# Scientific achievements of the CryoSat mission

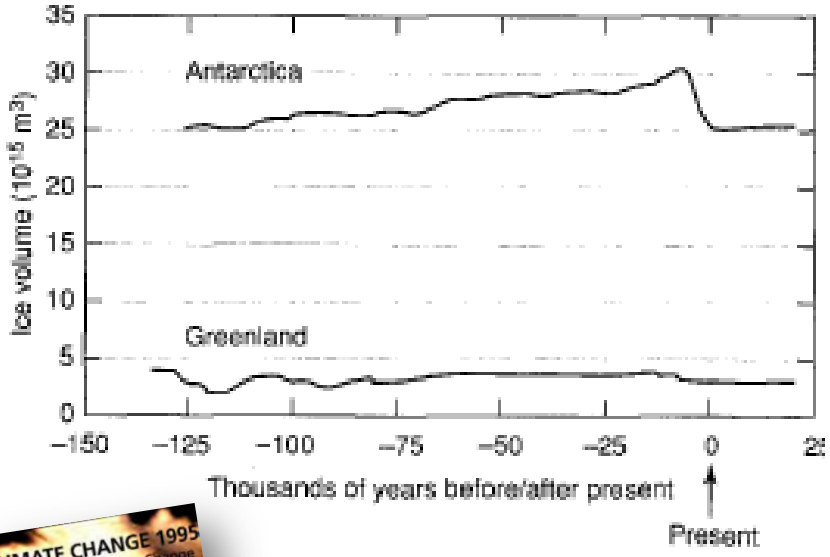
T. Armitage, K. Briggs, R. Cullen, K. Giles, A. Hogg, S. Laxon, M. McMillan, A. Muir, A. Ridout, A. Shepherd, A. Sundal, R. Tilling, D. Wingham

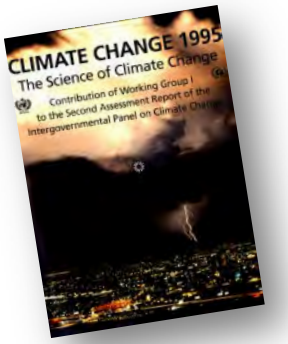
cpom

- Mission concept
- Sea ice achievements
- Land ice achievements
- Wider scientific achievements

