

# Satellite altimetry = glaciology

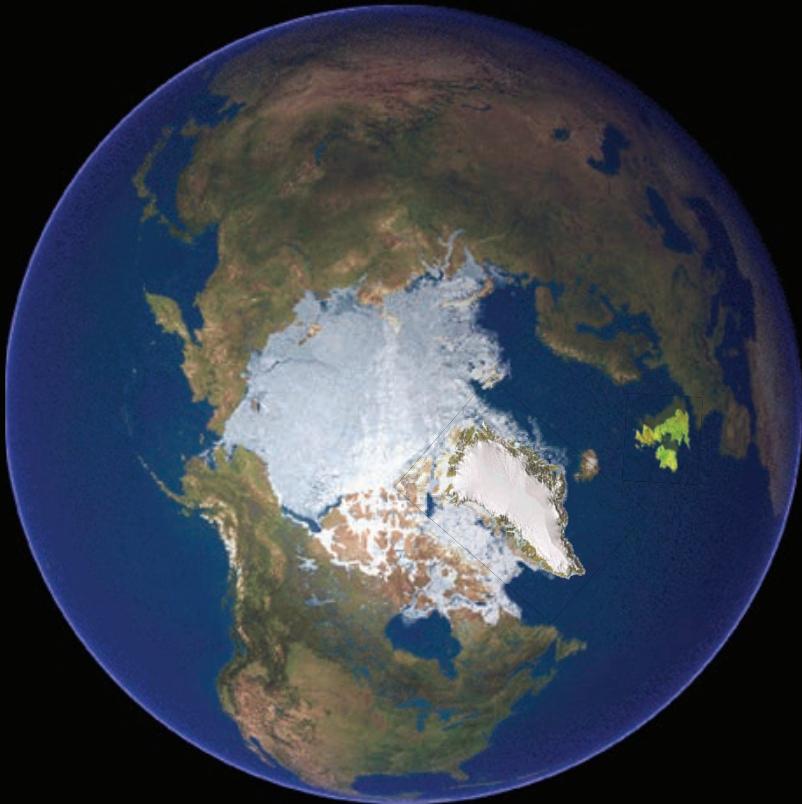
*Andrew Shepherd, Kate Briggs, Lin Gilbert, Anna Hogg,  
Hannes Konrad, Malcolm McMillan, Alan Muir, Andy  
Ridout, Rachel Tilling*

*Centre for Polar Observation  
and Modelling, University of Leeds*

# Outline

1. Why is ice an important part of Earth's climate?
2. Ice Sheet Altimetry
3. Ice Sheet Mass Balance
4. Sea Ice Altimetry



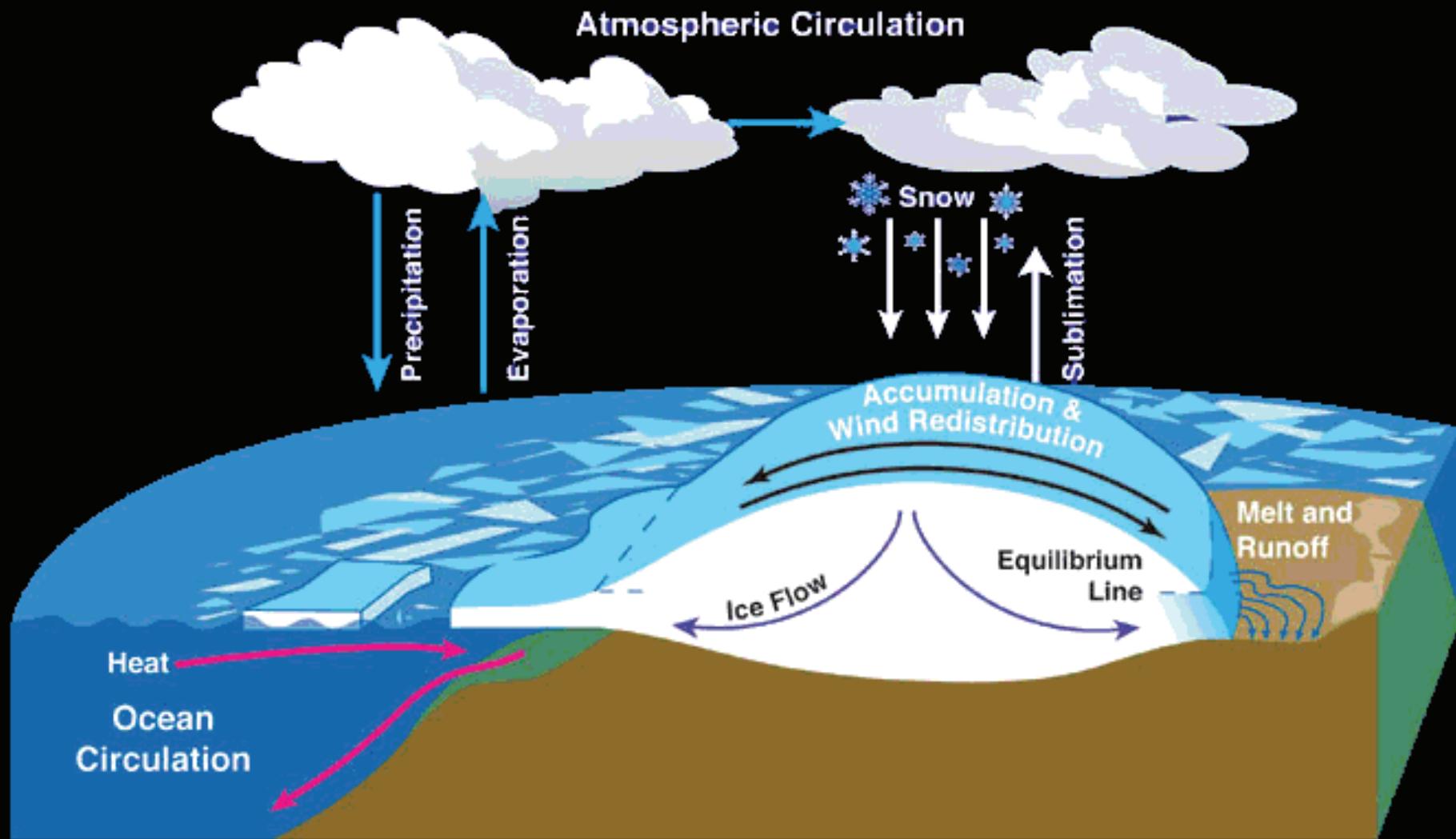


Greenland contains  
enough ice to raise  
sea levels by 7m

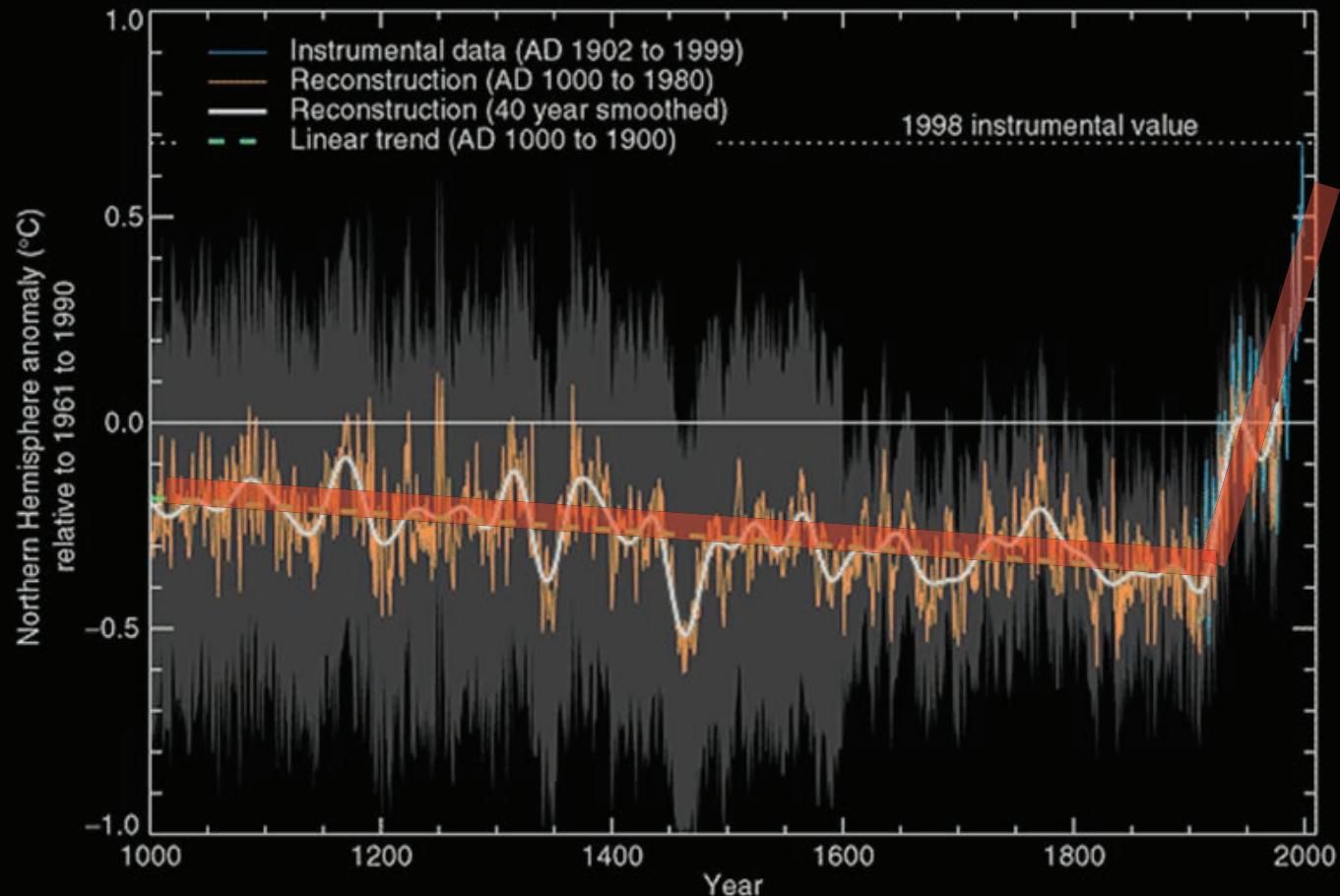


Antarctica contains  
enough ice to raise  
sea levels by 57m

# 1. Ice and Climate



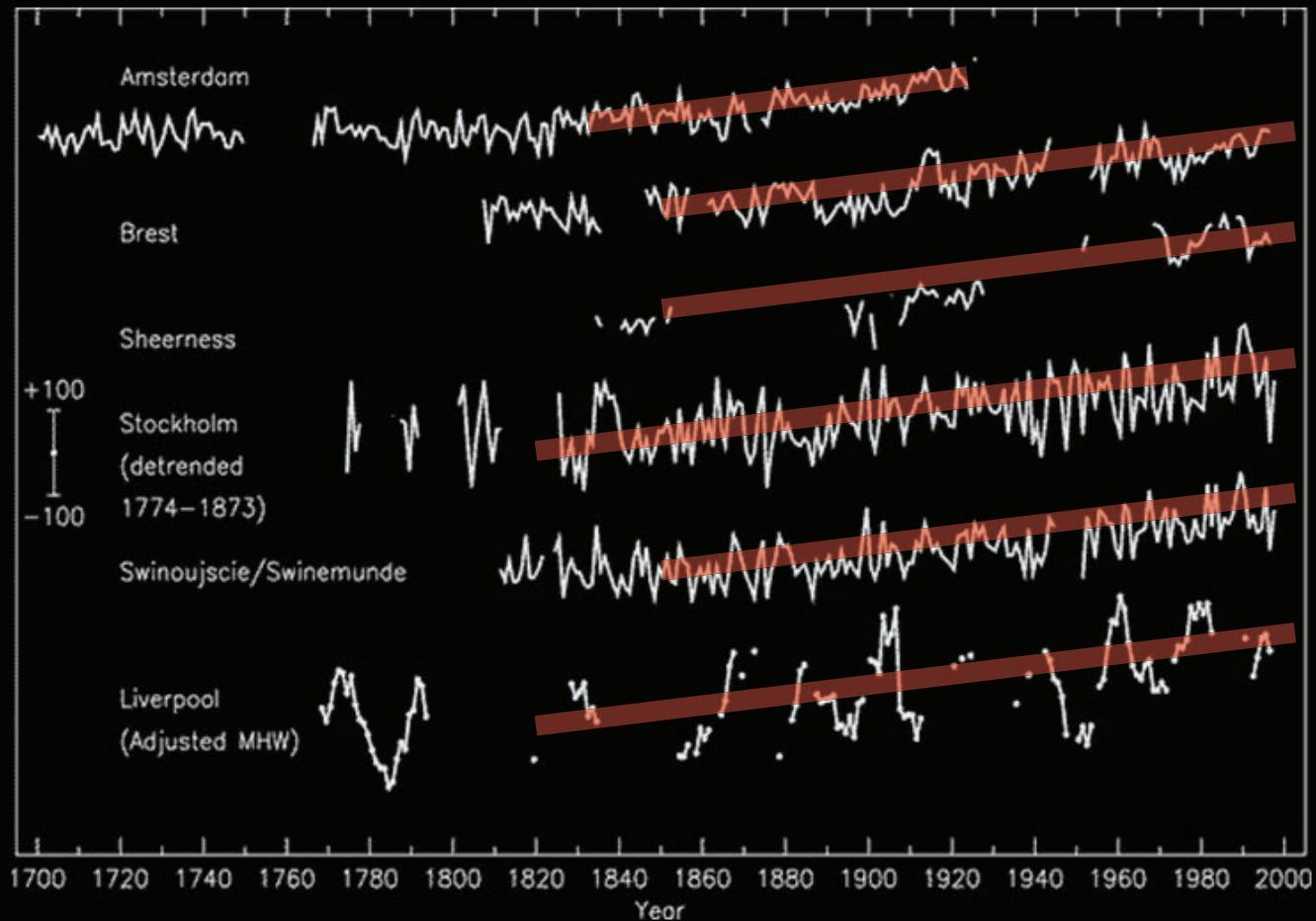
\* IPCC Assessment reports (1990, 1995, 2001, 2007, **2013**)



0.6 rise since 1900

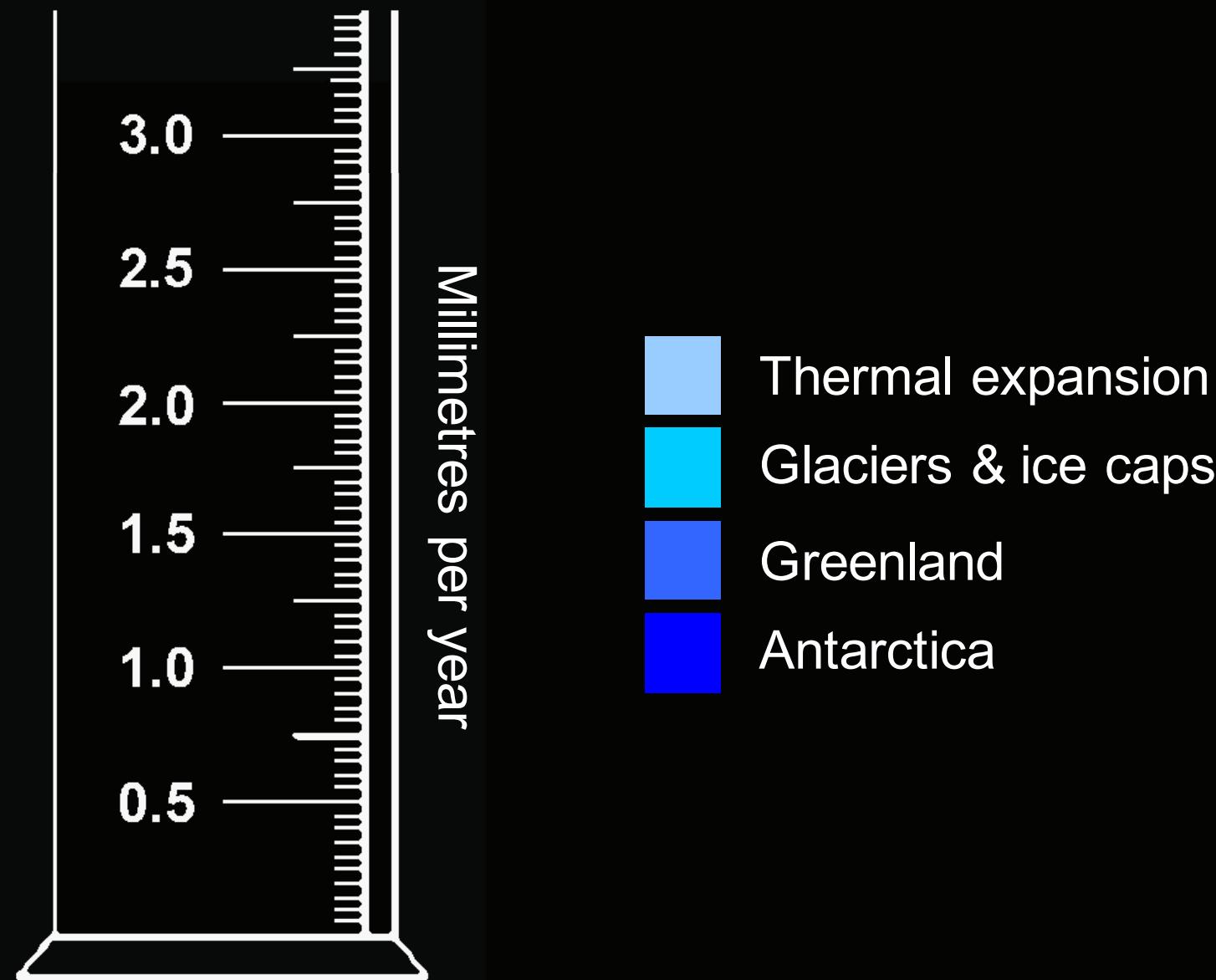
## 1. Ice and Climate

\* IPCC Assessment reports (1990, 1995, 2001, 2007, **2013**)



