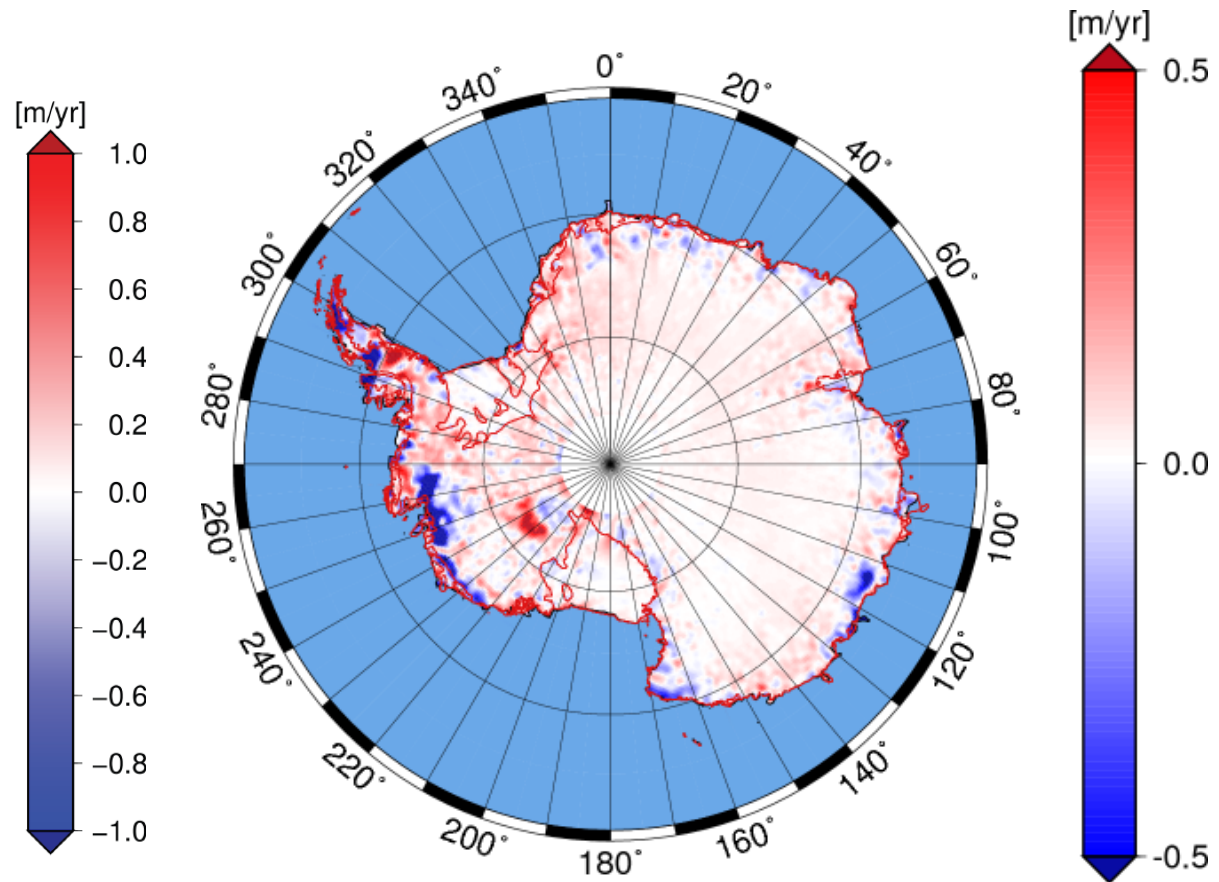


# Satellite altimetry: Height changes 2003-9 – ICESat

## Greenland

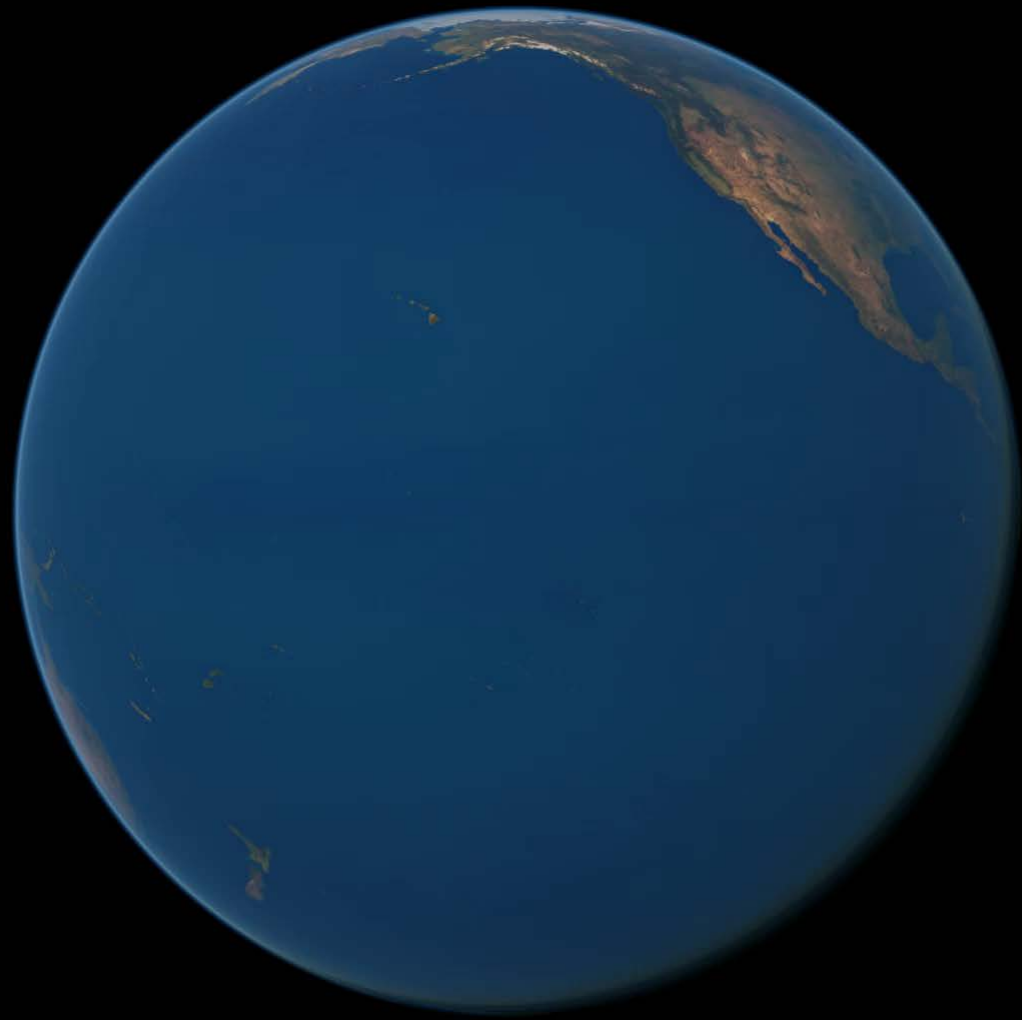