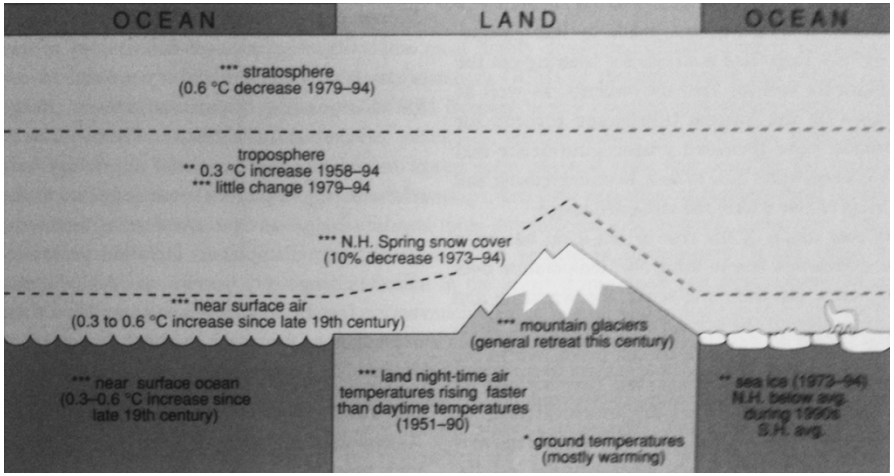
## Ice sheets

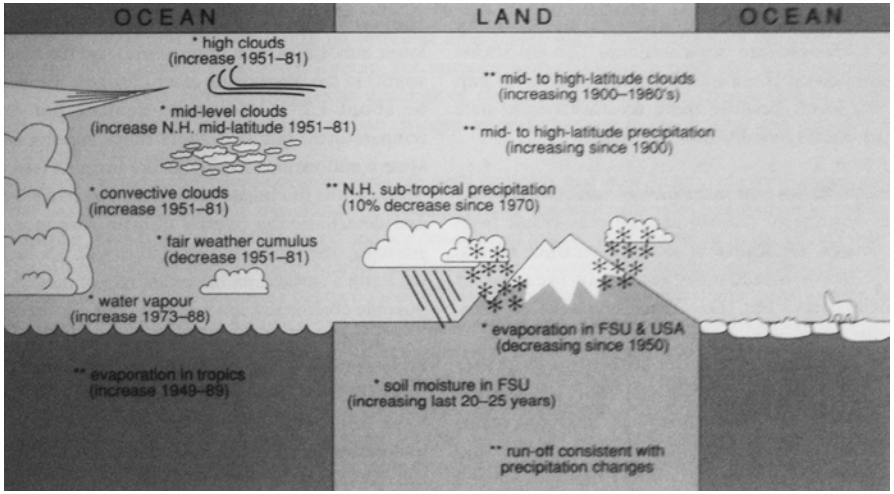
Recent attempts to measure the surface elevation include the use of satellite radar altimetry. The results are still controversial. Zwally *et al.* (1989) used satellite radar altimetry to estimate the change in surface elevation of the Greenland ice sheet south of 72°N (excluding the margins).