**15 cm rise since 1900**

## 1. Ice and Climate



## 1. Ice and Climate

- \* Slow climate change



Mt Kilimanjaro, 1993

## 1. Ice and Climate

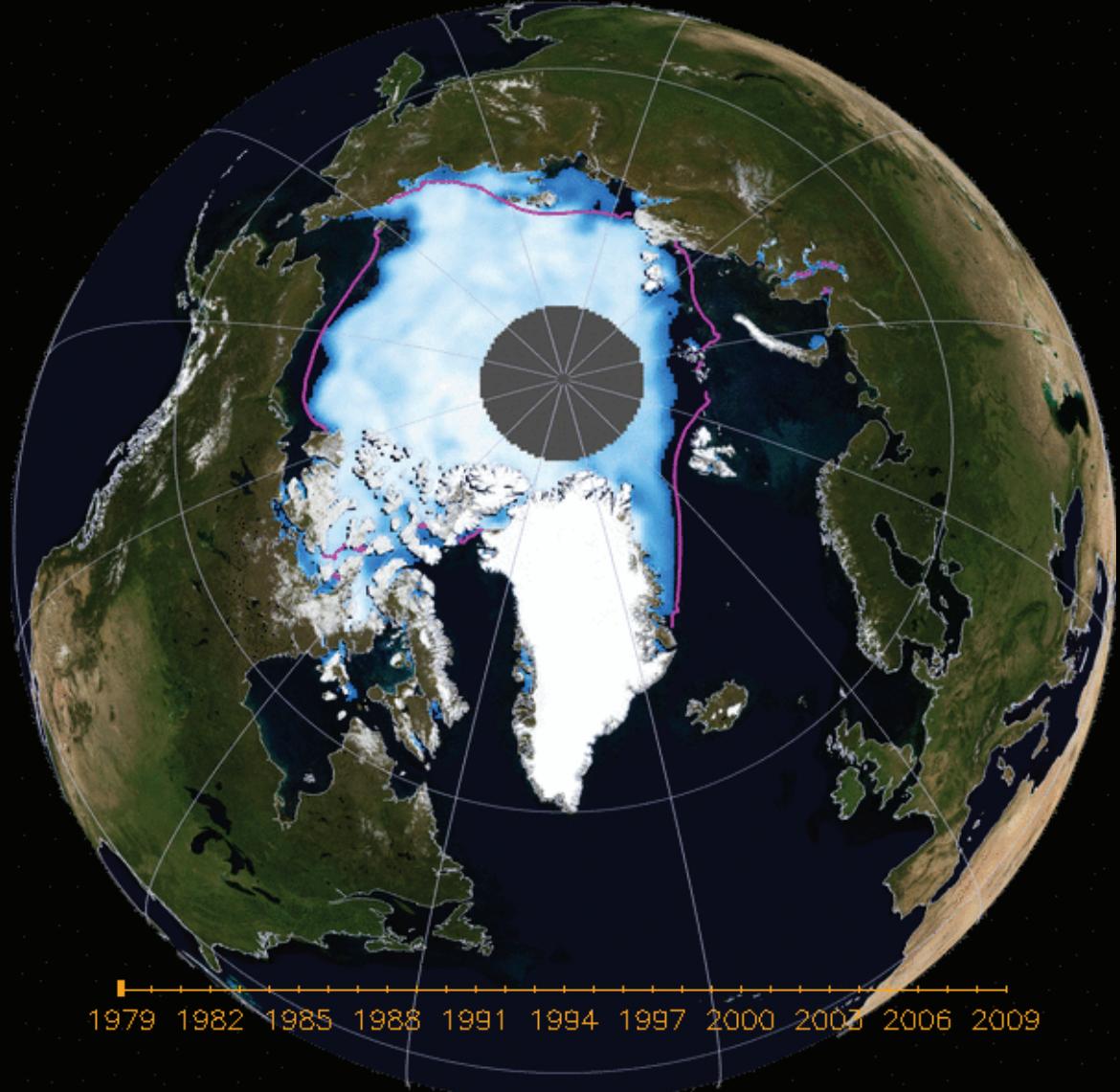
- \* Slow climate change



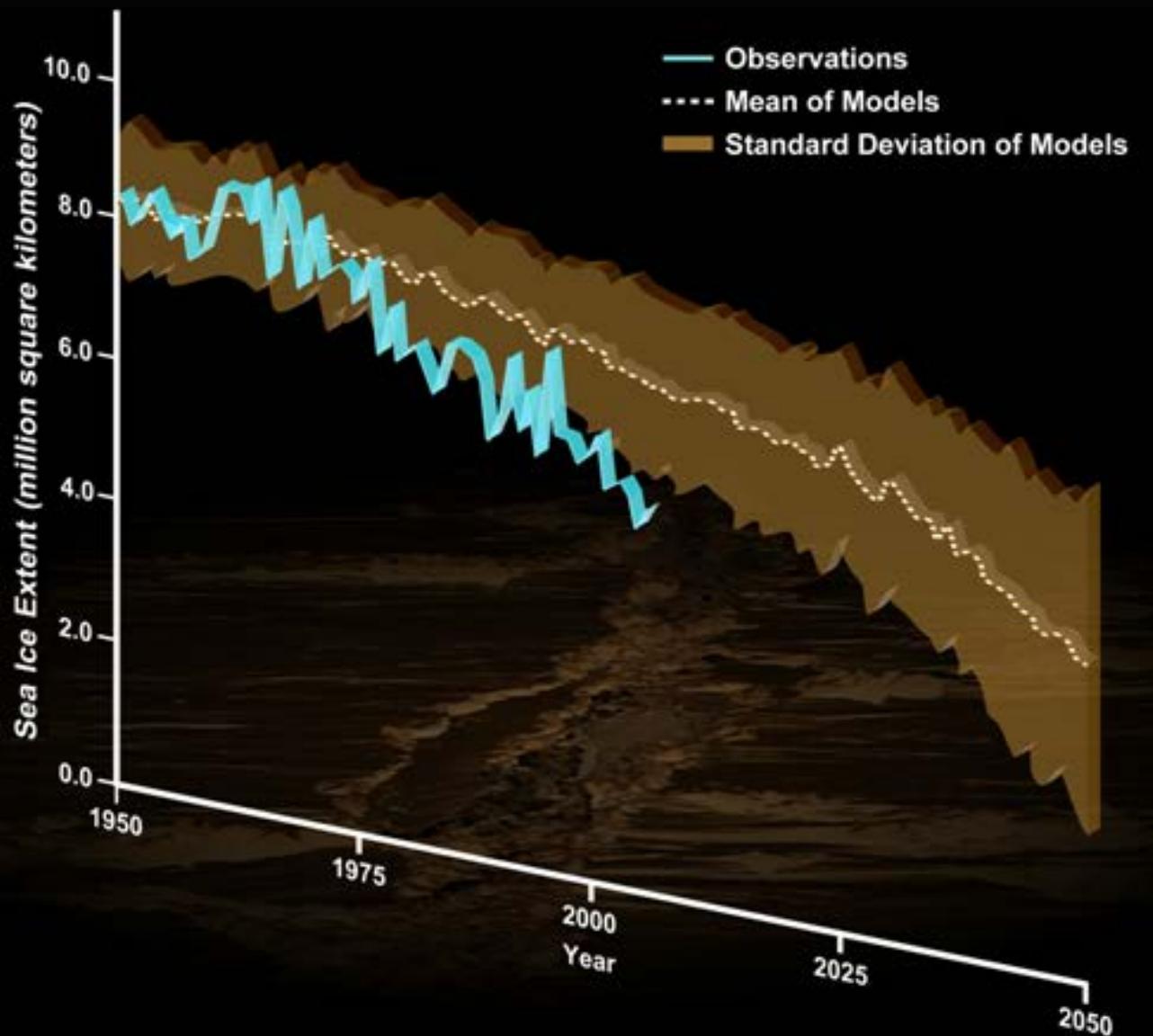
Mt Kilimanjaro, 2000

## 1. Ice and Climate

- ★ Rapid climate change



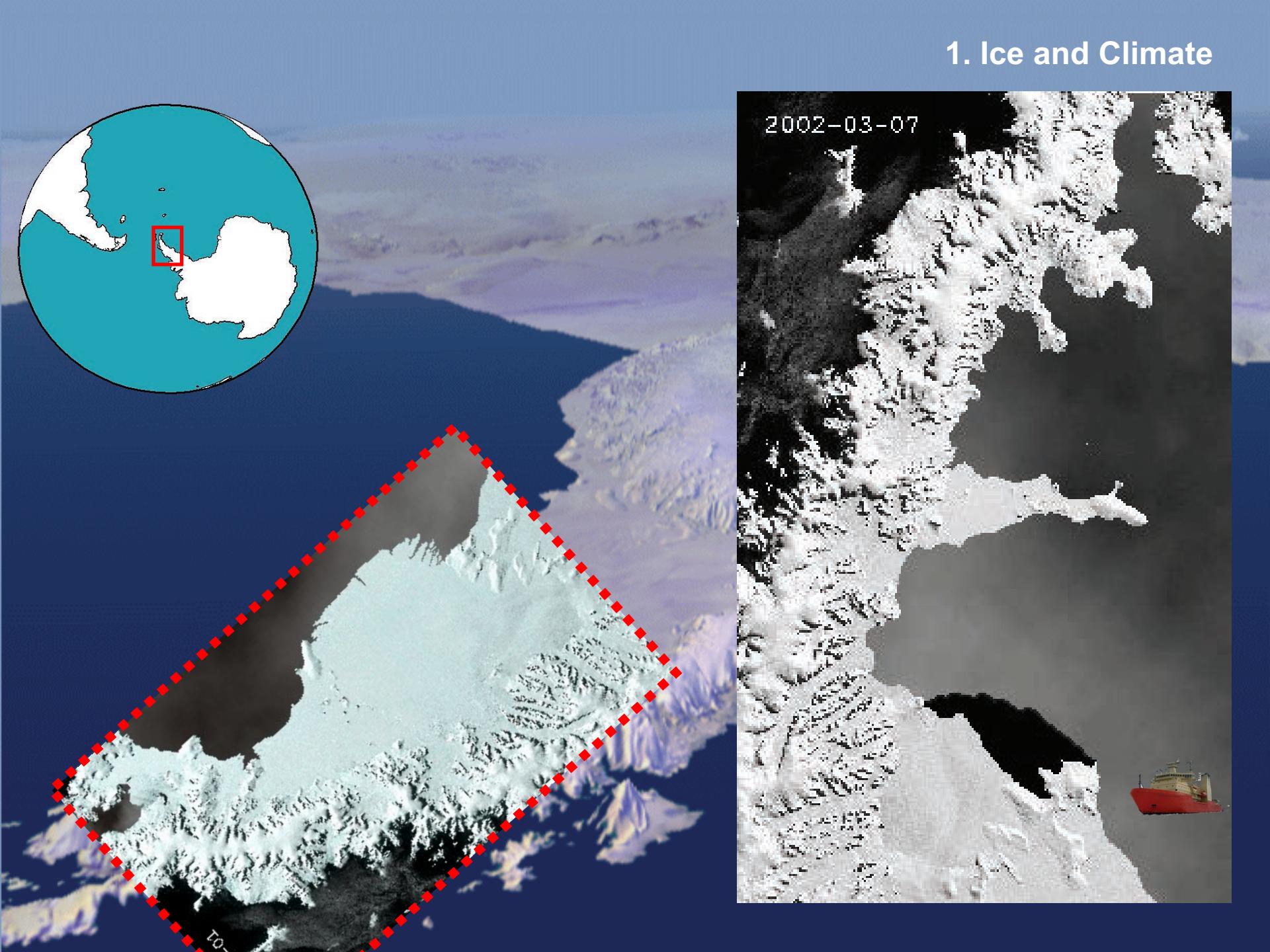
## \* Rapid climate change



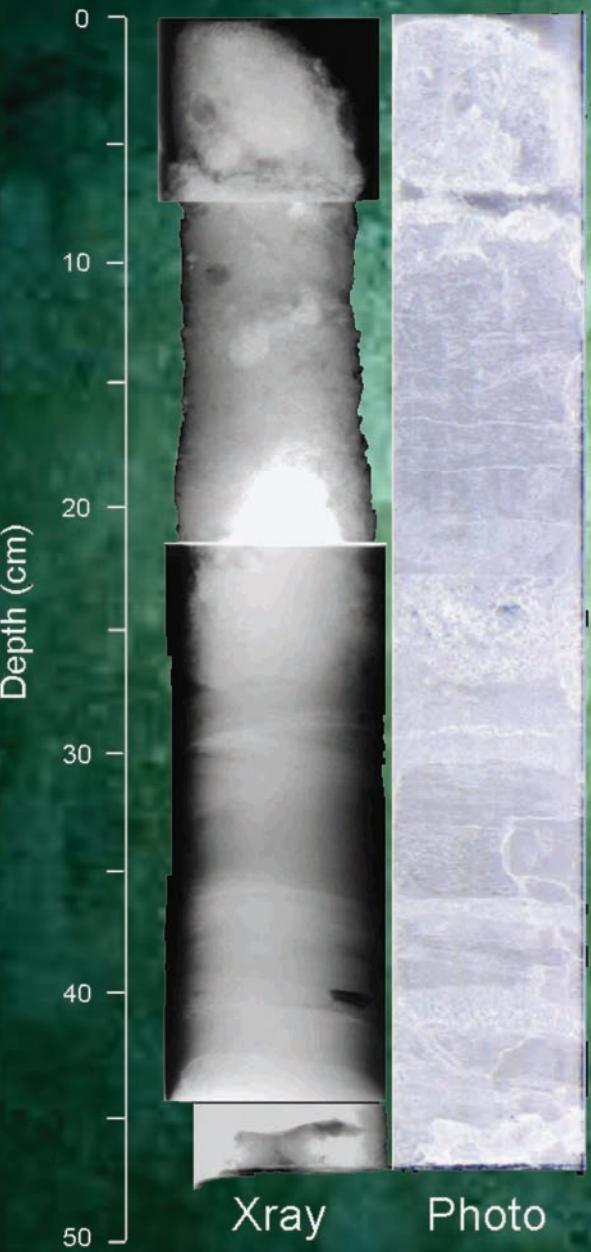
- ✳ Abrupt climate change



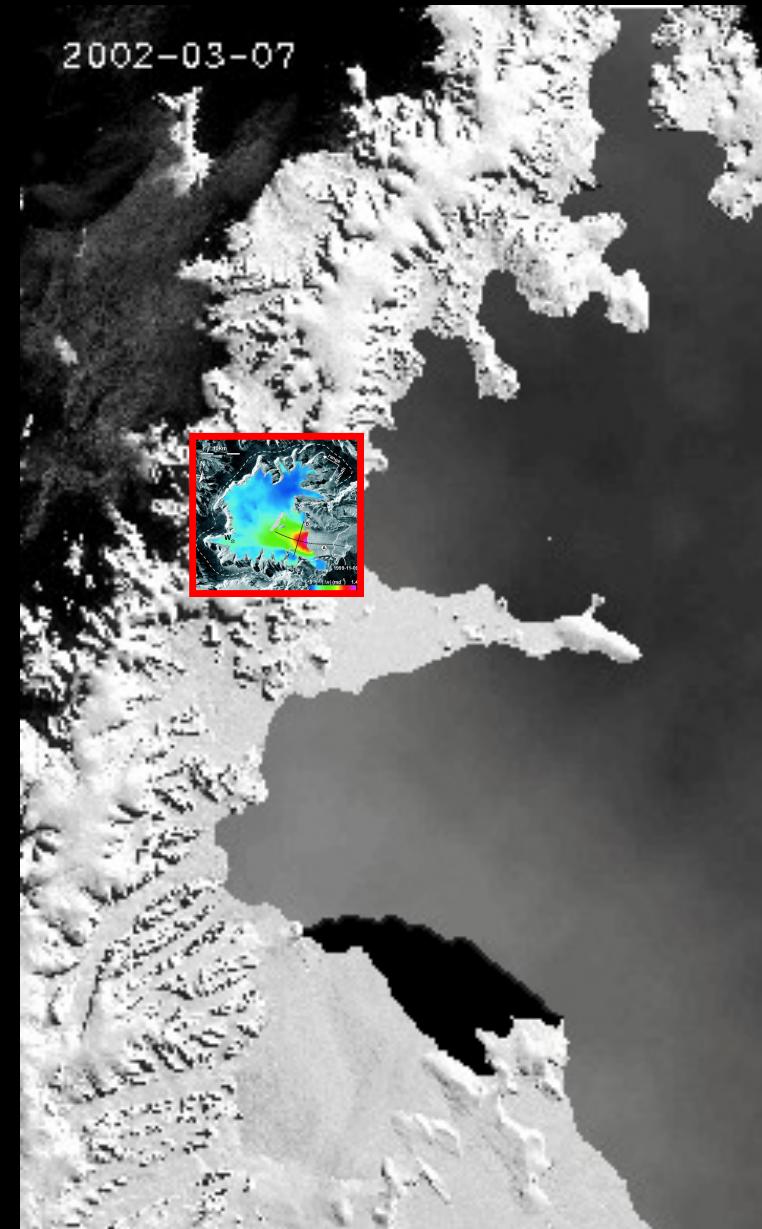
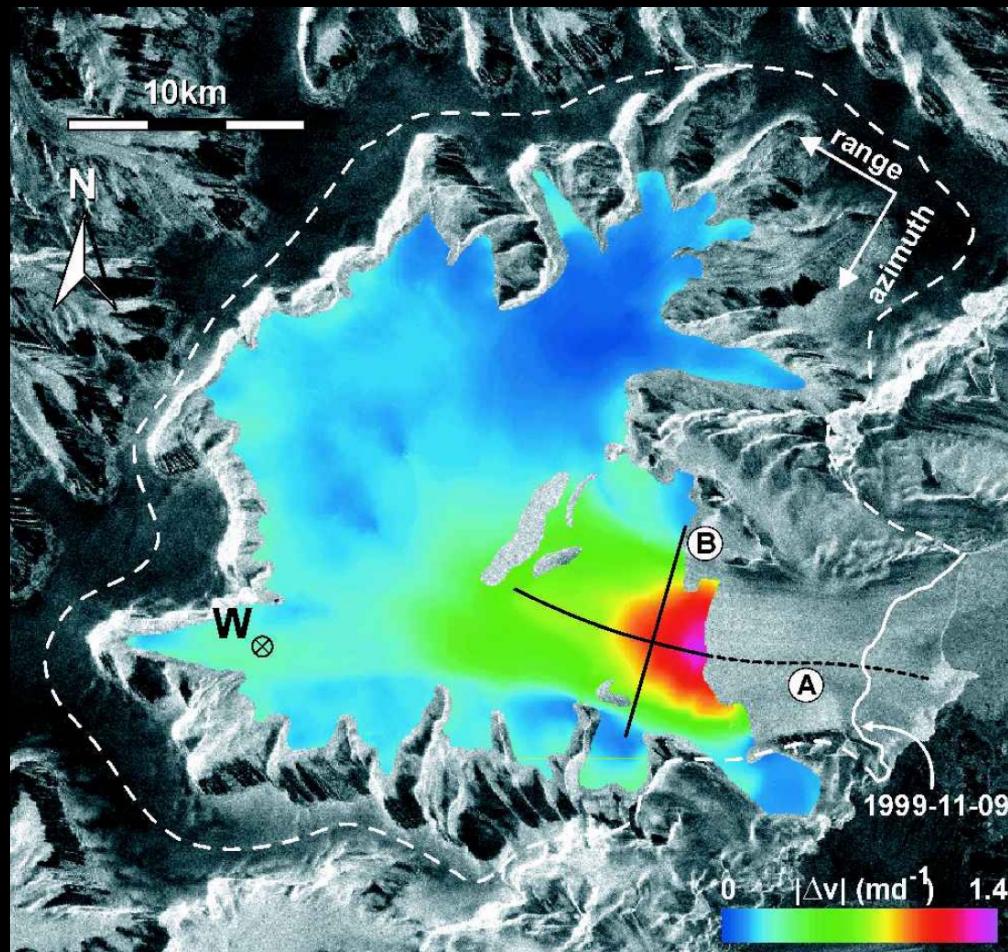
# 1. Ice and Climate



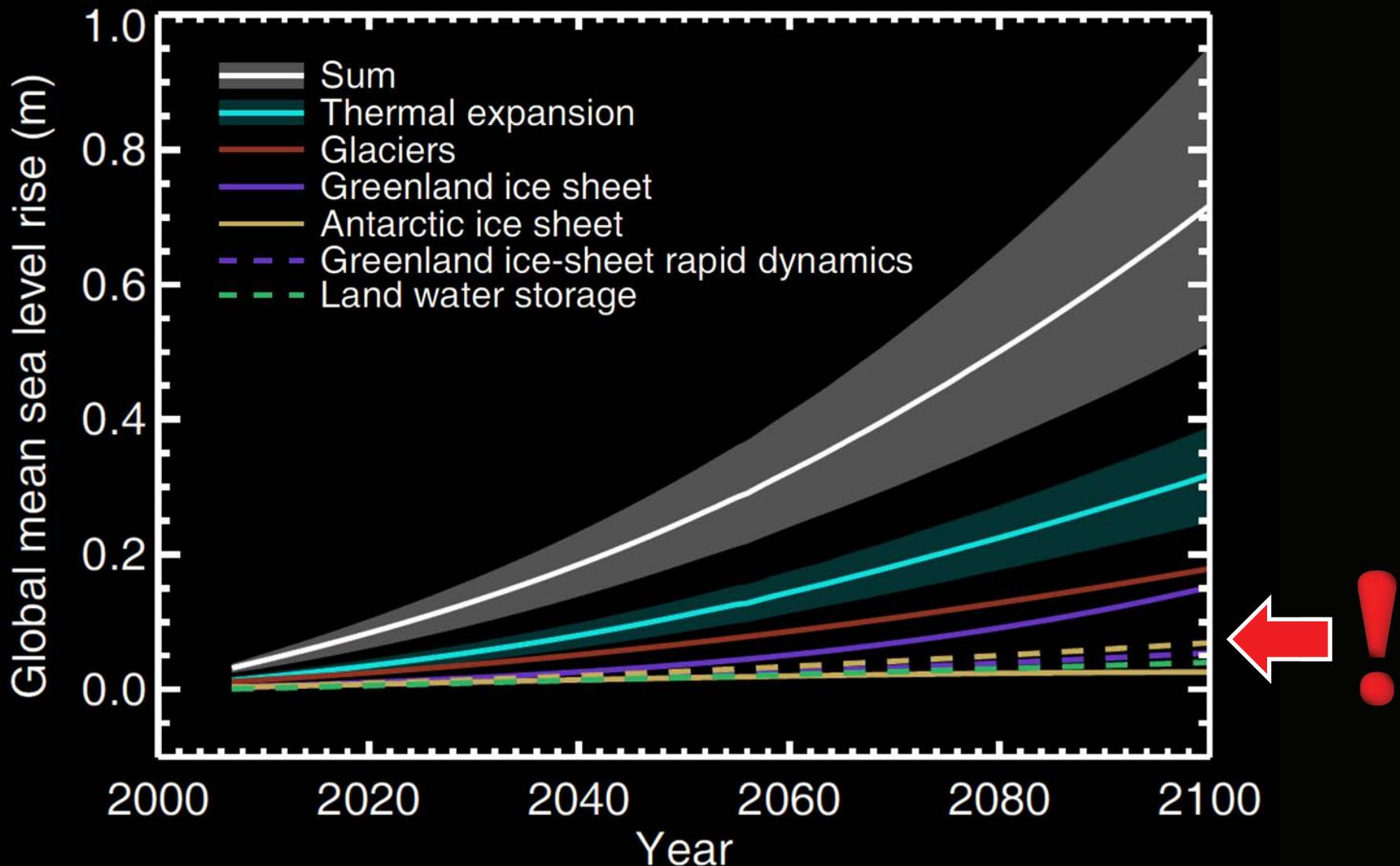
# 1. Ice and Climate



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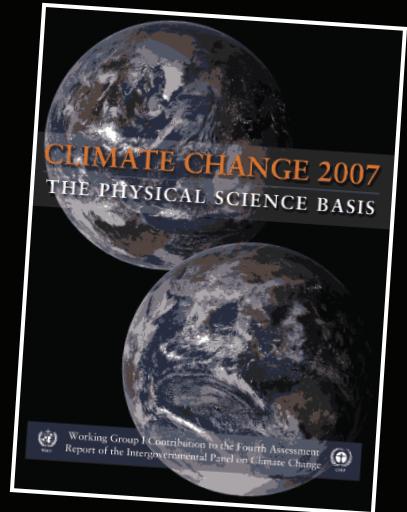


## 1. Ice and Climate



### AR4 (2007):

*“Models used to date do not include the full effects of changes in ice sheet flow, because a basis in published literature is lacking....”*

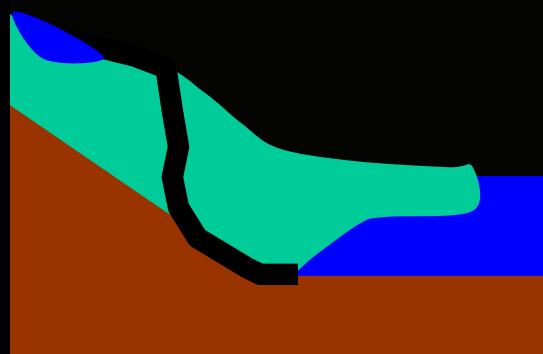


### AR5 (2013):

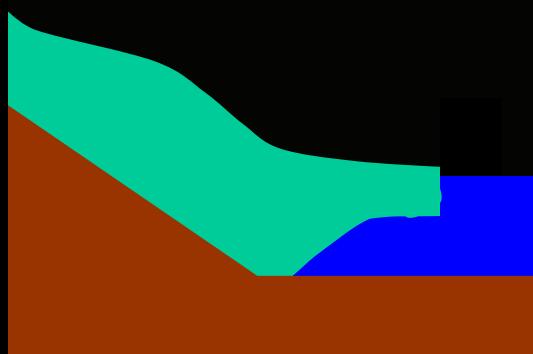
*“There has been substantial progress in ice-sheet modelling, particularly for Greenland.”*

*“Significant challenges remain in the process-based projection of the dynamic response of marine terminating glaciers and the Antarctic Ice Sheet.”*

# 1. Ice and Climate



Lubrication



Calving



Ocean Melting

## 1. Ice and Climate



86 m.a.s.l.



50 m.a.s.l.



35 m.a.s.l.

10 m.a.s.l.

# Outline

1. Why is ice an important part of Earth's climate?
2. Ice Sheet Altimetry
3. Ice Sheet Mass Balance
4. Sea Ice Altimetry