## Antarctica

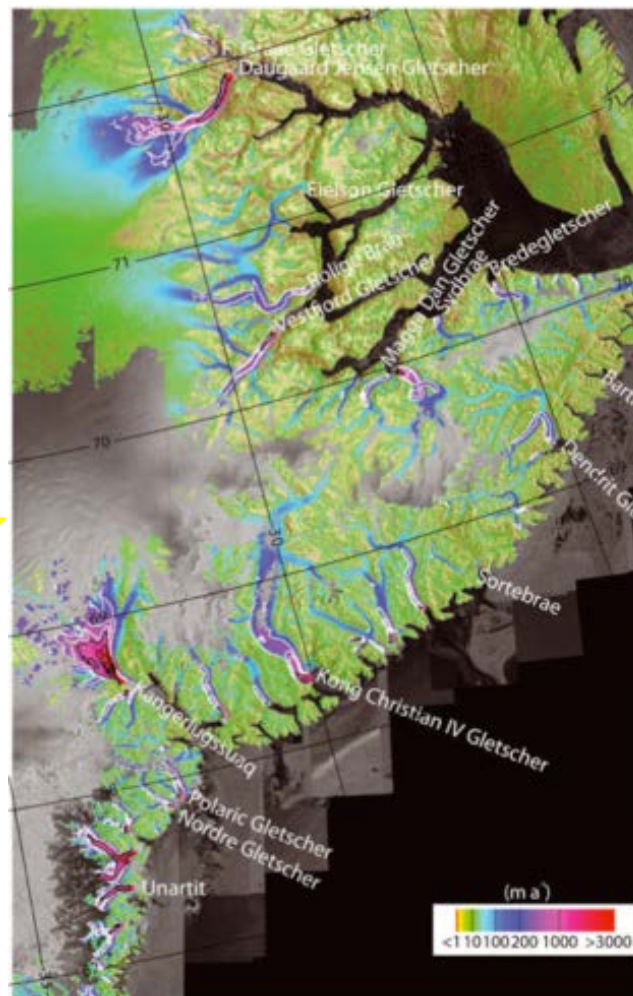
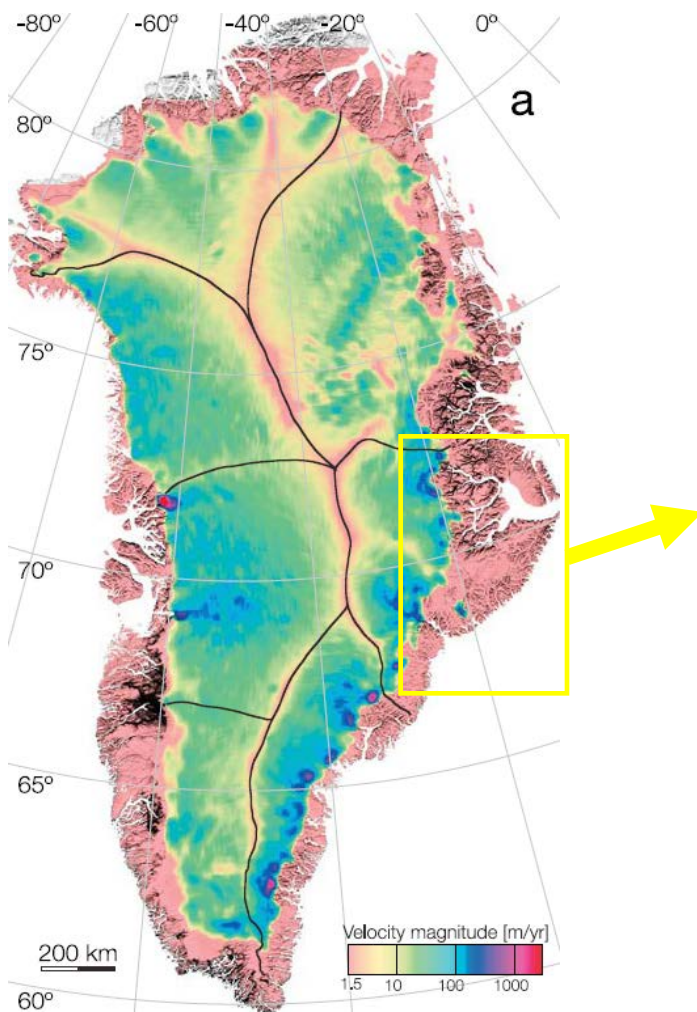
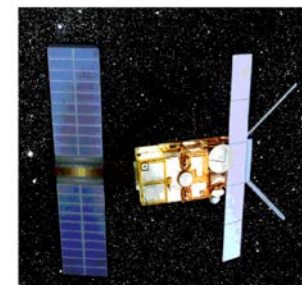