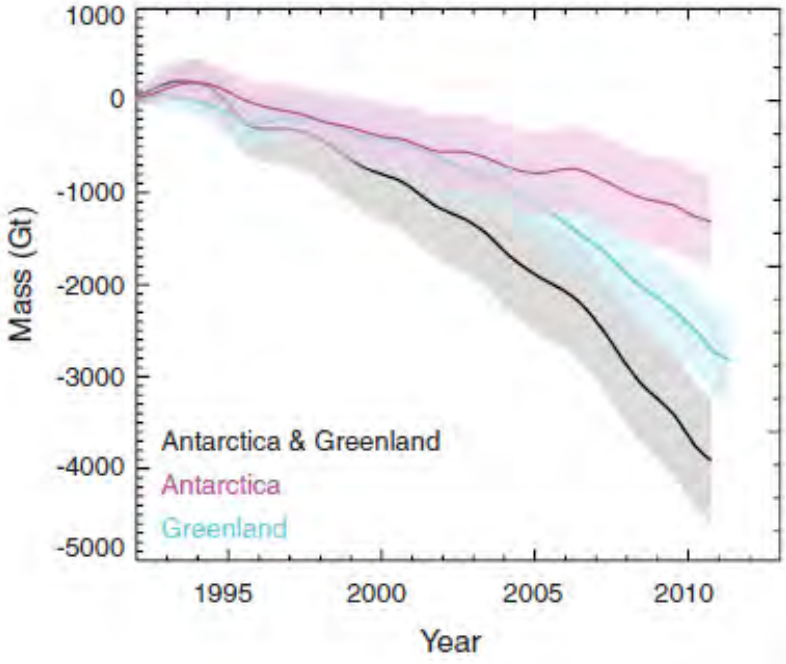




## Sea ice

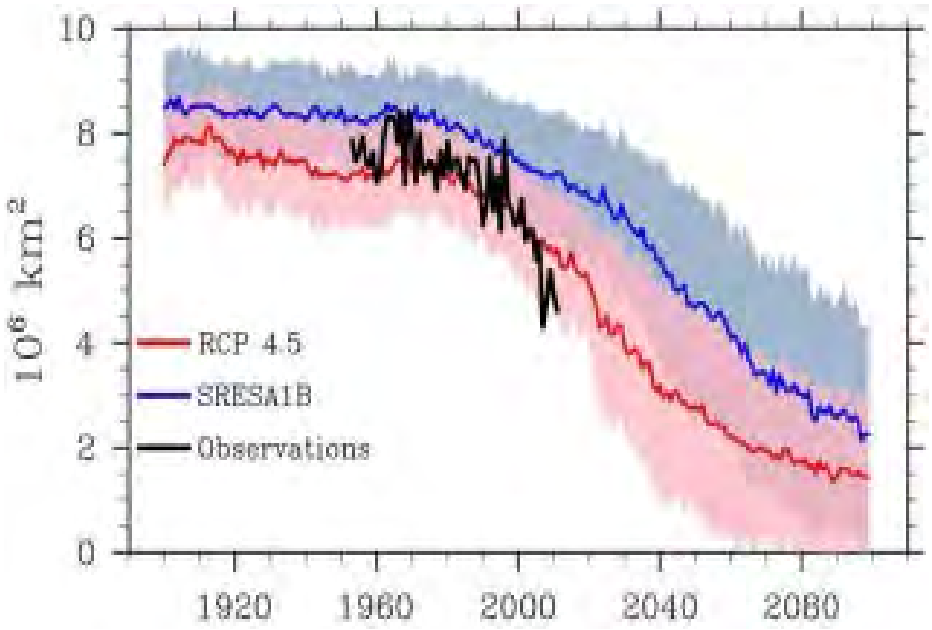


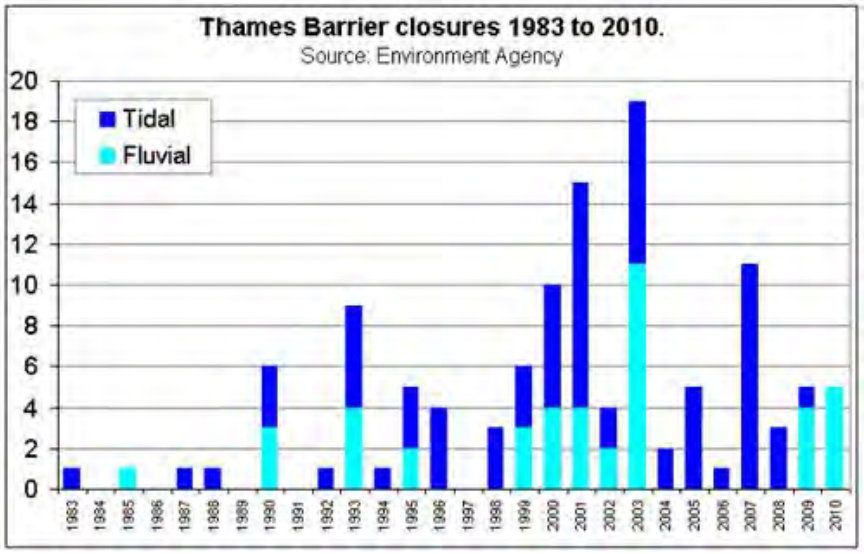