## 2. Ice Sheet Altimetry



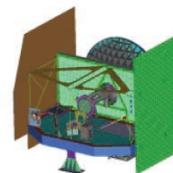
ERS1



ERS2



EnviSAT



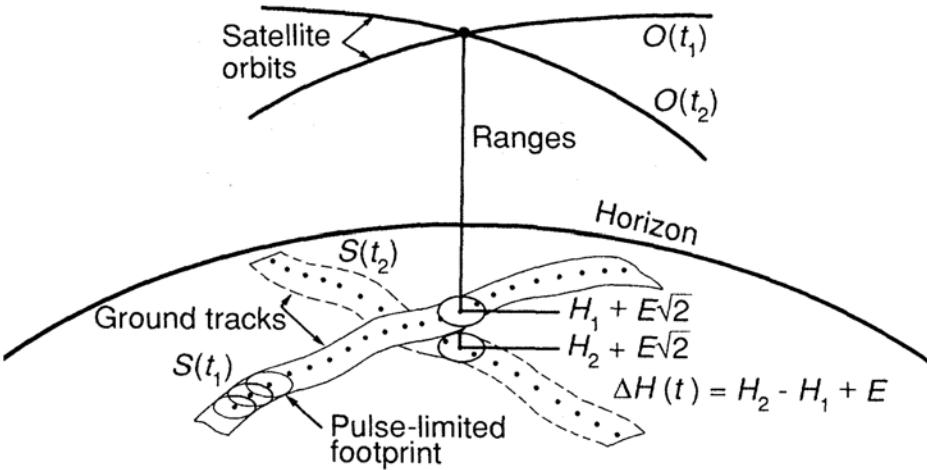
ICESat



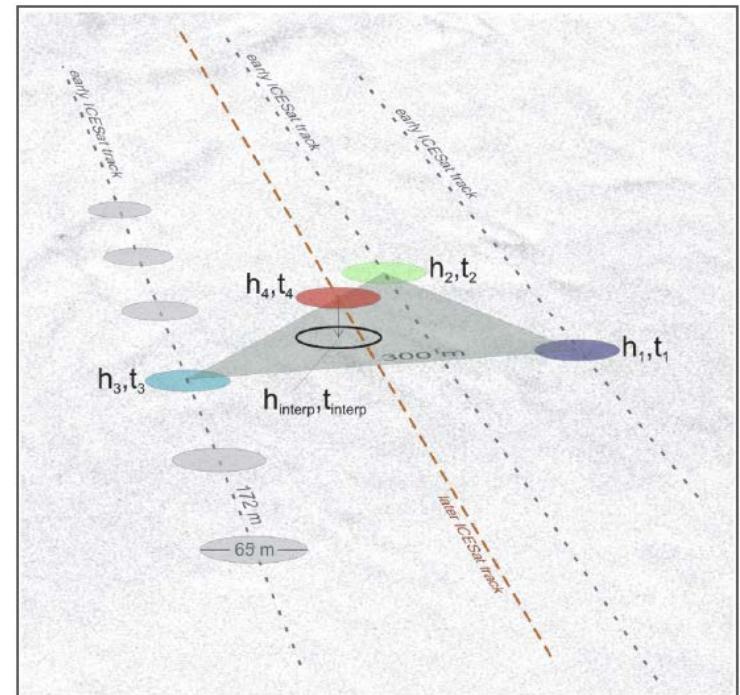
CryoSat-2



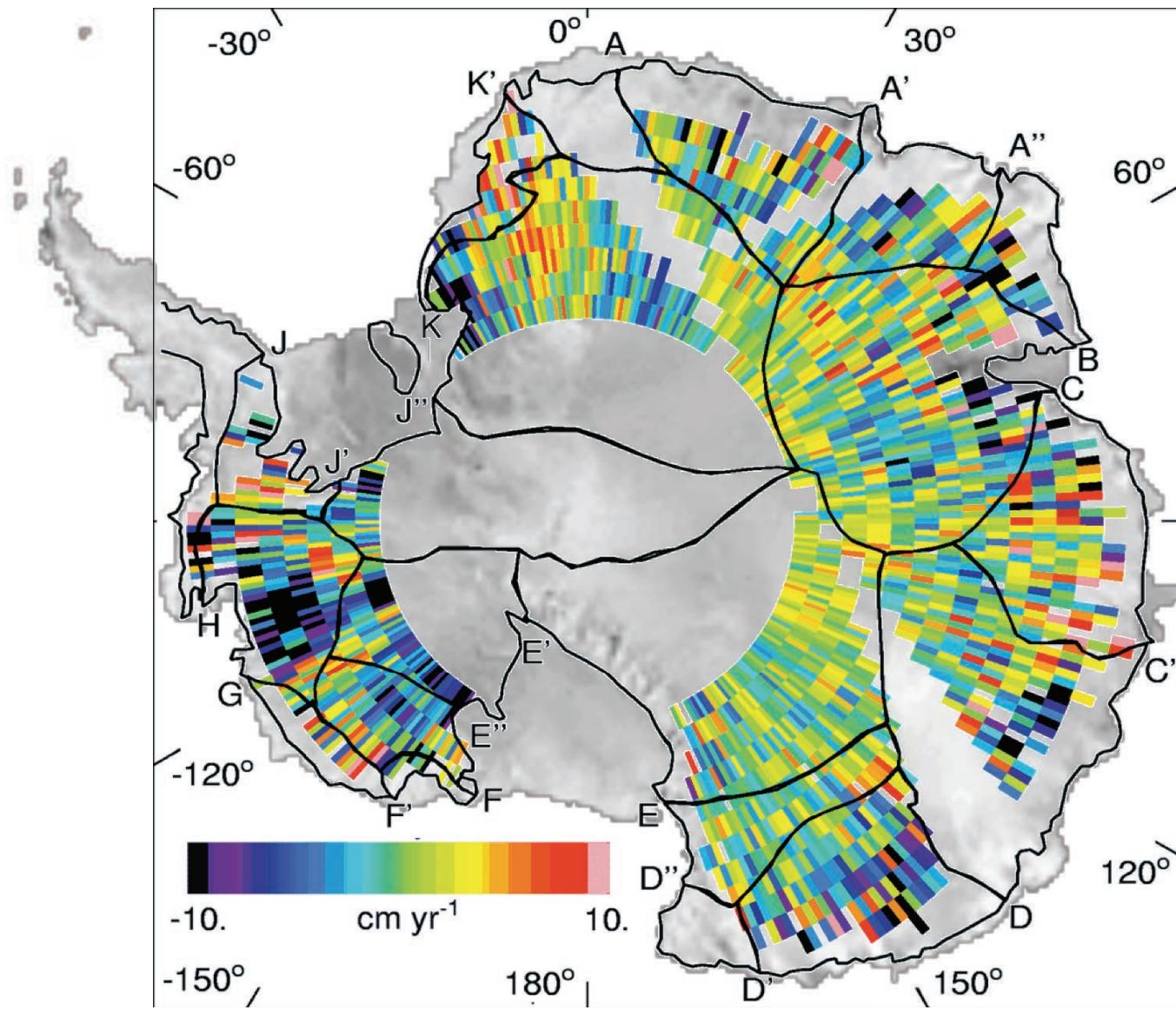
### Crossovers



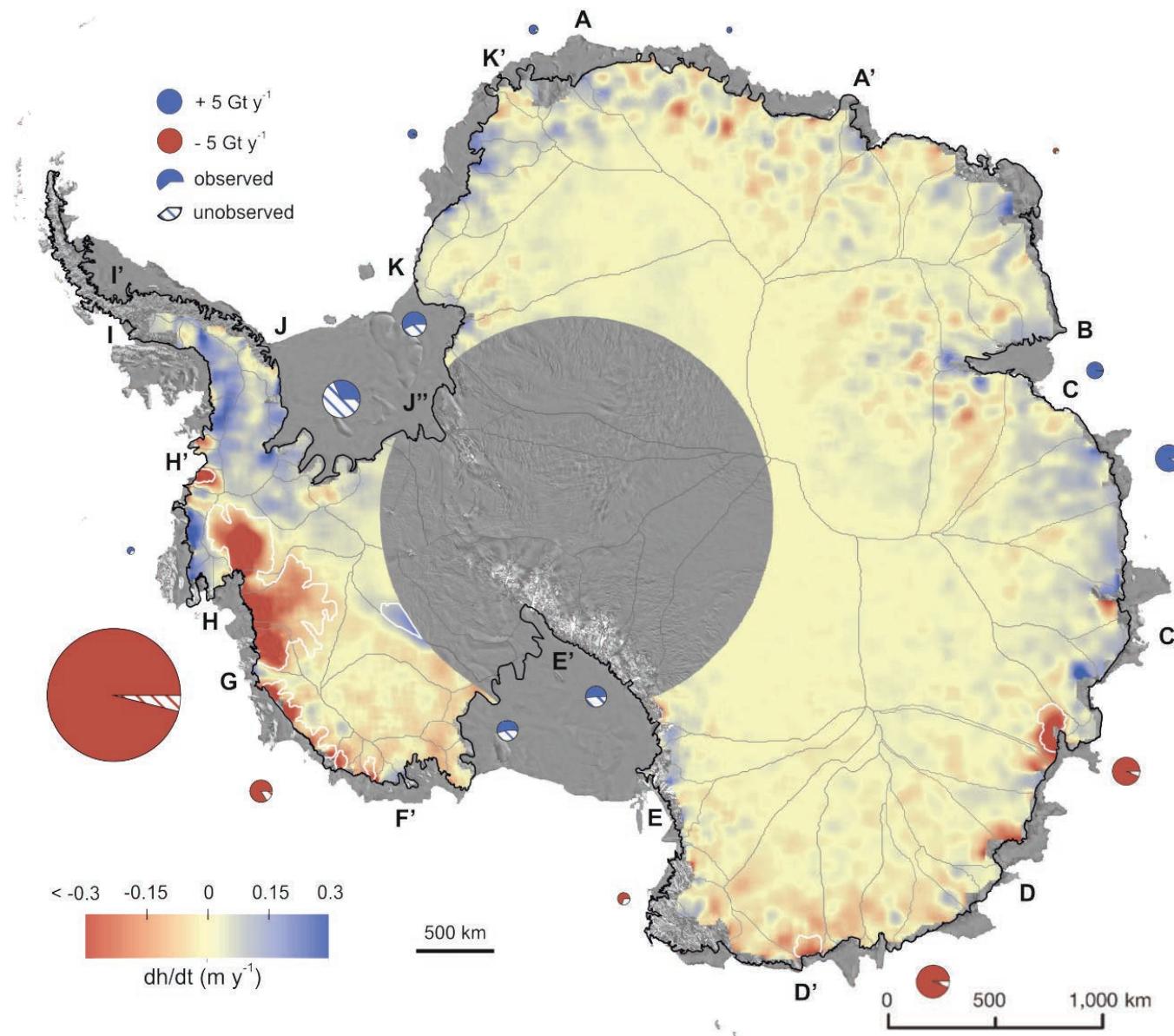
### Plane fit



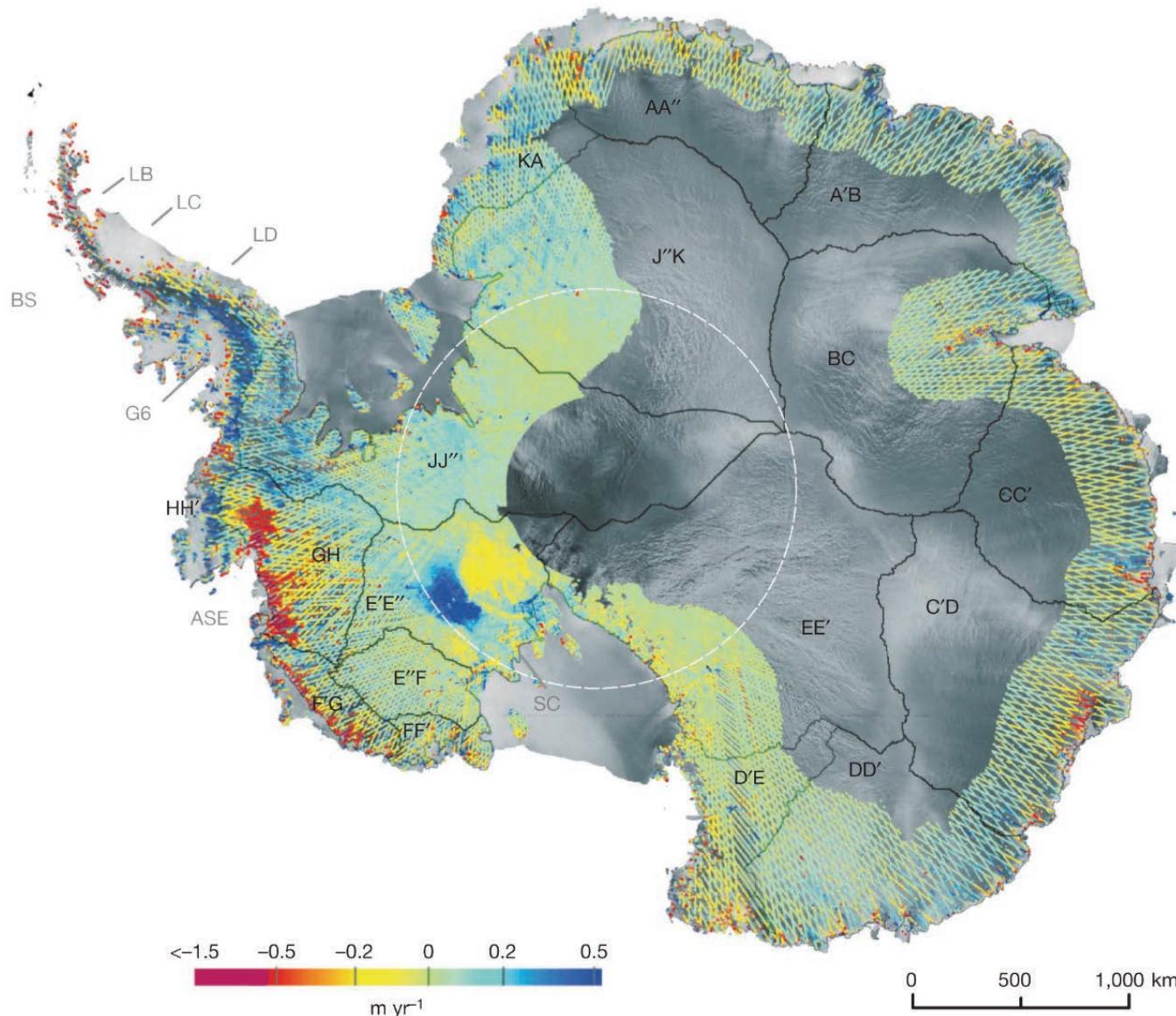
## 2. Ice Sheet Altimetry



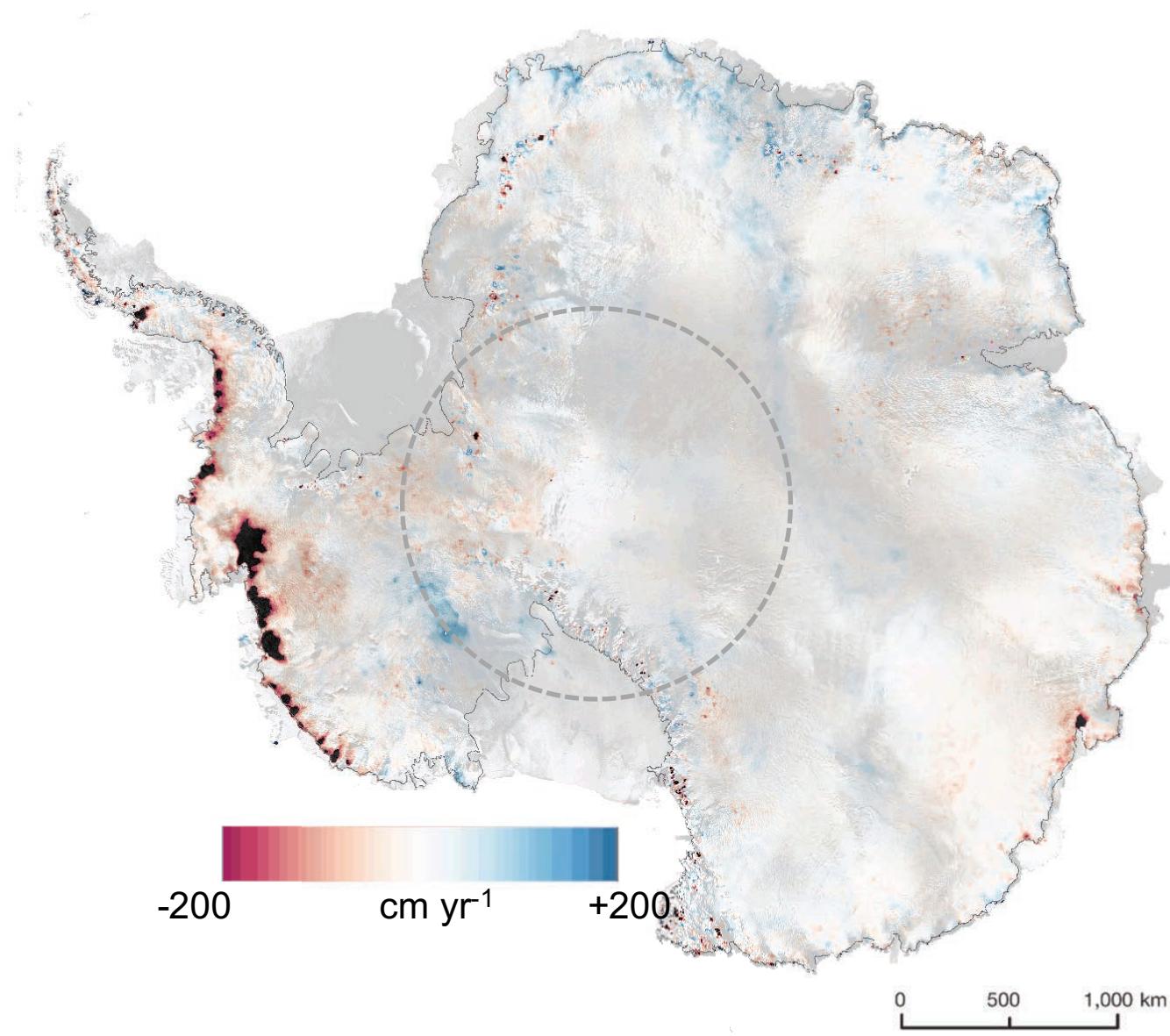
## 2. Ice Sheet Altimetry



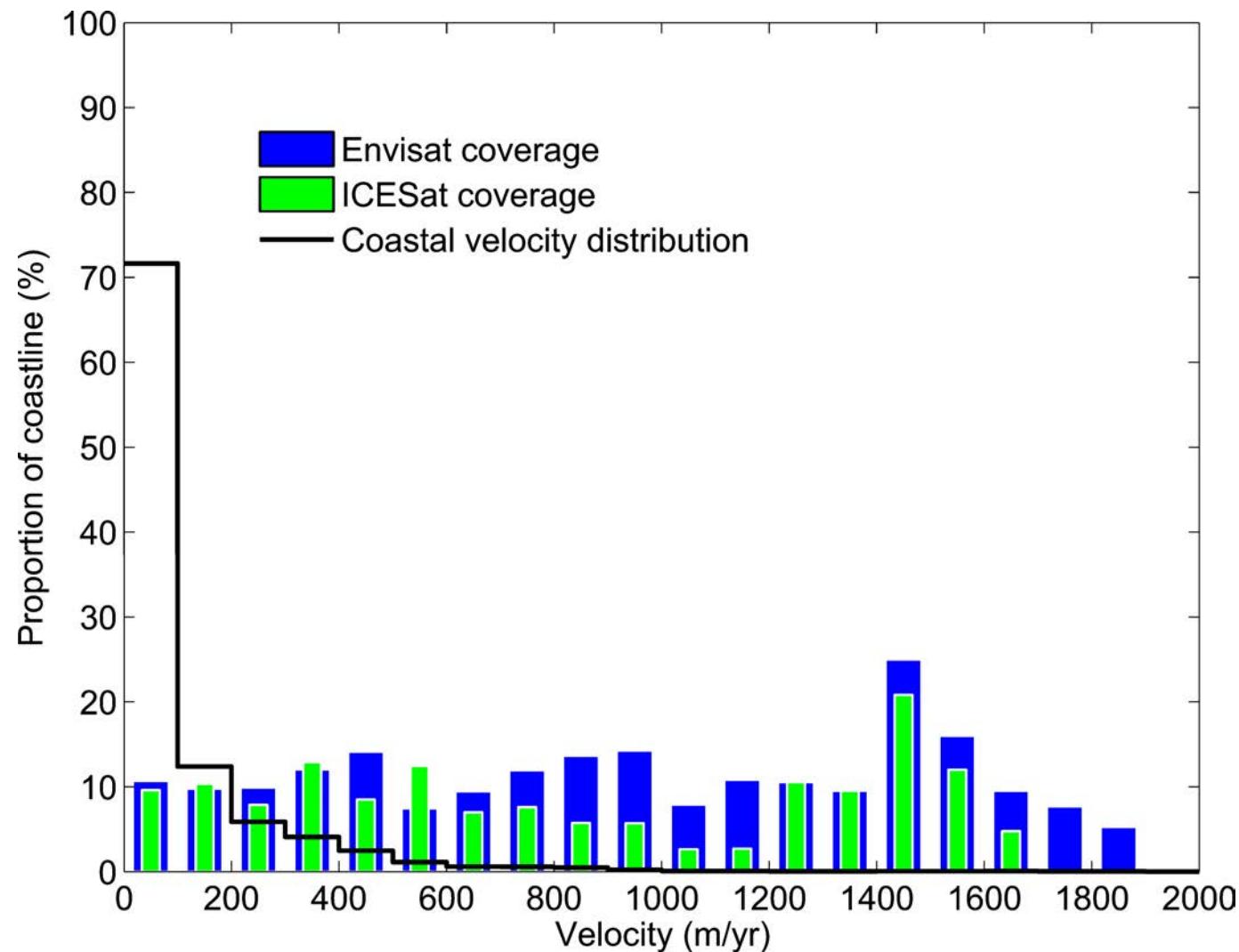
## 2. Ice Sheet Altimetry



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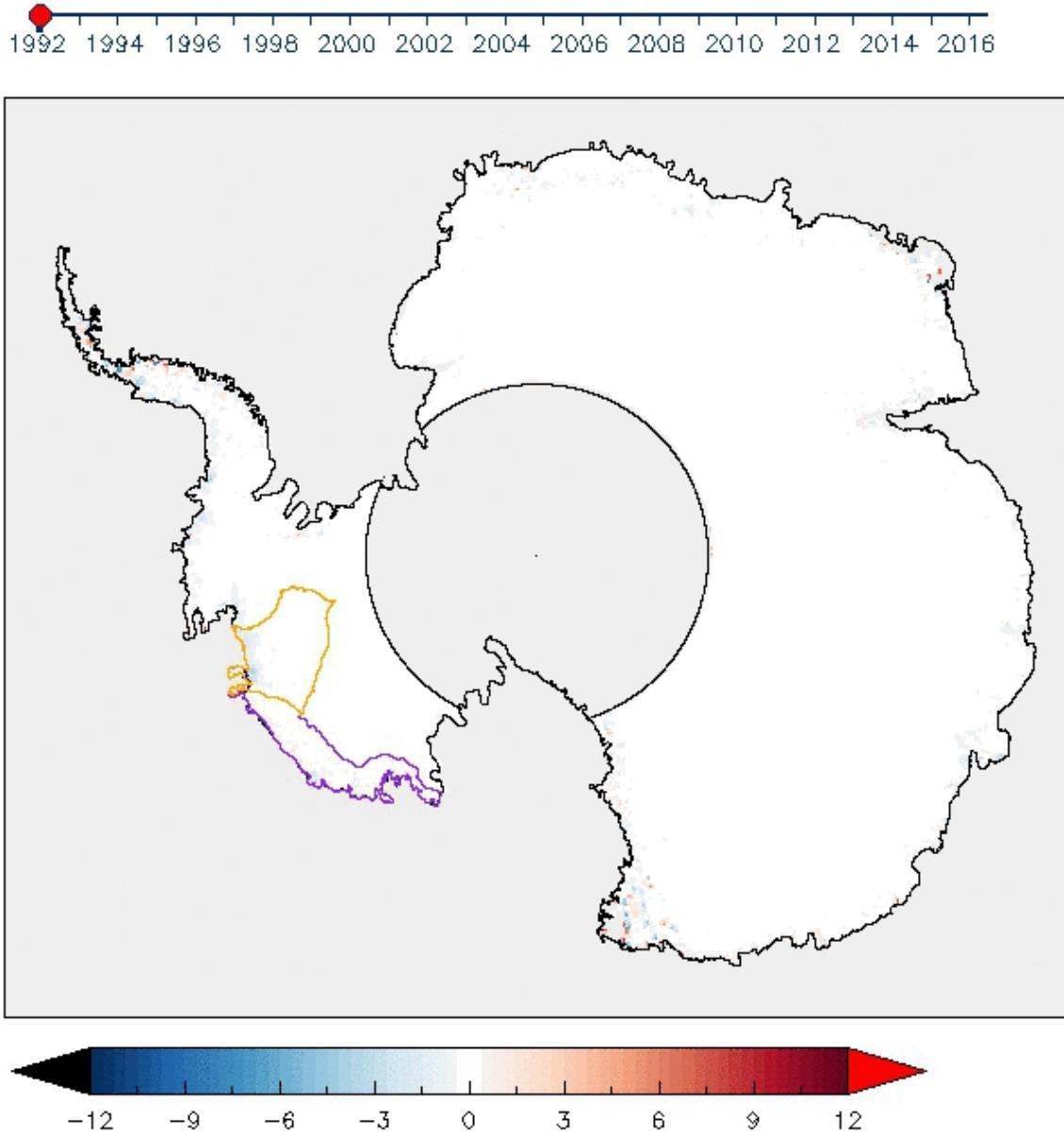