# SAR interferometry: Mapping glacier speeds by repeated satellite radar

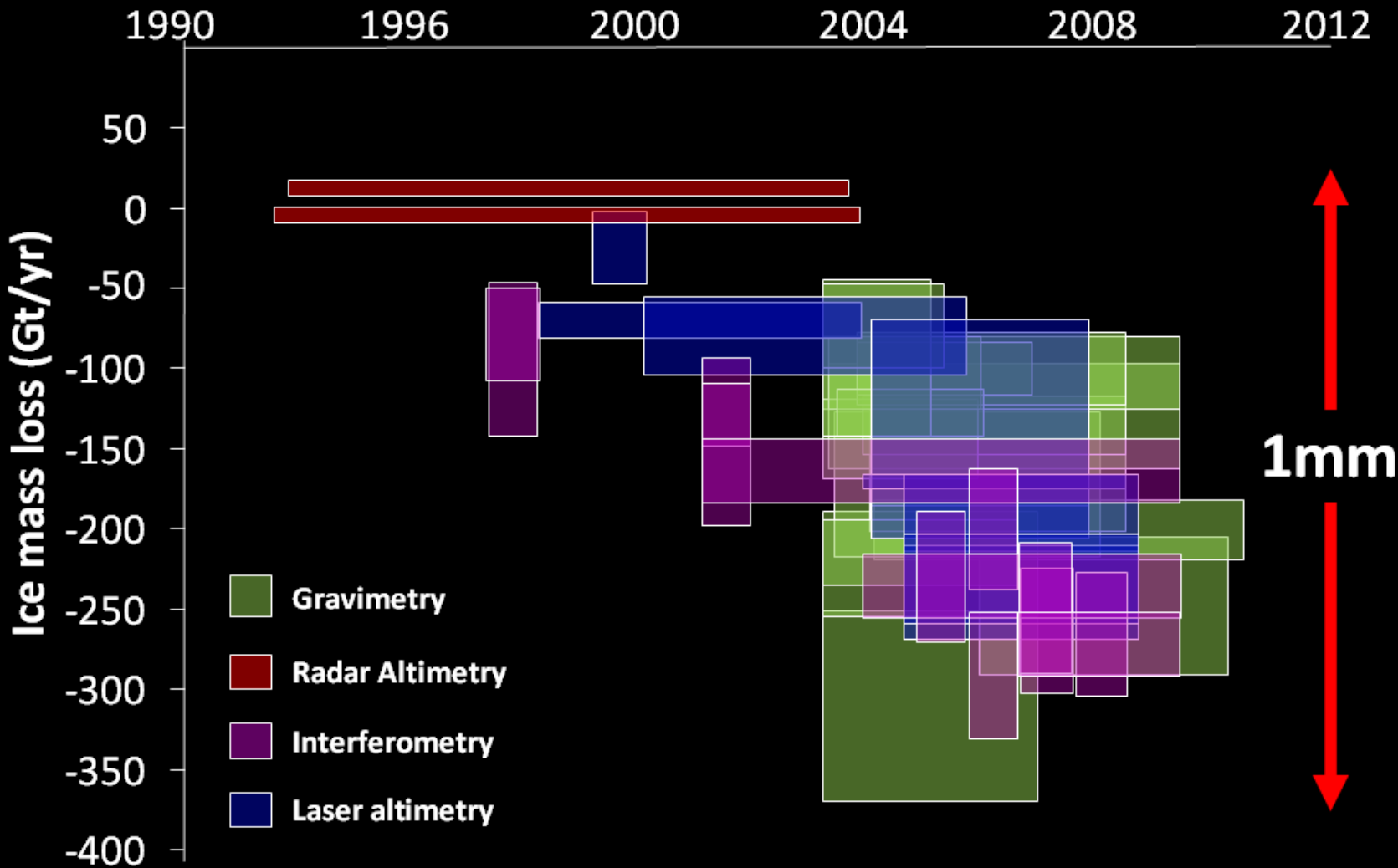


*"Input-output" SAR method requires detailed information on snow fall in interior and thickness of glaciers*