## Ice sheets



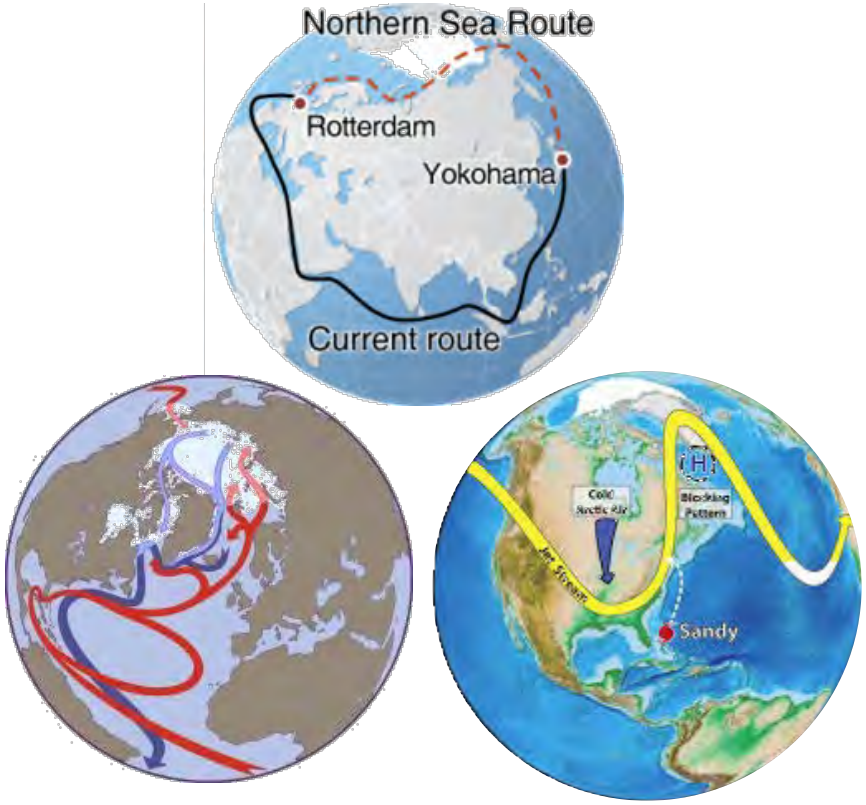

## Sea ice




## Ice sheets

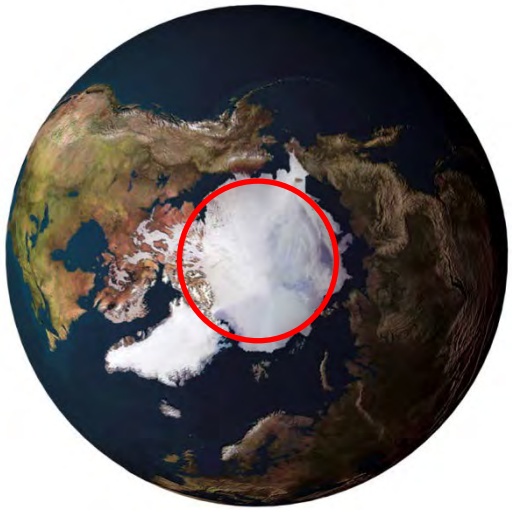


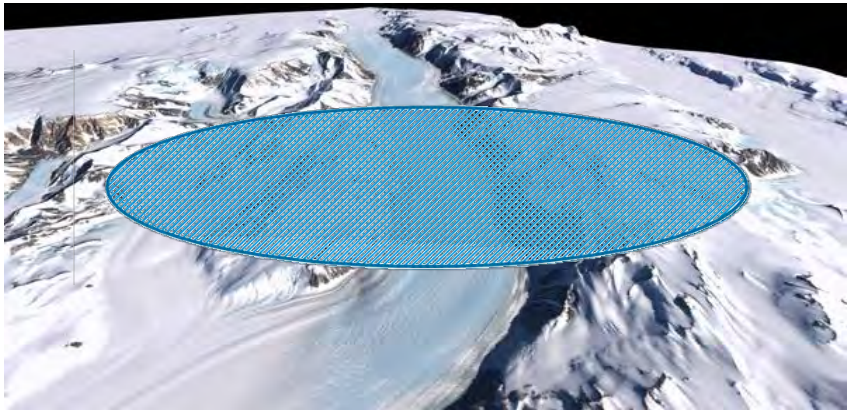