## 2. Ice Sheet Altimetry



Elevation Change (m) 1992 to 2015

## 2. Ice Sheet Altimetry



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### 3. Ice Sheet Mass Balance

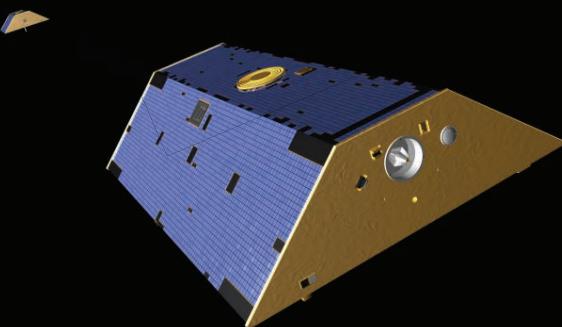
**Altimetry** measures changes in ice sheet shape



**Mass budget** differences ice discharge and accumulation

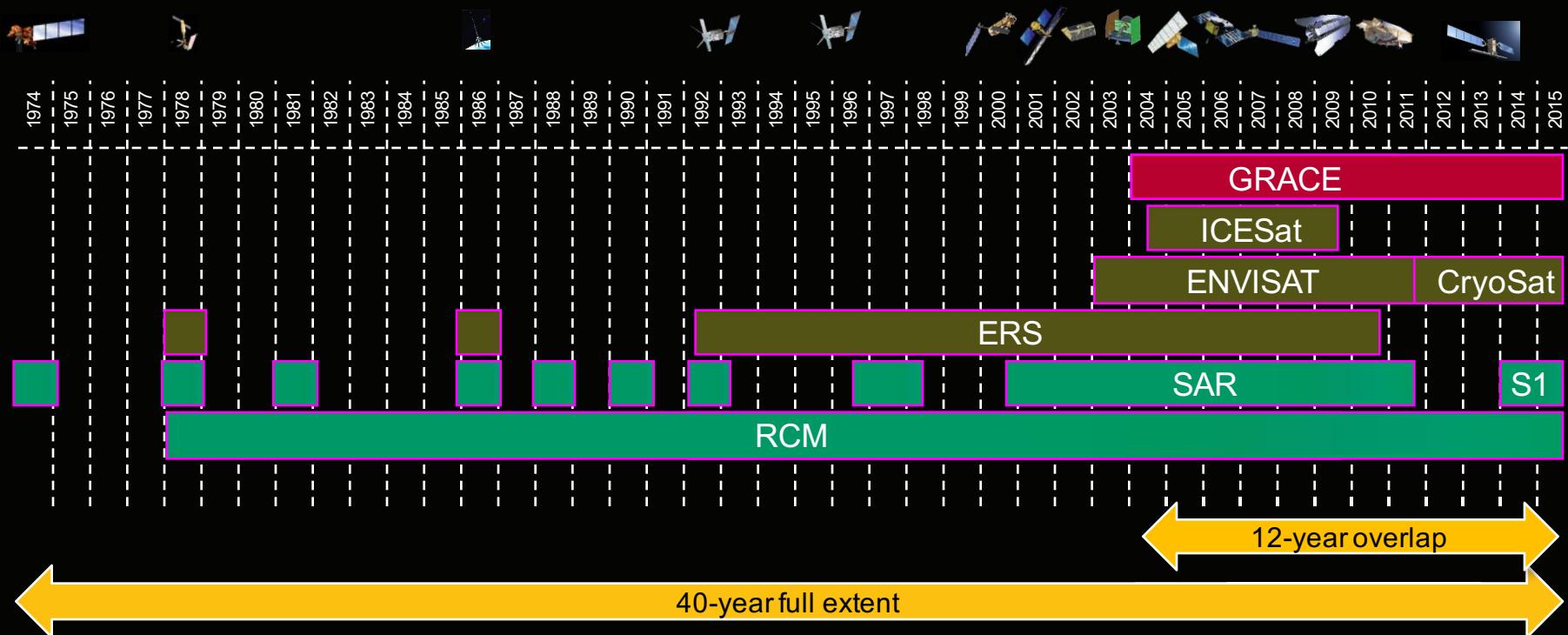


**Gravimetry** measures changes in ice sheet weight

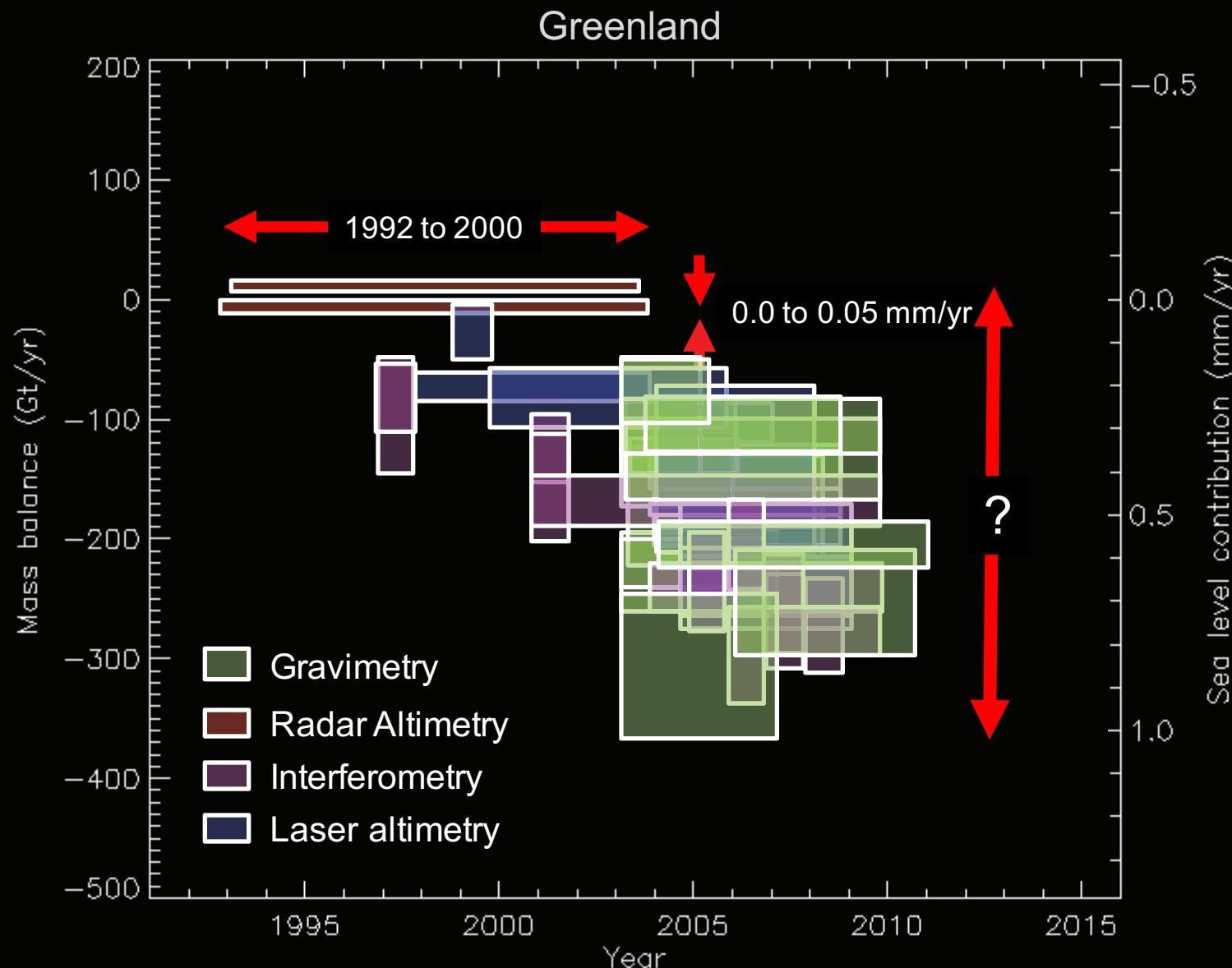


### 3. Ice Sheet Mass Balance

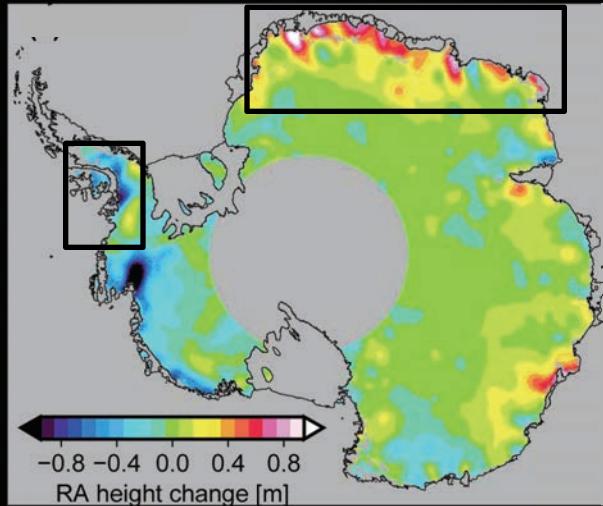
- \* 15+ satellite missions, 80+years of data