*(I Joughin, UW)*

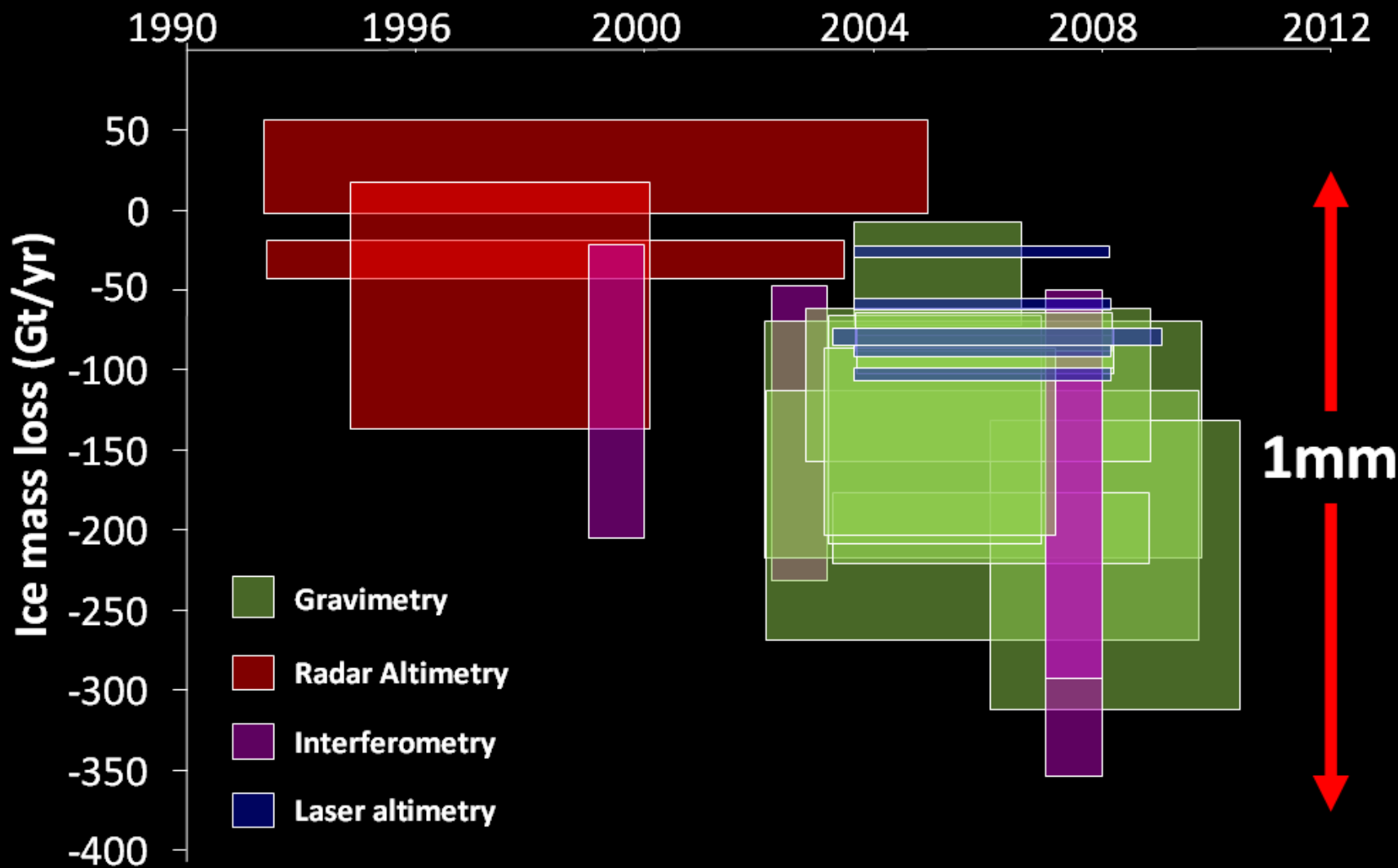
# Differences in space-based mass estimates

## Previous surveys: Greenland





# Previous surveys: Antarctica



## Earlier investigations:

- \* Almost 40 previous geodetic estimates of ice sheet imbalance since 1989
- \* There remains poor agreement between estimates
- \* Published sea level change results range between -0.2 and +1.9 mm/yr

## International Mass Balance Intercomparison Experiment 2011-12:

- \* ESA and NASA supported – leading teams from N America and Europe
- \* Contribution to IPCC AR5, reconcile estimates to one set of numbers ..