## Sea ice

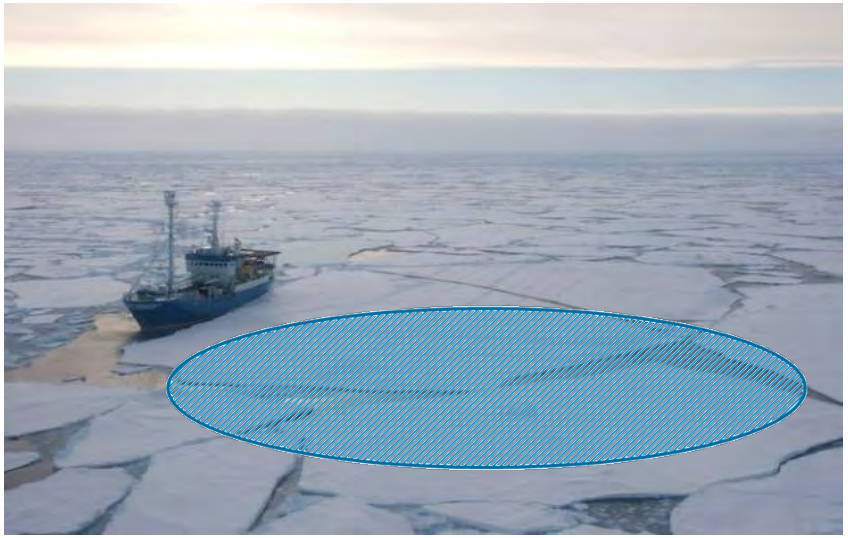


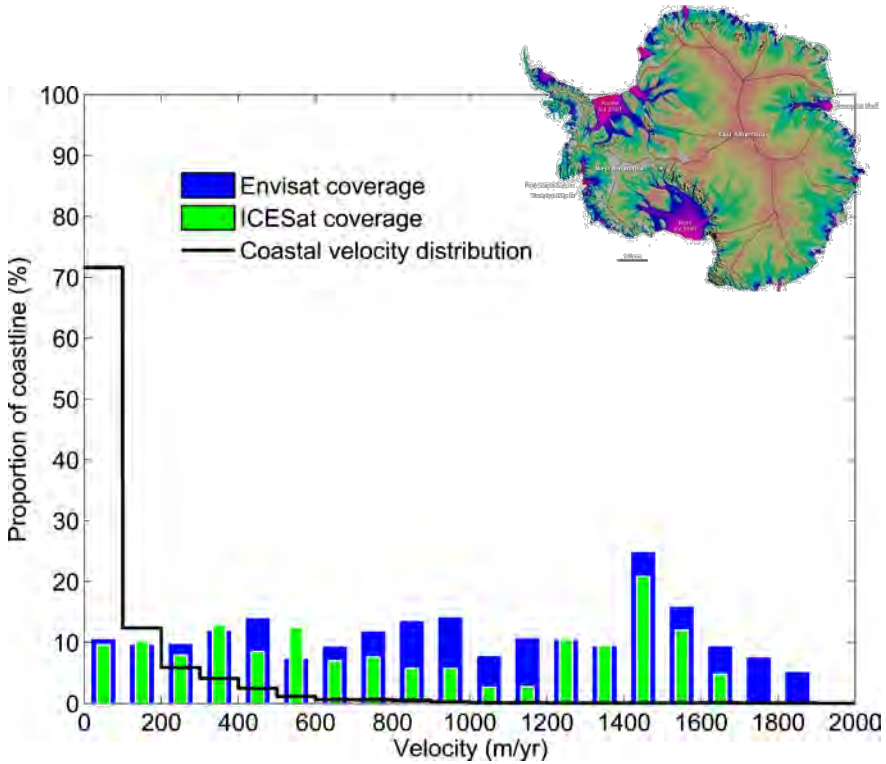
# Limitations of past altimeter missions