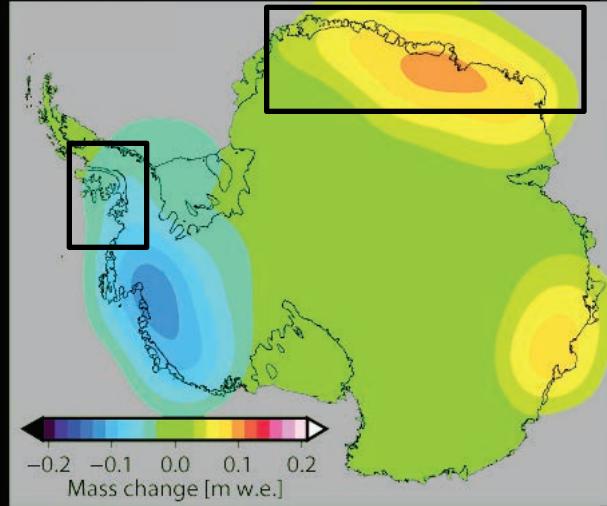
### 3. Ice Sheet Mass Balance



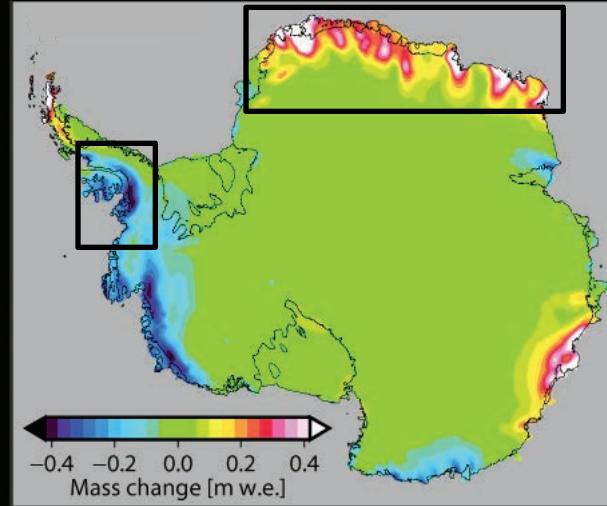
Altimetry



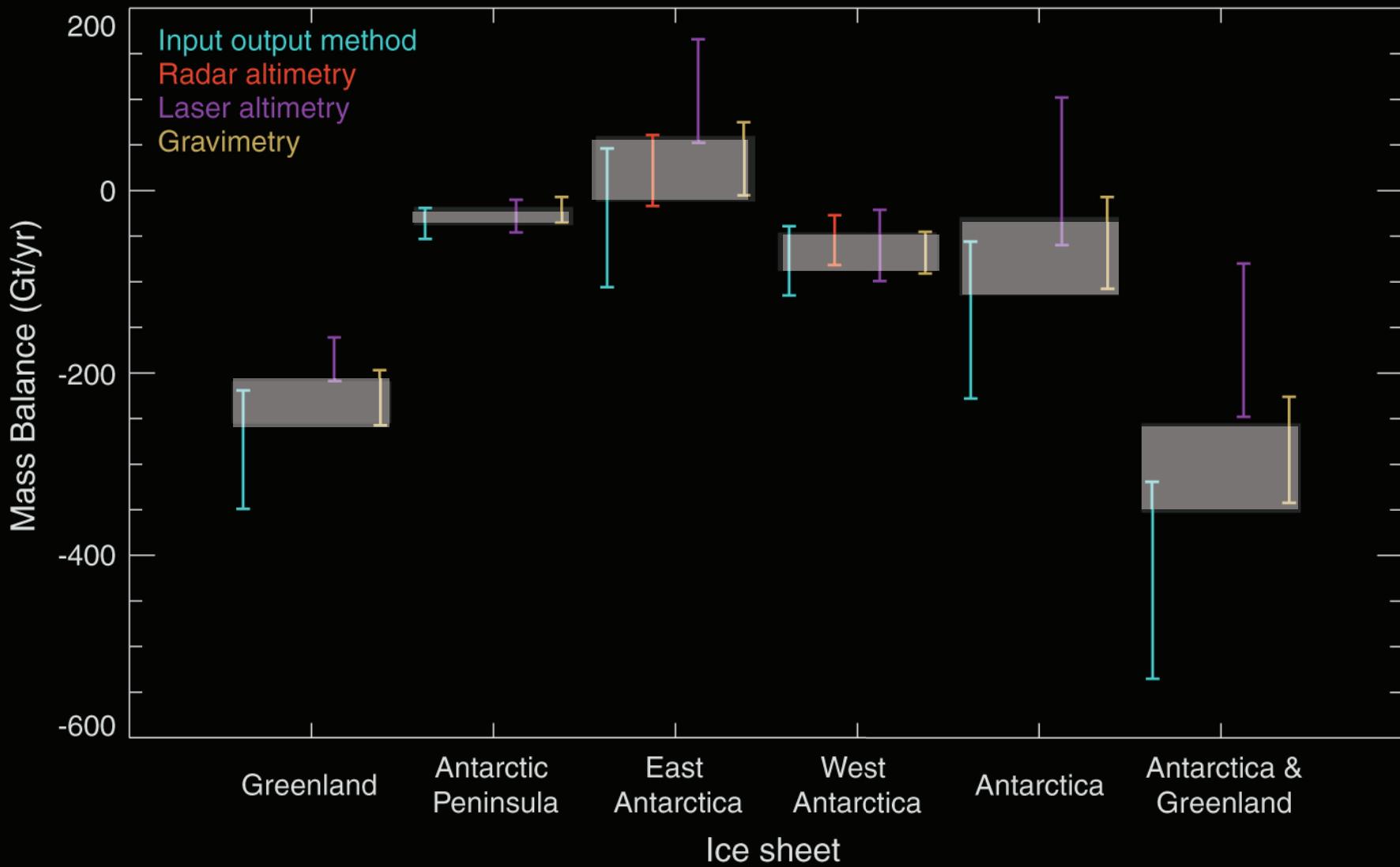
Gravimetry



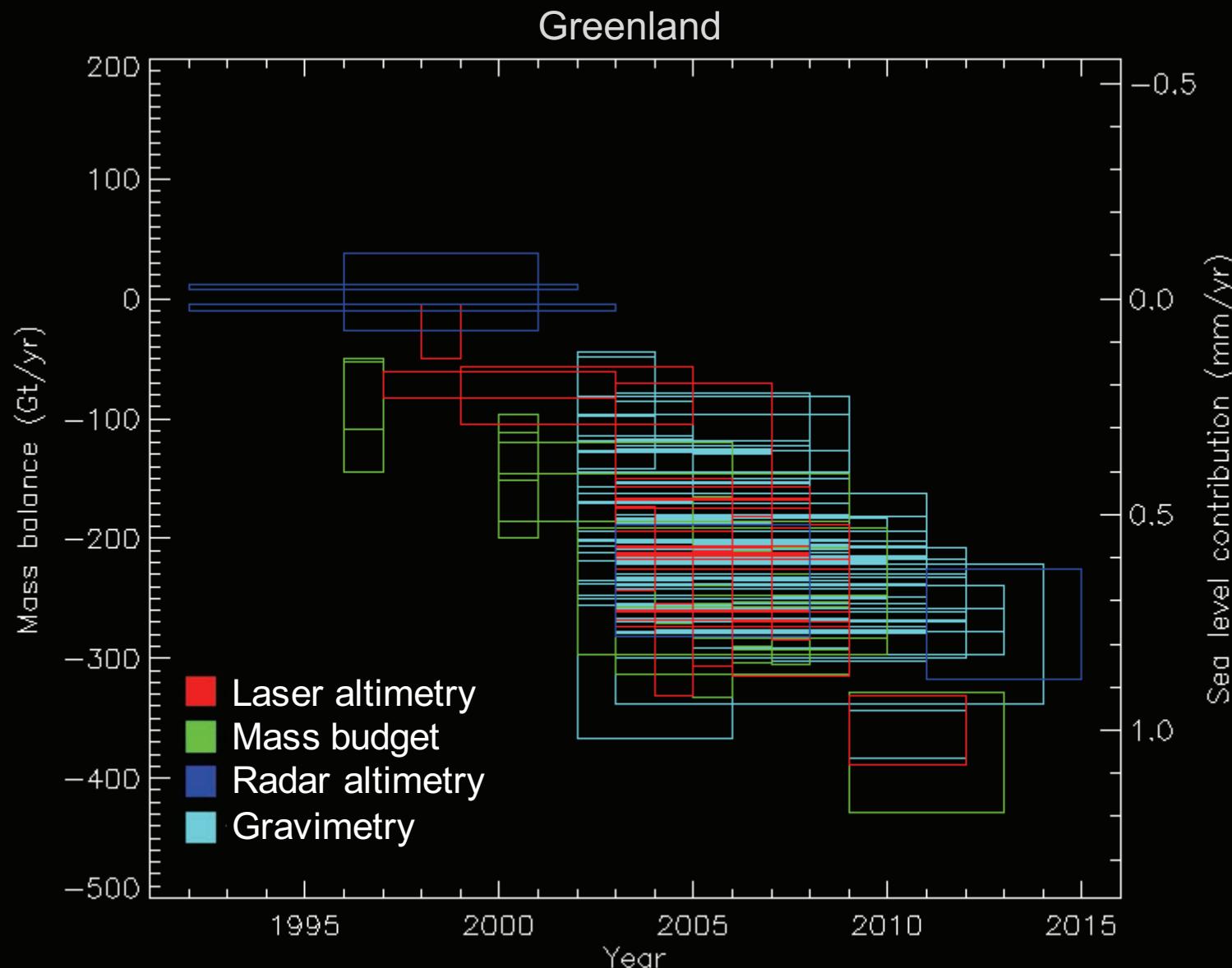
Surface mass balance



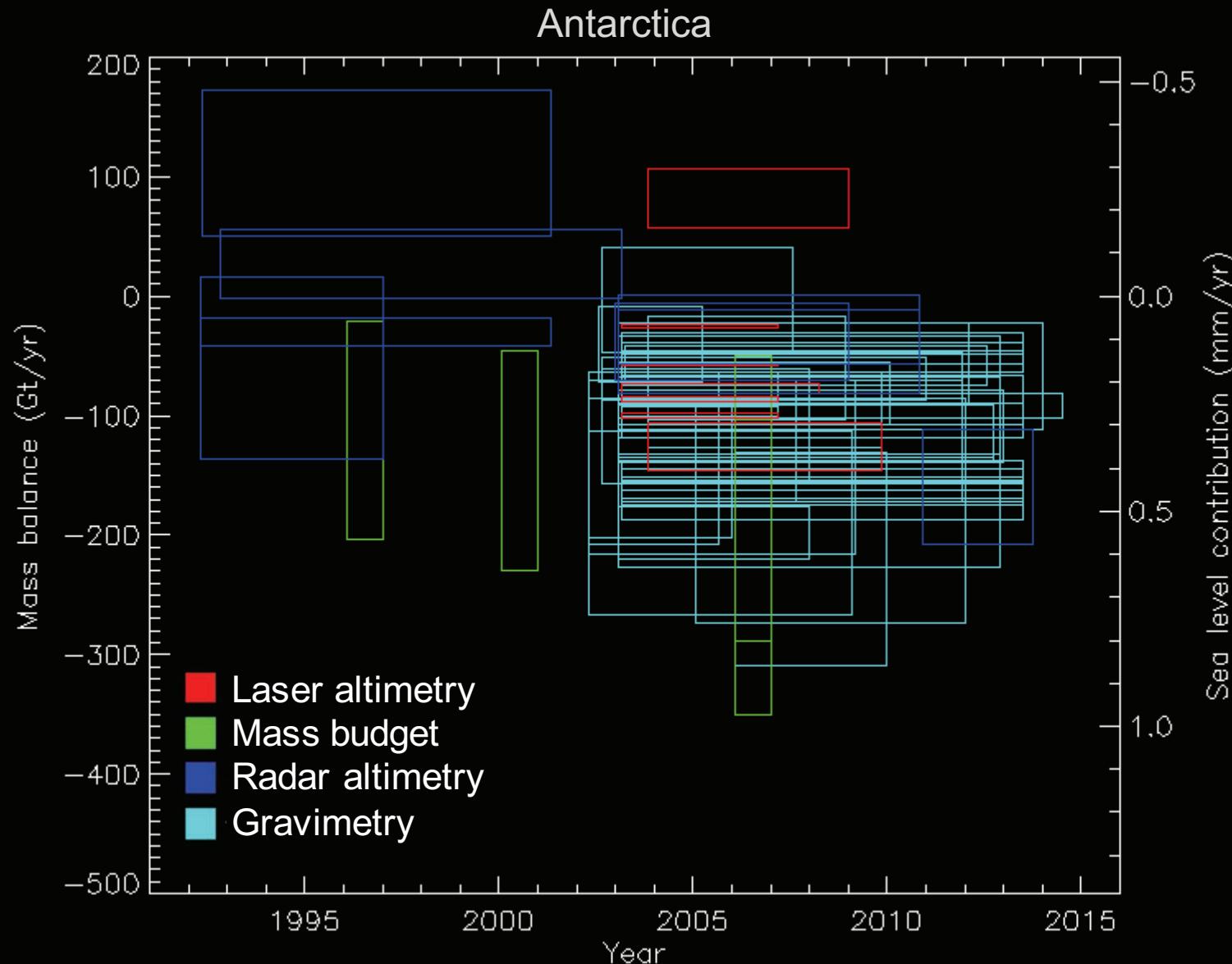
### 3. Ice Sheet Mass Balance



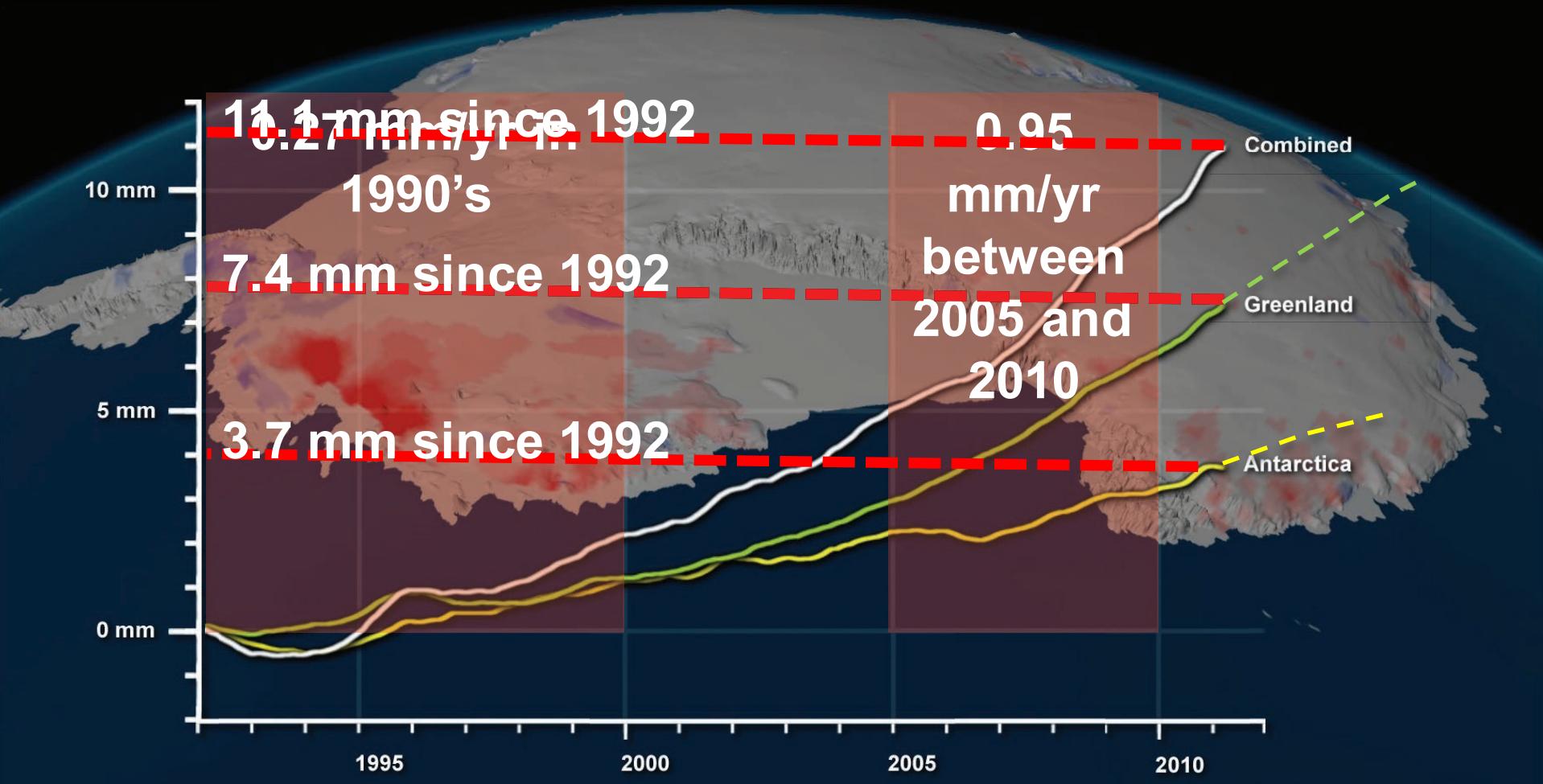
### 3. Ice Sheet Mass Balance



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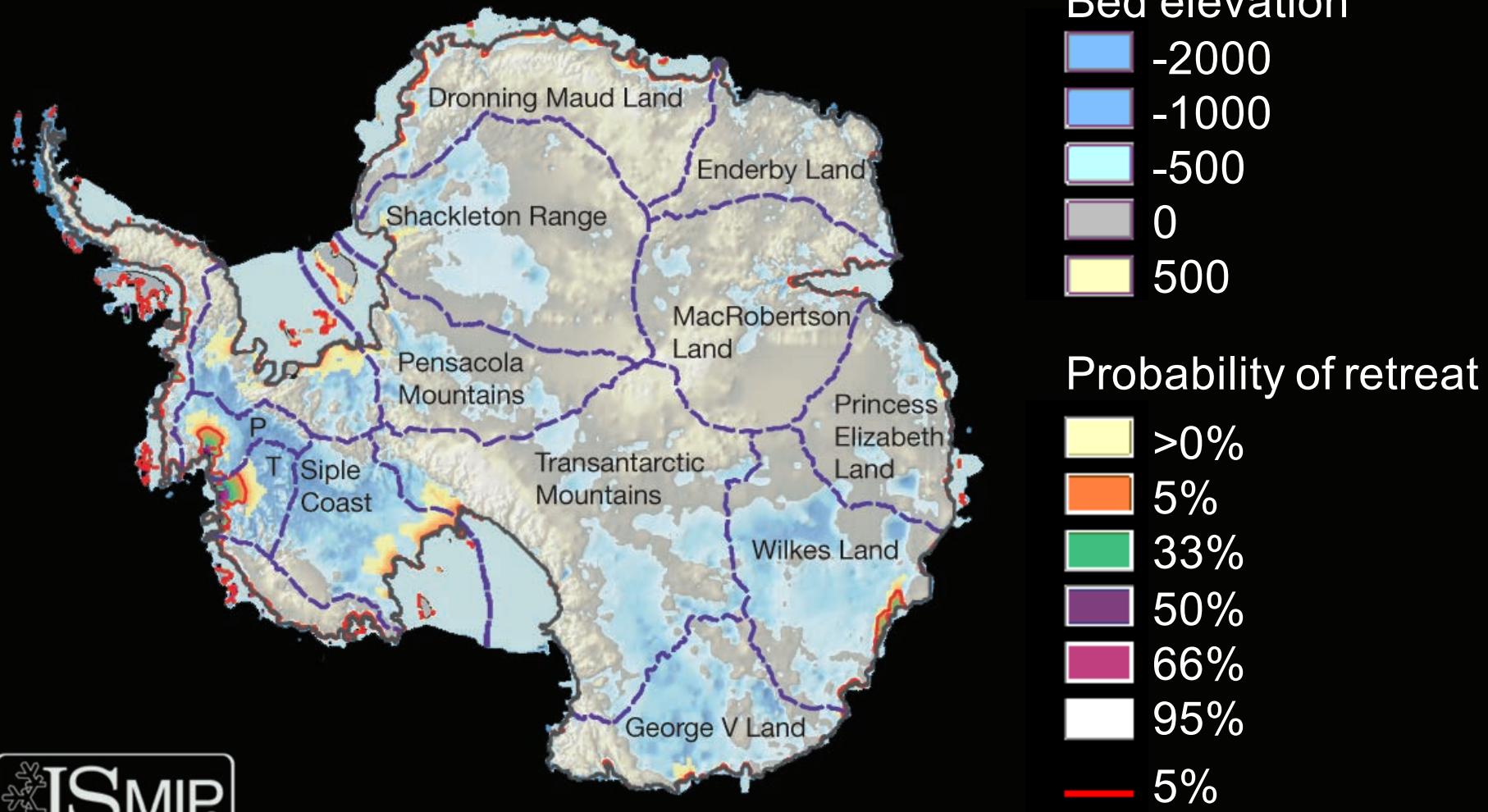


### 3. Ice Sheet Mass Balance



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Simulated Antarctic ice sheet retreat by 2100