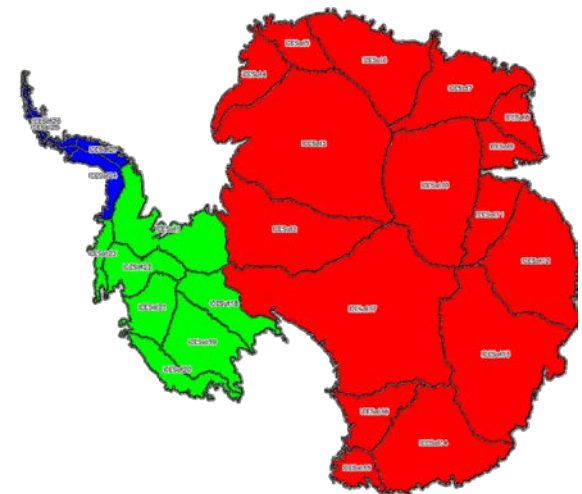
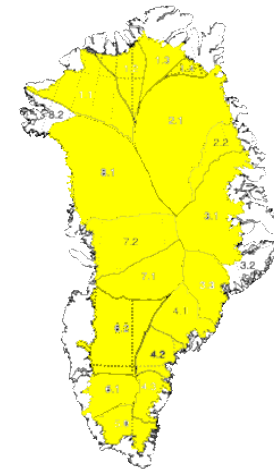
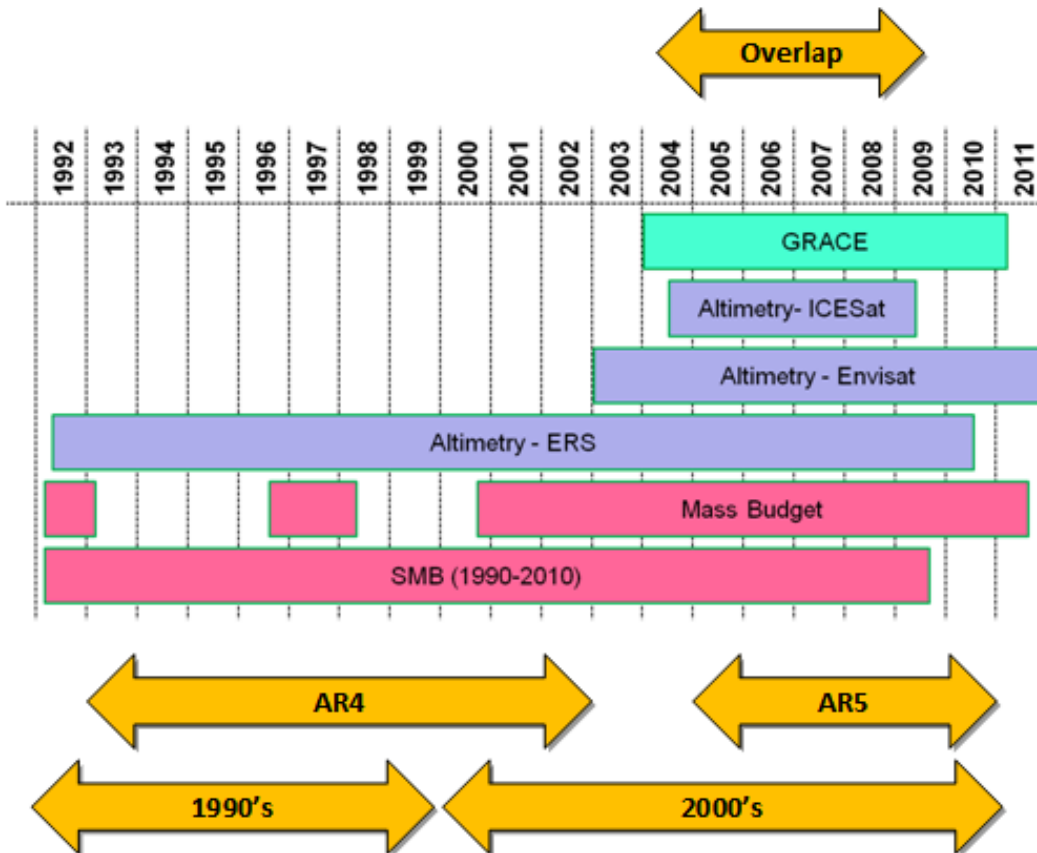
imbie



*IMBIE paper  
released today  
in "Science"*

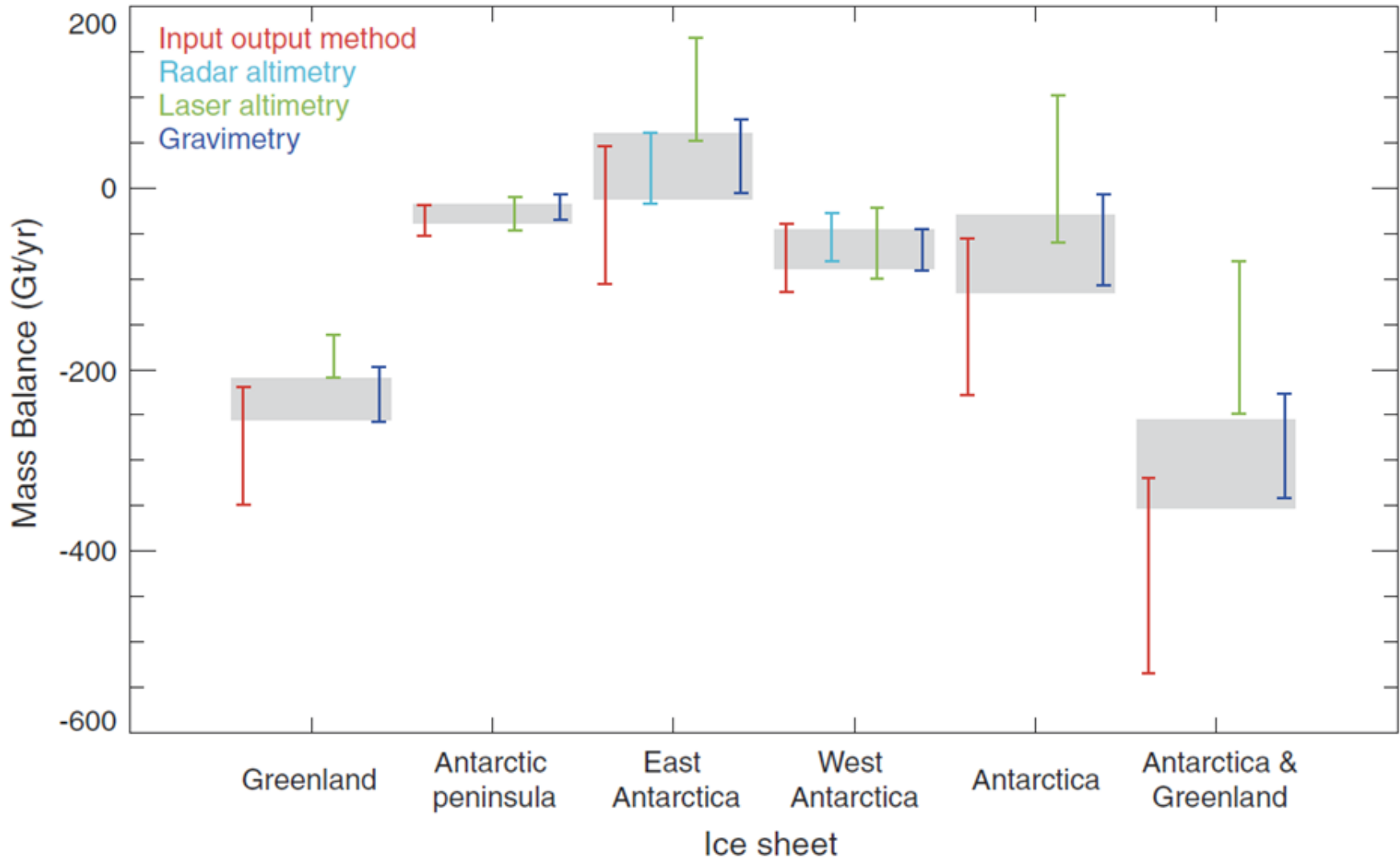
# IMBIE exersize: common period, common regions, "best" practices