## Mission Concept

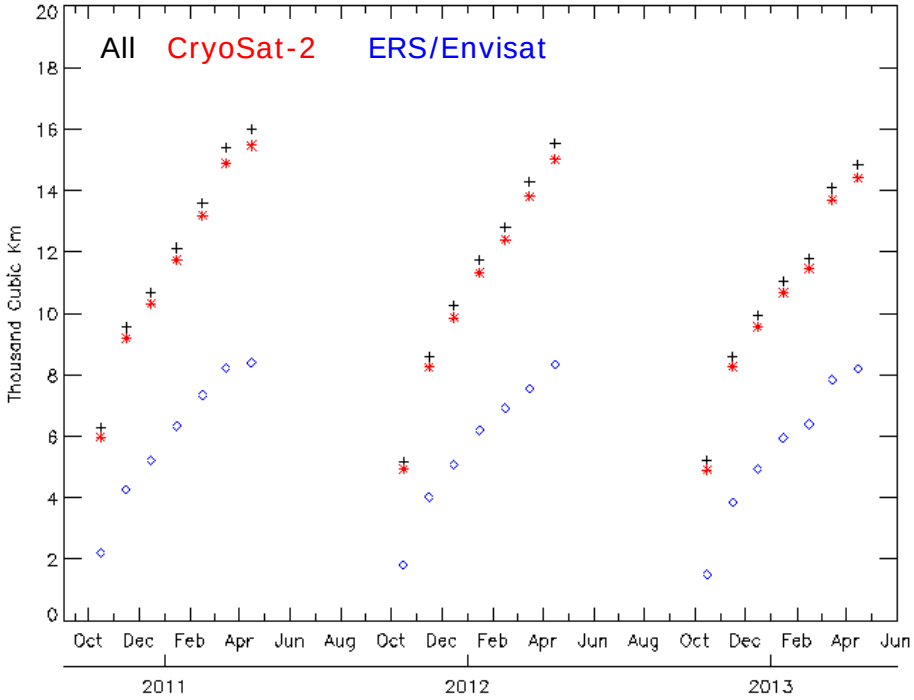









McMillan et al., 2014




Ridout, 2014

## Primary Mission Goals

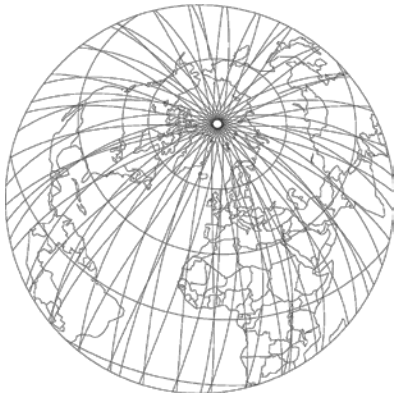
- Determination of regional and basin-scale trends in perennial Arctic sea ice thickness and mass
- Determination of regional and total contributions to global sea-level of the Antarctic and Greenland ice sheets

## Secondary Mission Goals

- Observation of seasonal cycle and variability of Arctic and Antarctic sea ice mass and thickness
- Observation of variation in thickness of the world's ice caps and glaciers

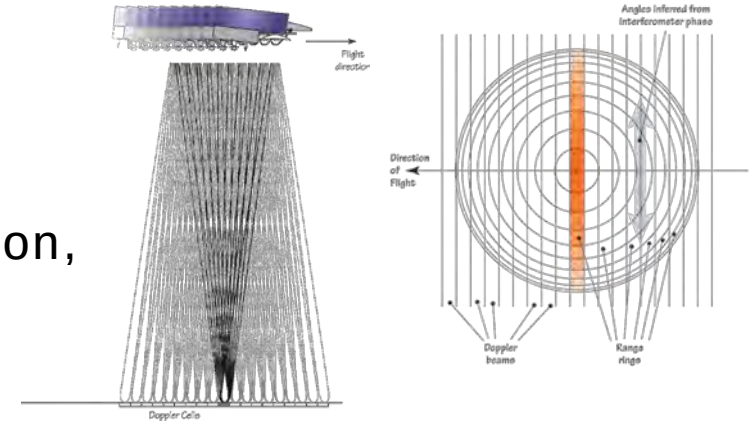
## Global Sampling

- 92 degree orbit inclination to survey Arctic Sea Ice and Antarctic and Greenland ice sheets
- 369 day repeat with 30 day sub cycle provides dense across track sampling and captures temporal change