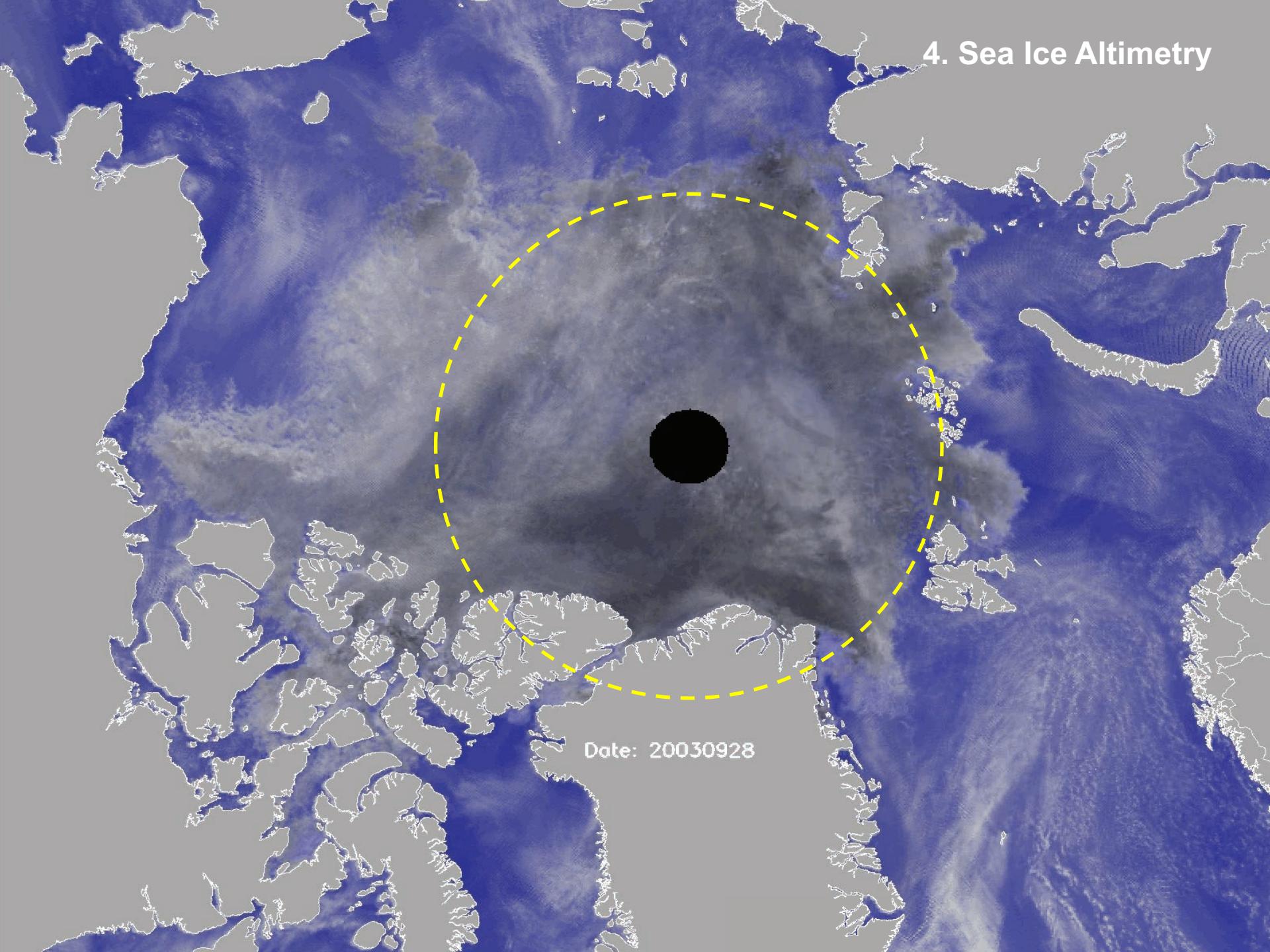


# Outline

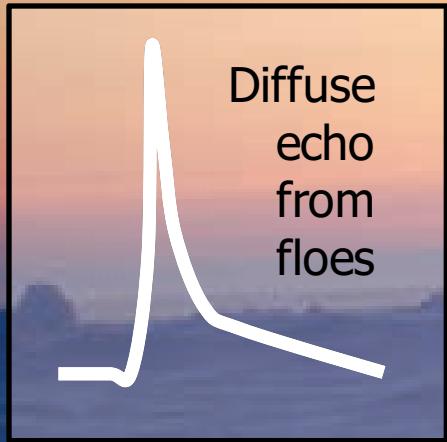
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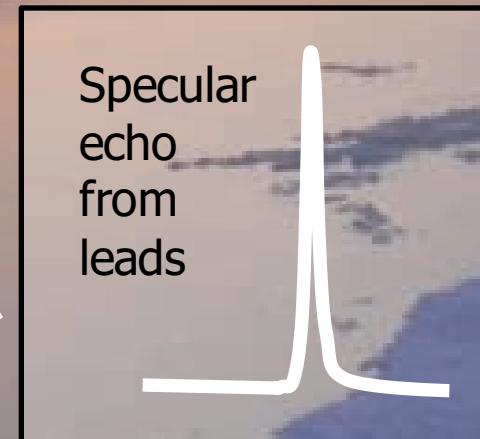
#### 4. Sea Ice Altimetry