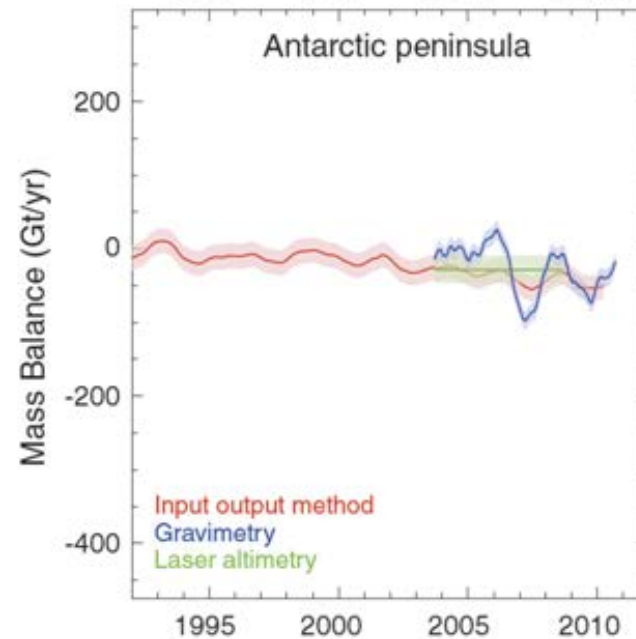
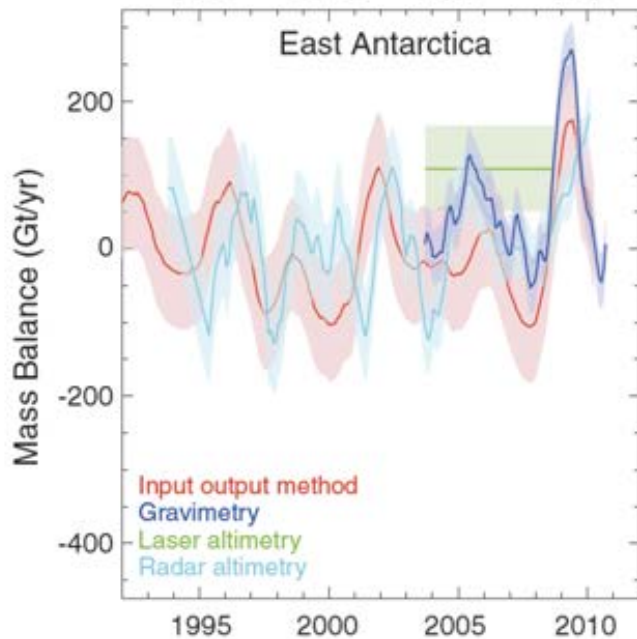
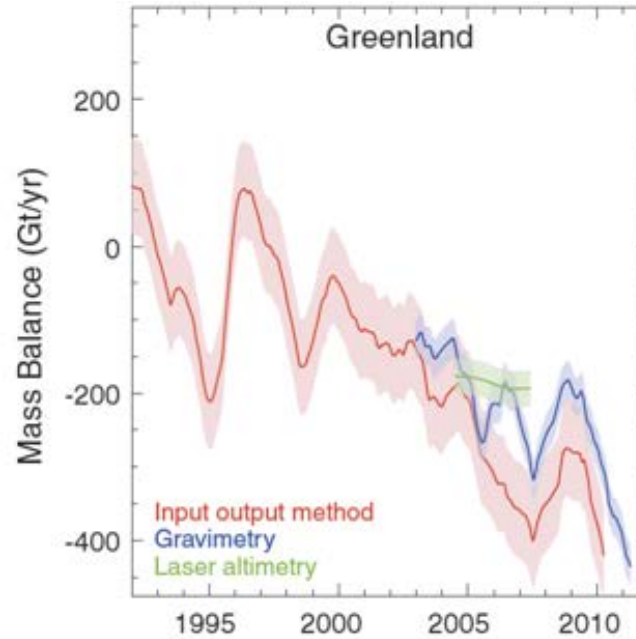
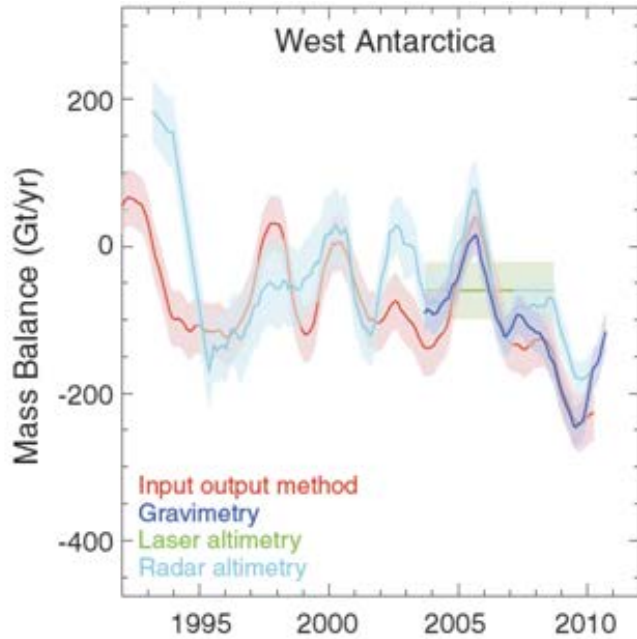
All of Greenland, East and West Antartica, Antarctic Peninsula  
Improved GIA (Glacial Isostatic Adjustment models)





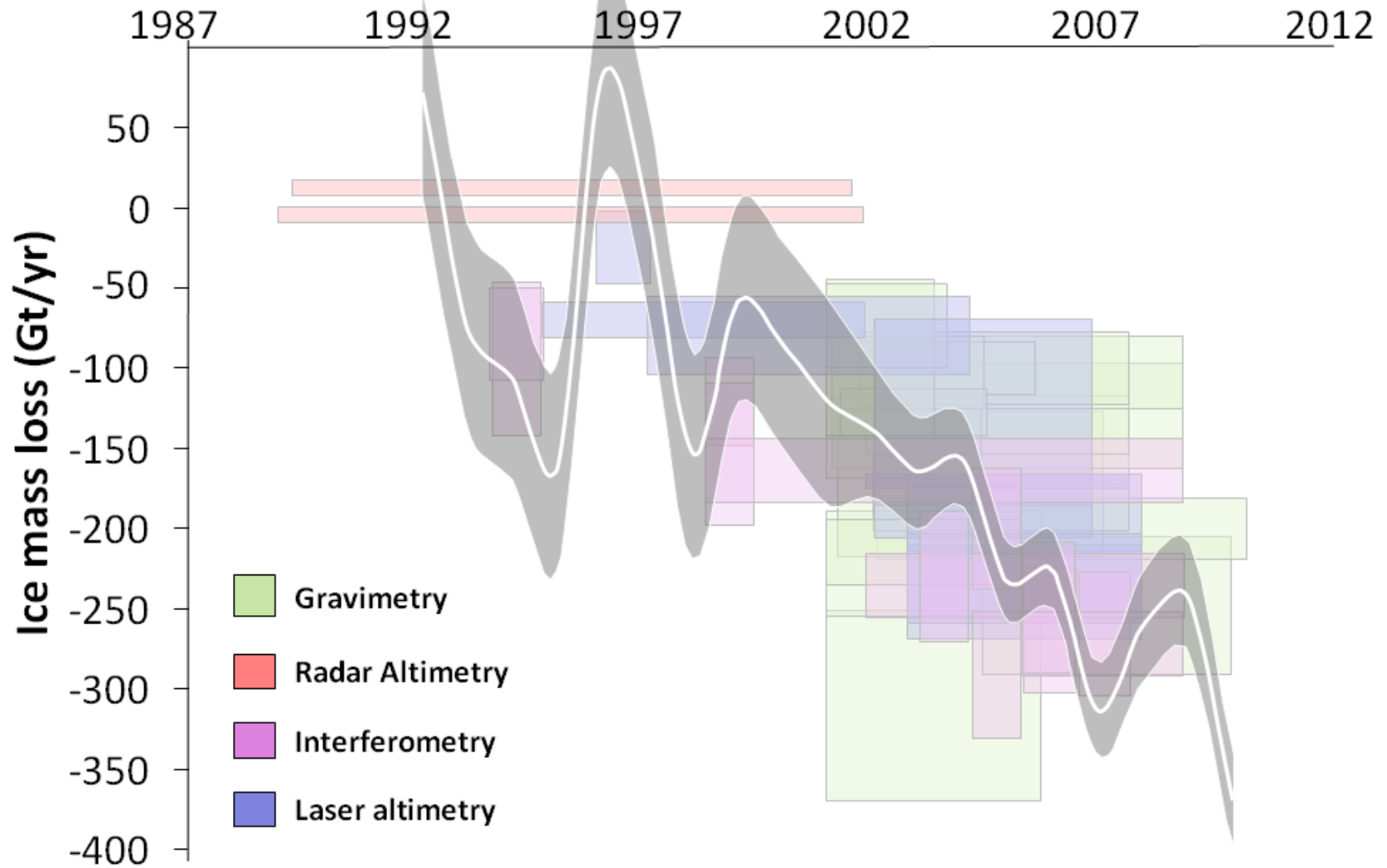
## IMBIE average yearly mass loss





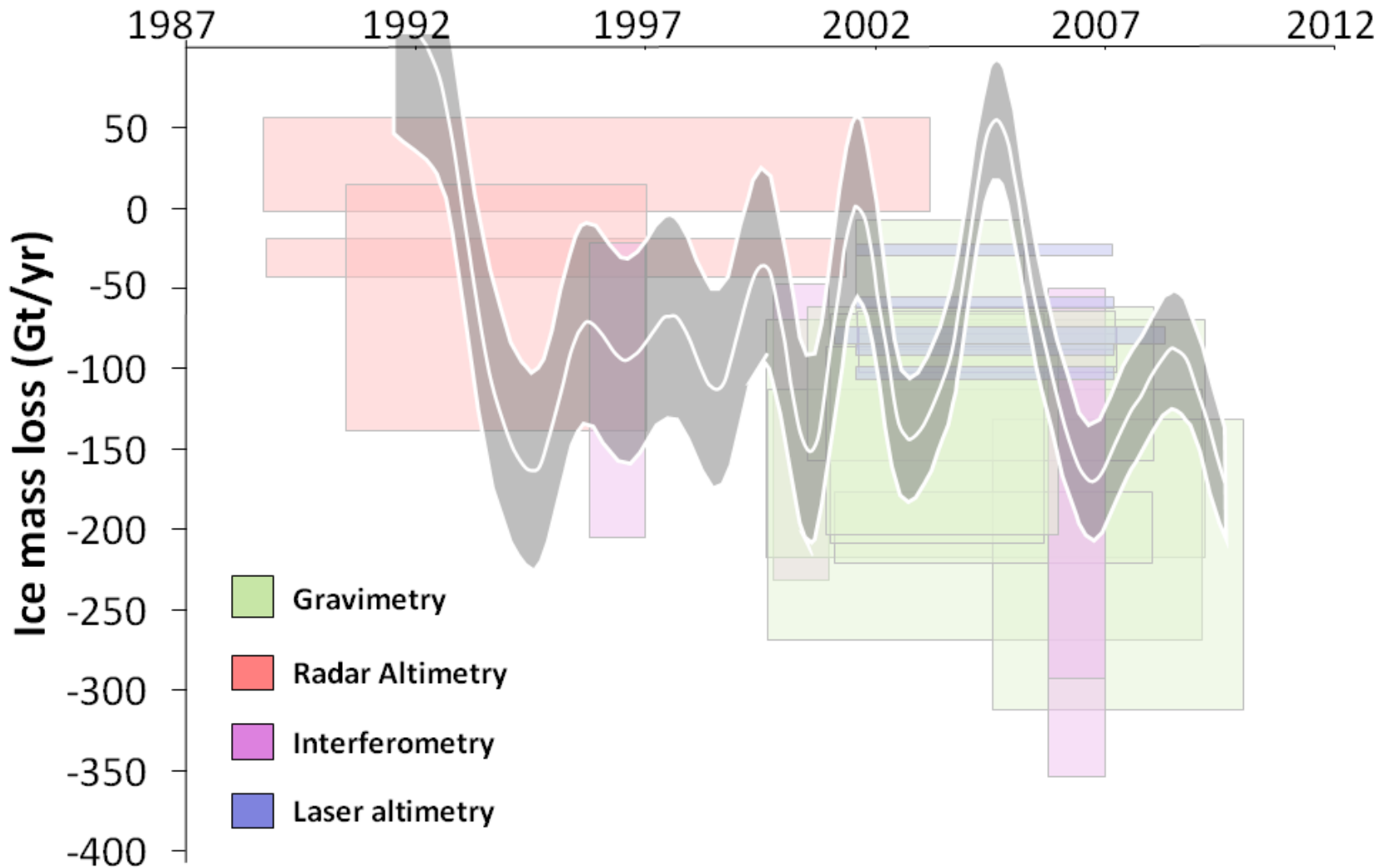
**IMBIE**  
time change  
results  
for the 4  
ice sheet  
regions

# Greenland mass imbalance





# Antarctica mass imbalance



# **A reconciled estimate of ice sheet mass balance**

**ESA / NASA IMBIE**

## Conclusions:

Space-based methods show consistent Greenland and Antarctica mass loss .. *space data gives facts*

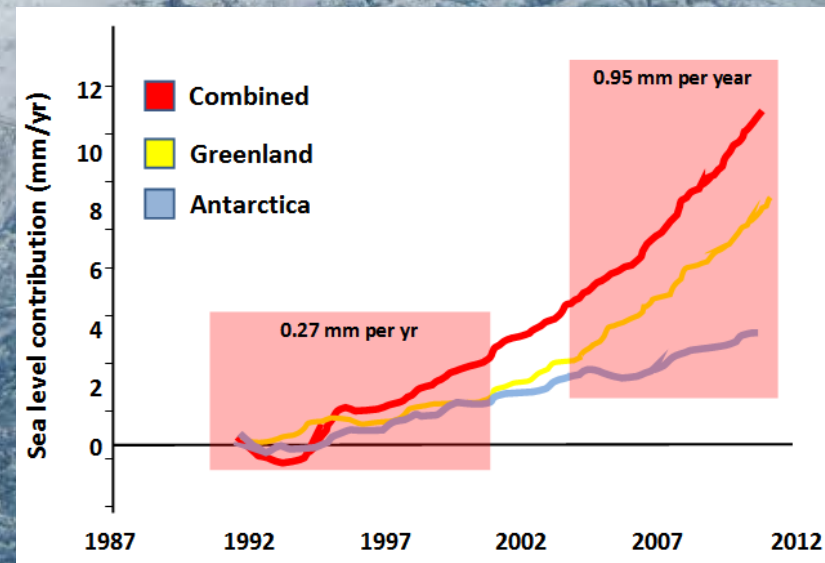
IMBIE "best" reconciled estimates 2000-11:

Greenland  $-223 \pm 37$  GT/yr ( $\sim 0.7$  mm/yr sea level rise)


Antarctica  $-87 \pm 43$  GT/yr ( $\sim 0.3$  mm/yr)

*Mass loss 3x the 1990's values*

*Record Greenland melt season 2012 confirmed by GRACE  
.. current rates around -260 GT/yr*





A wide-angle landscape photograph of an Antarctic region. The foreground shows a dark, rocky slope with patches of snow. In the middle ground, there's a vast, flat expanse of ice or snow leading to a range of low mountains. The sky is filled with soft, horizontal clouds, and the sun is setting on the left, creating a warm orange and yellow glow that transitions into a cool blue as it reaches the horizon. The overall mood is serene and majestic.

**Thanks for your attention**