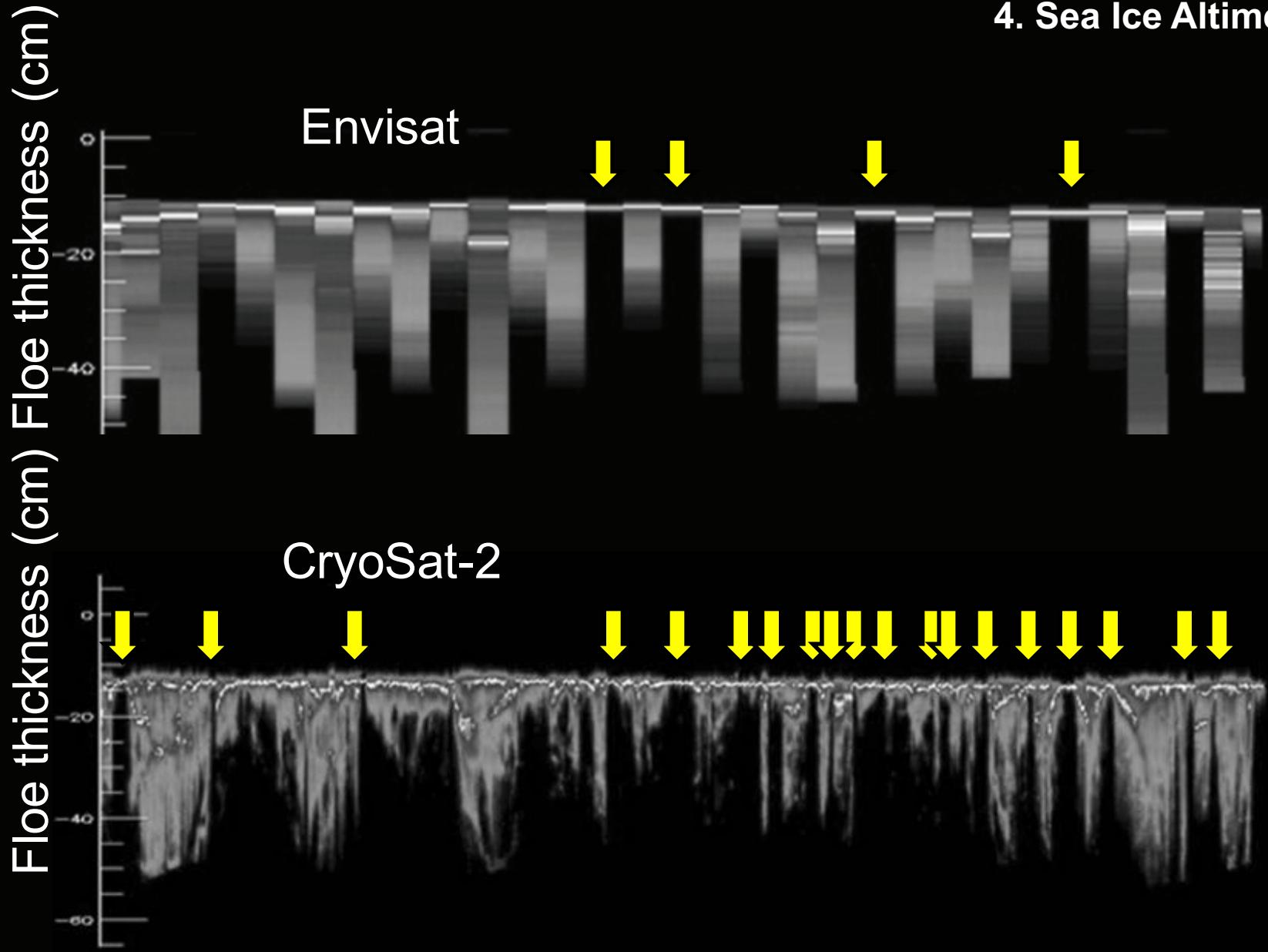
## 4. Sea Ice Altimetry



Freeboard

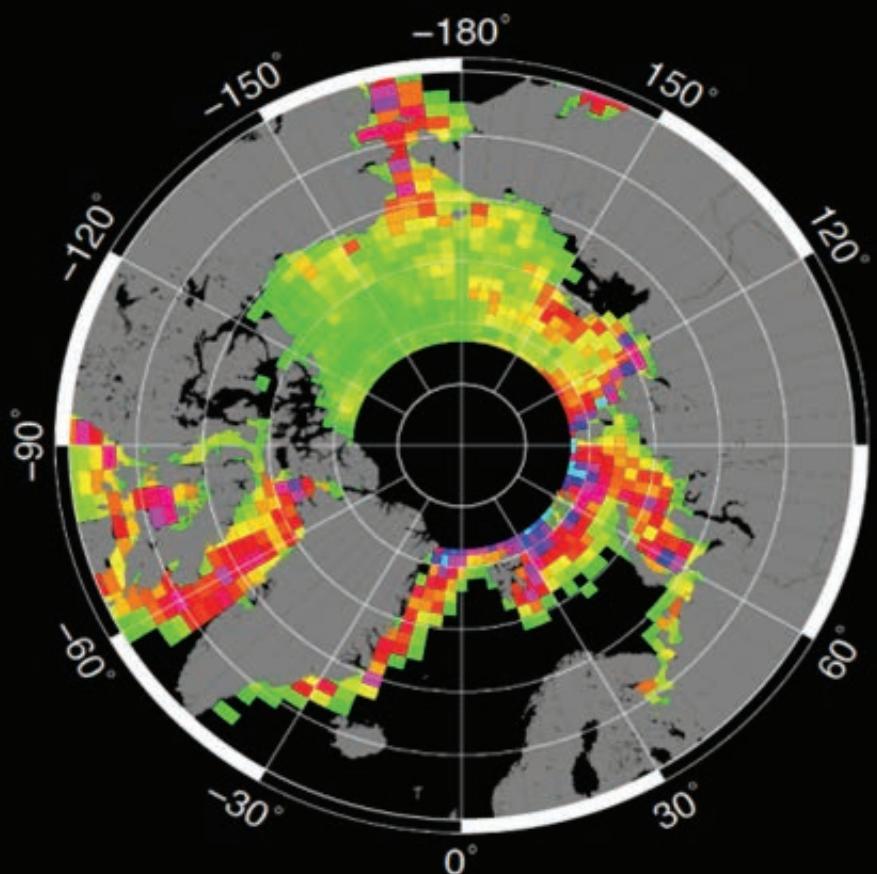


## 4. Sea Ice Altimetry

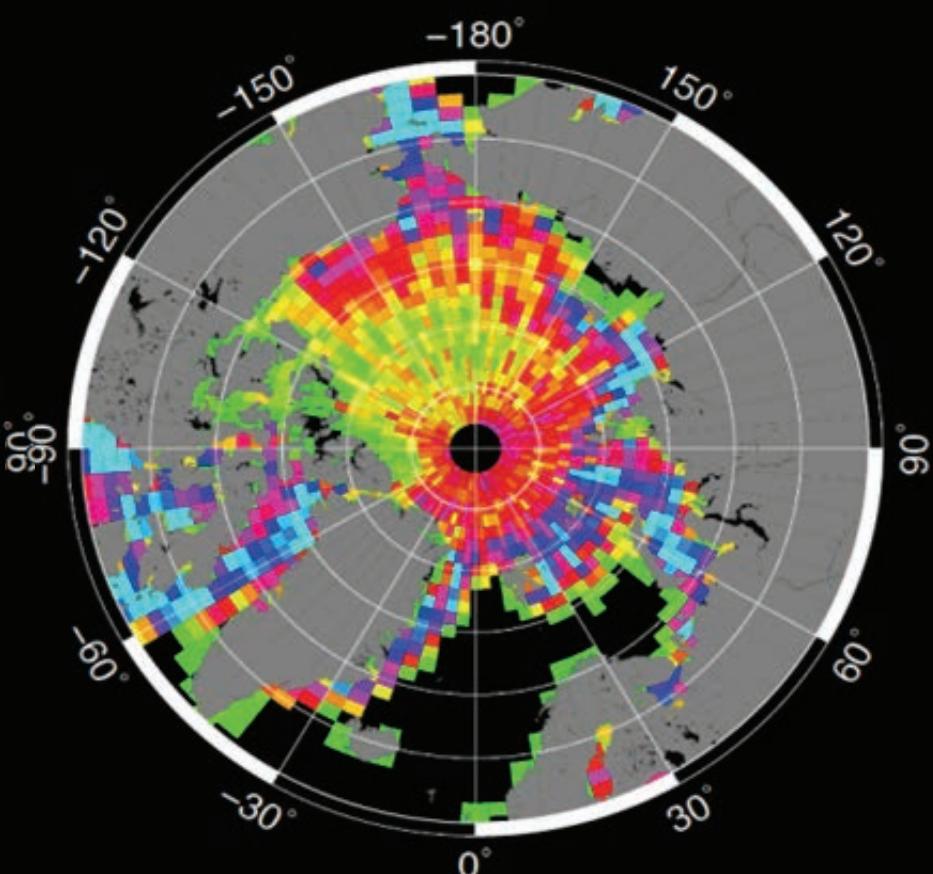


## 4. Sea Ice Altimetry

Envisat



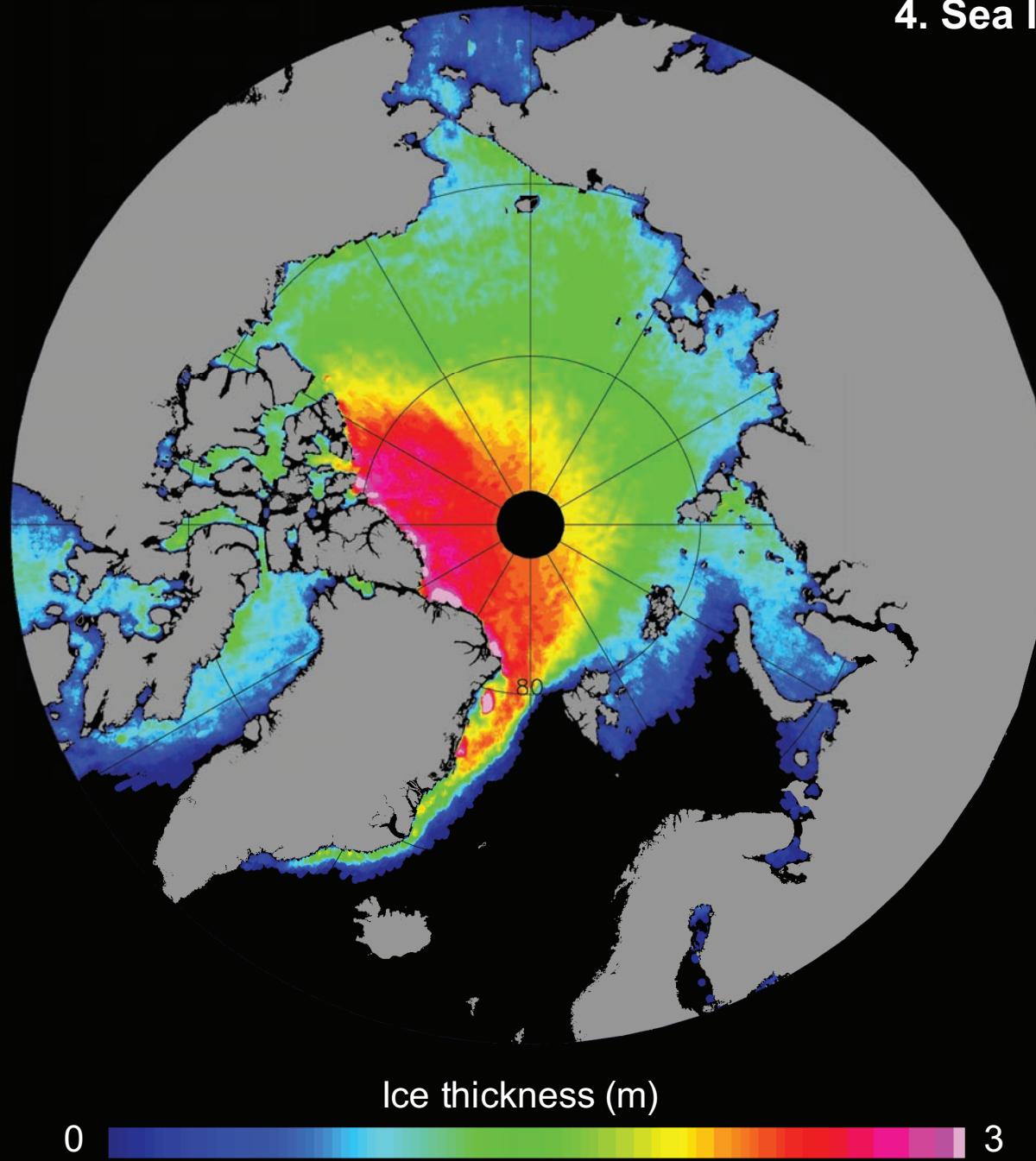
CryoSat



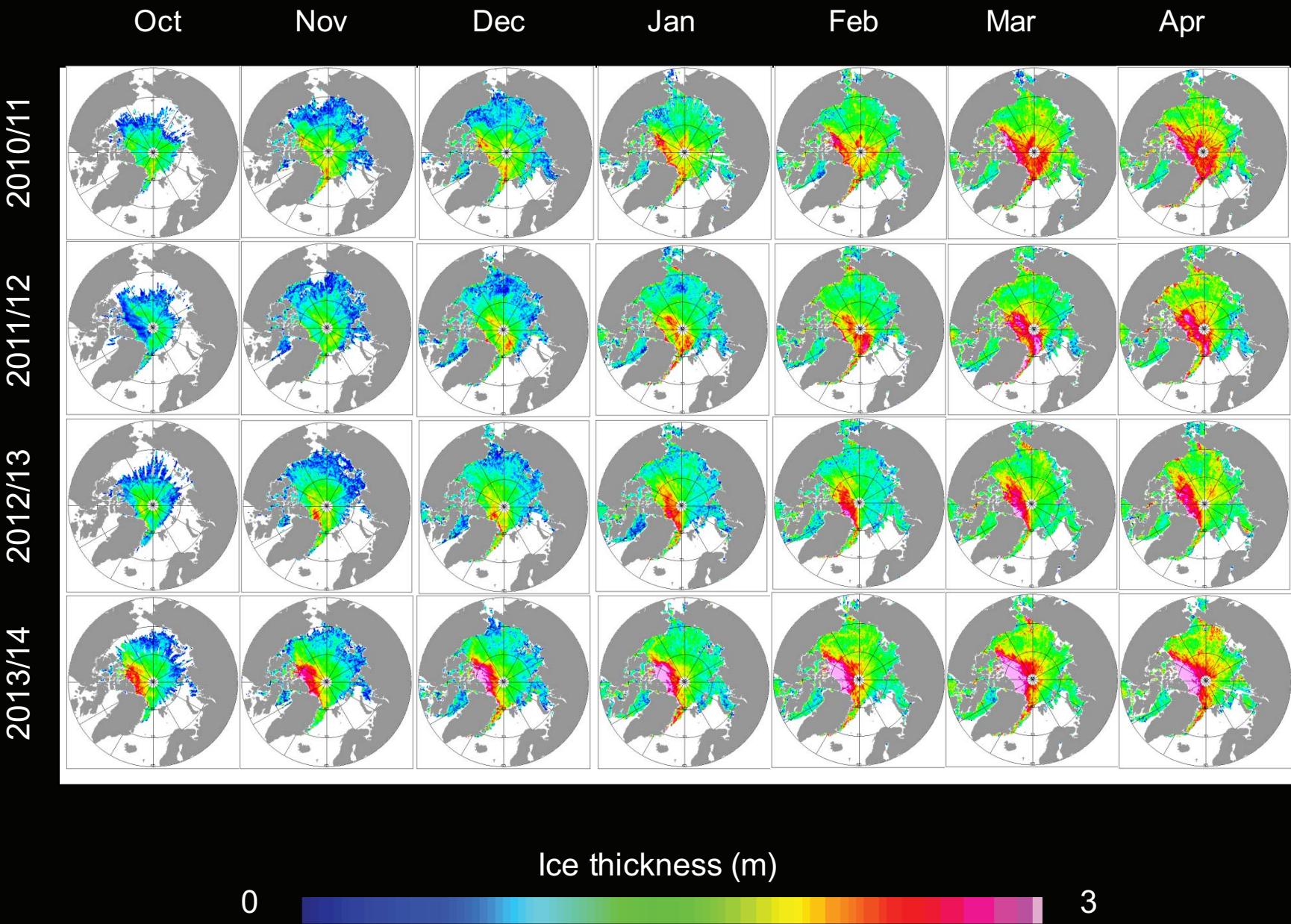
Lead density per 10 km square



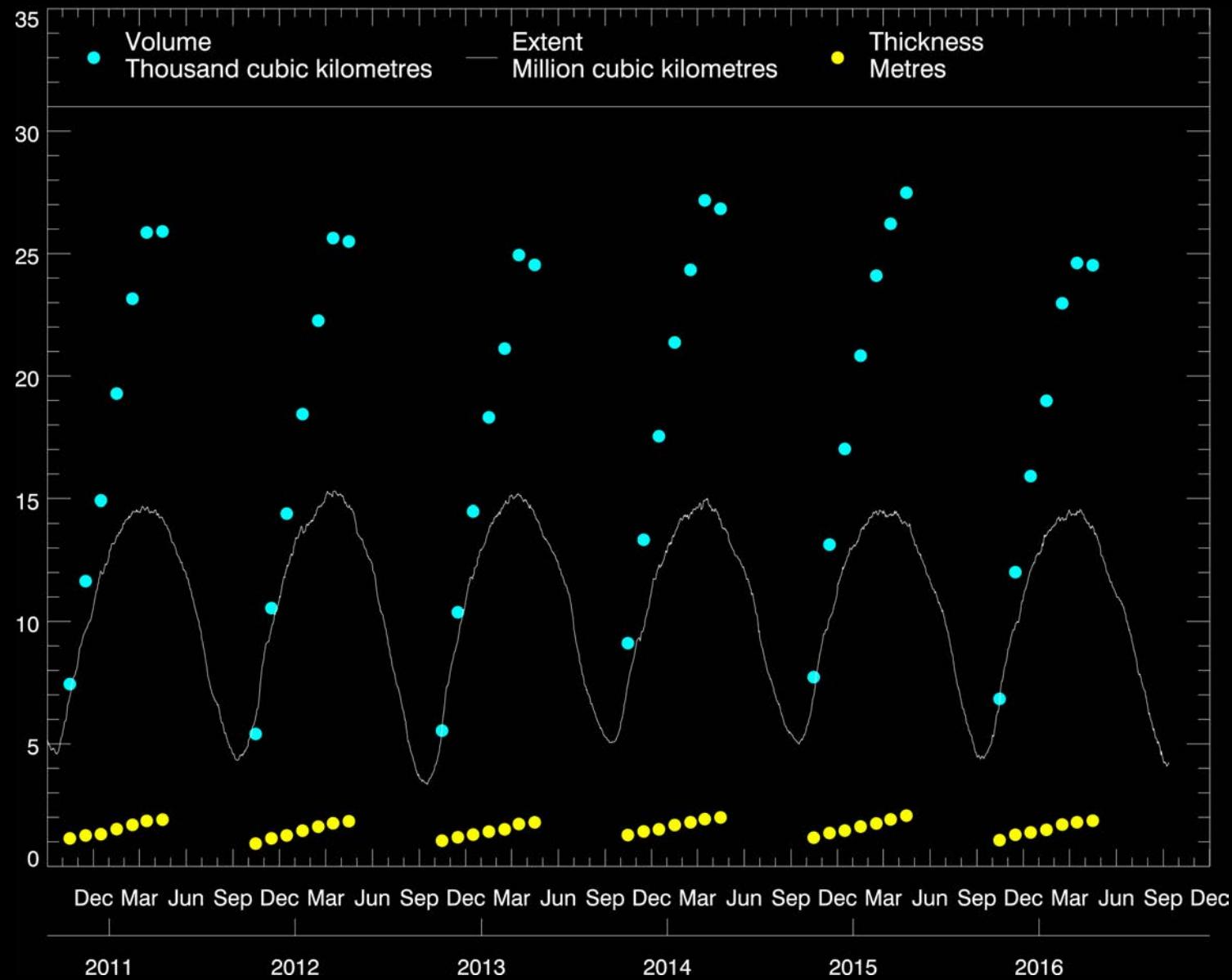
## 4. Sea Ice Altimetry



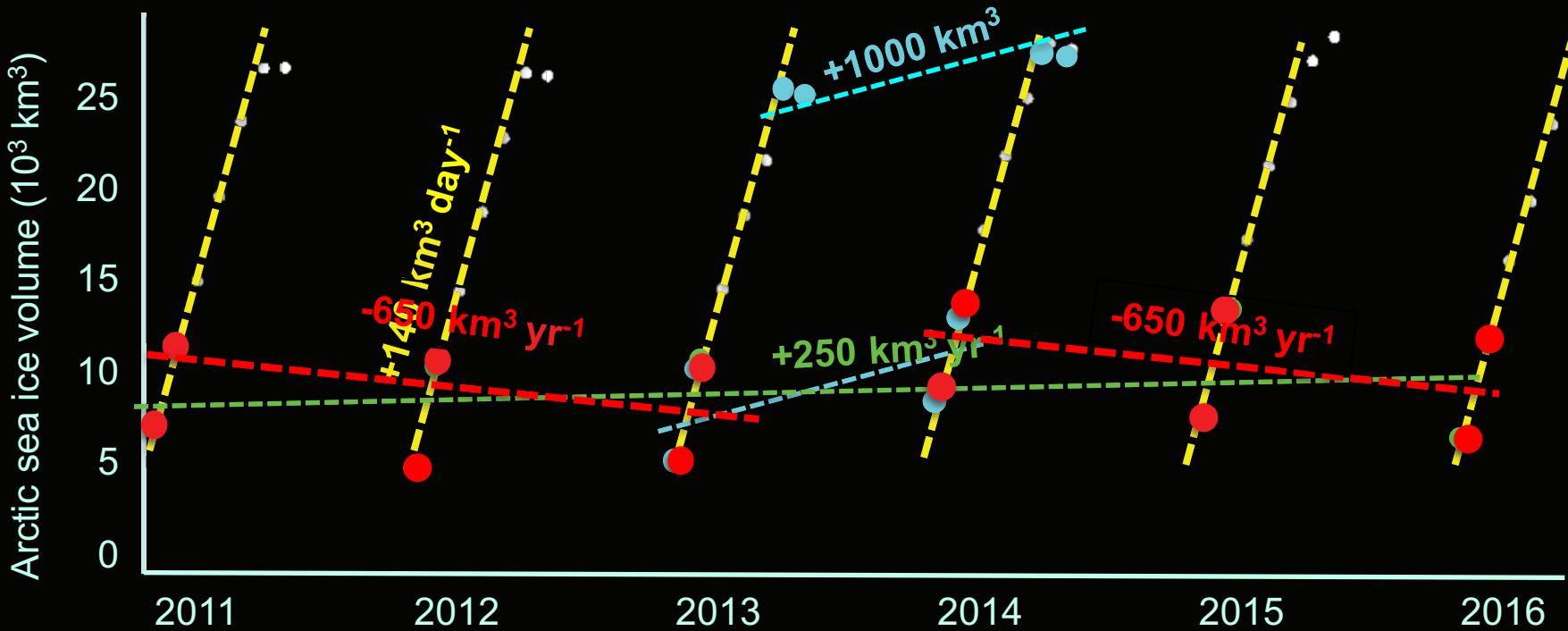
## 4. Sea Ice Altimetry



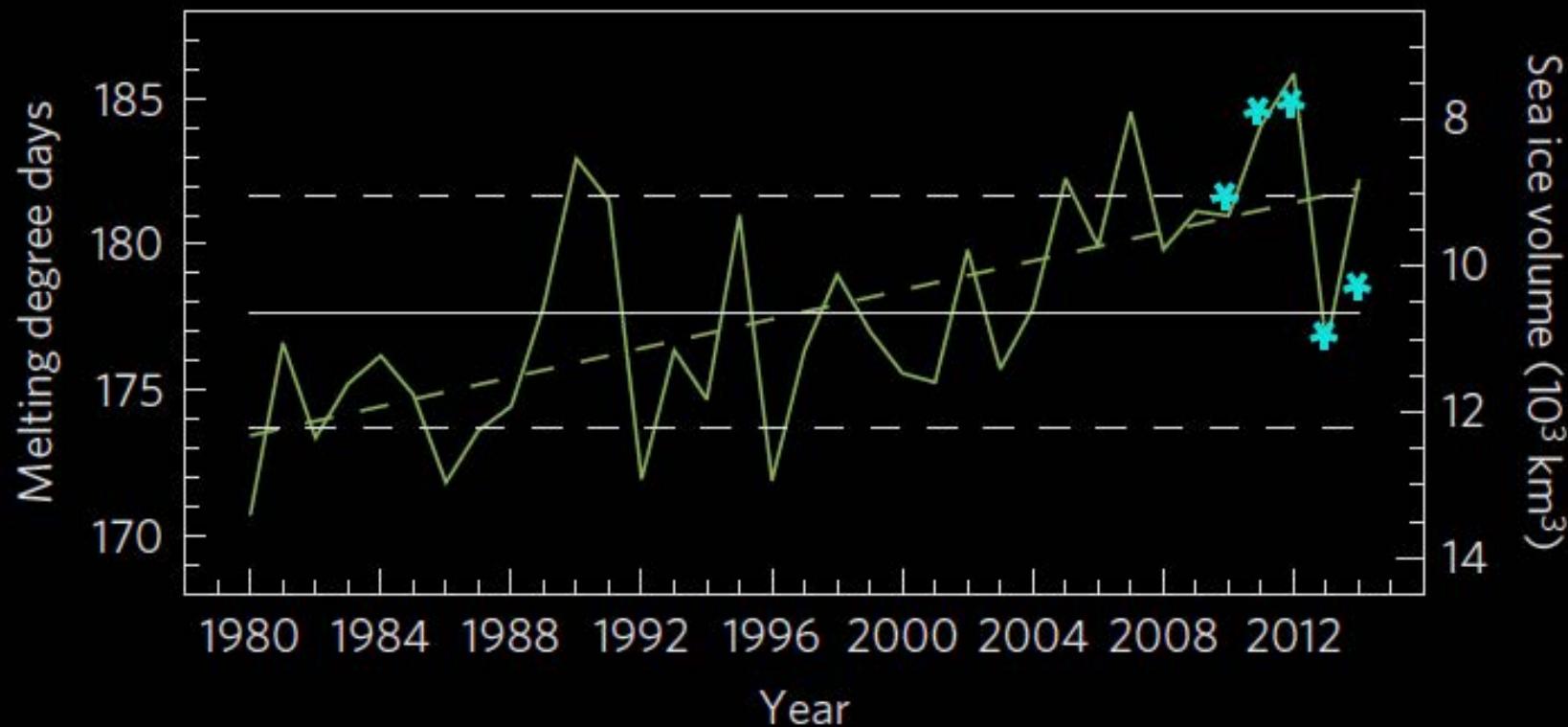
## 4. Sea Ice Altimetry



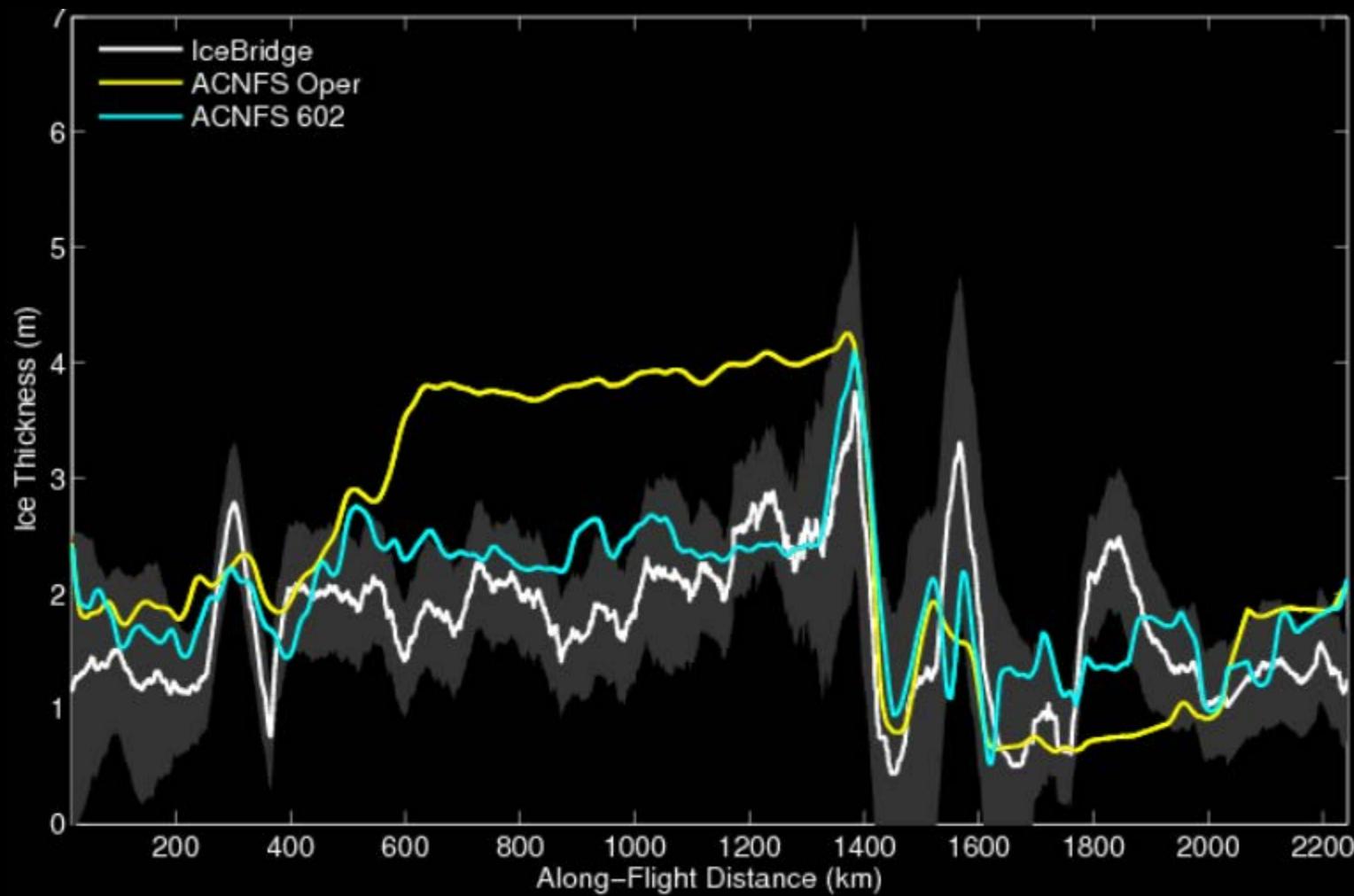
#### 4. Sea Ice Altimetry



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## 4. Sea Ice Altimetry



# Summary

1. 25+ years of continuous satellite altimetry
2. Powerful EO technique for glaciology
3. Ice dynamical imbalance
4. Ice mass balance
5. Sea ice thickness & volume