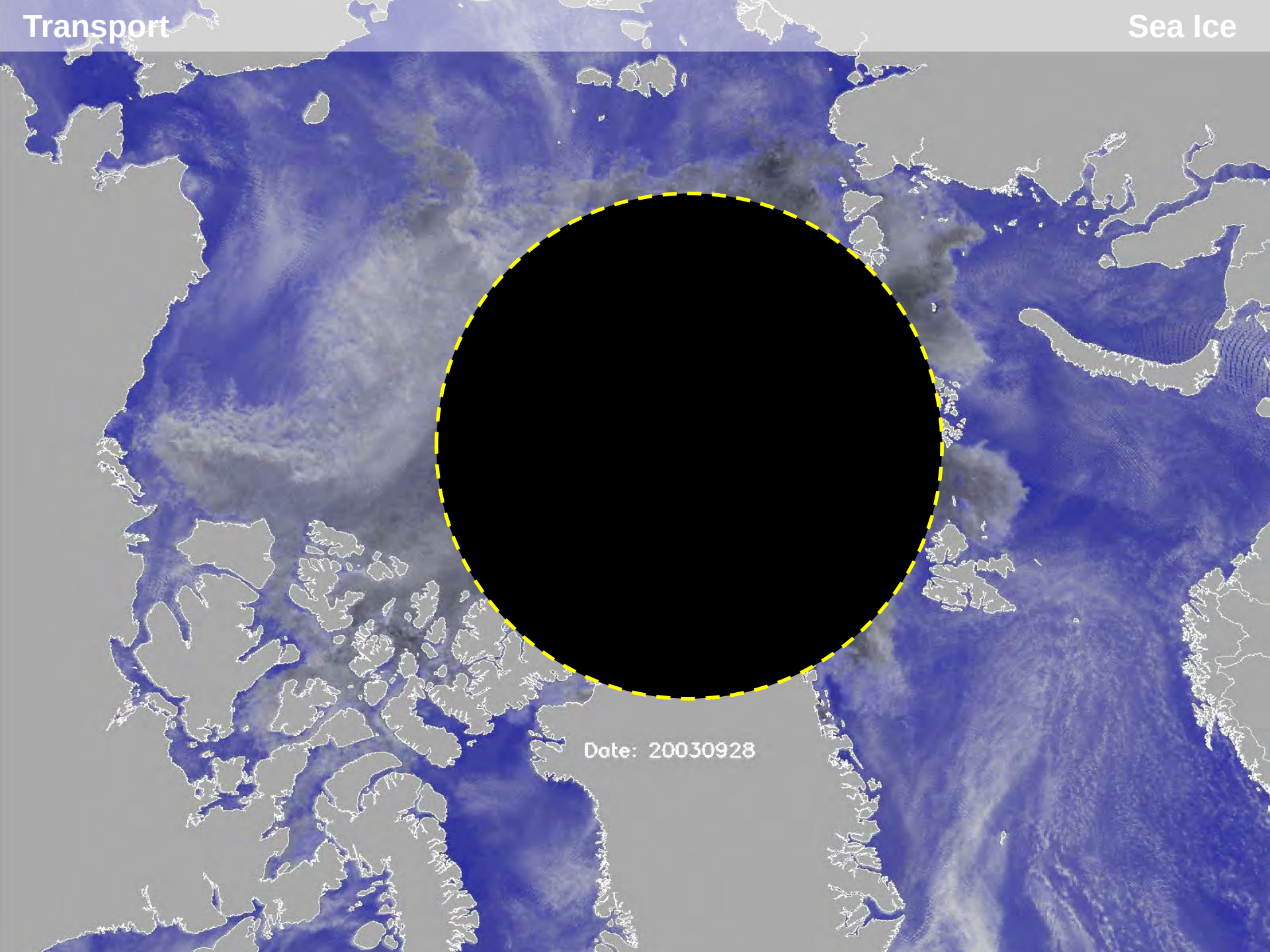
## Fine resolution

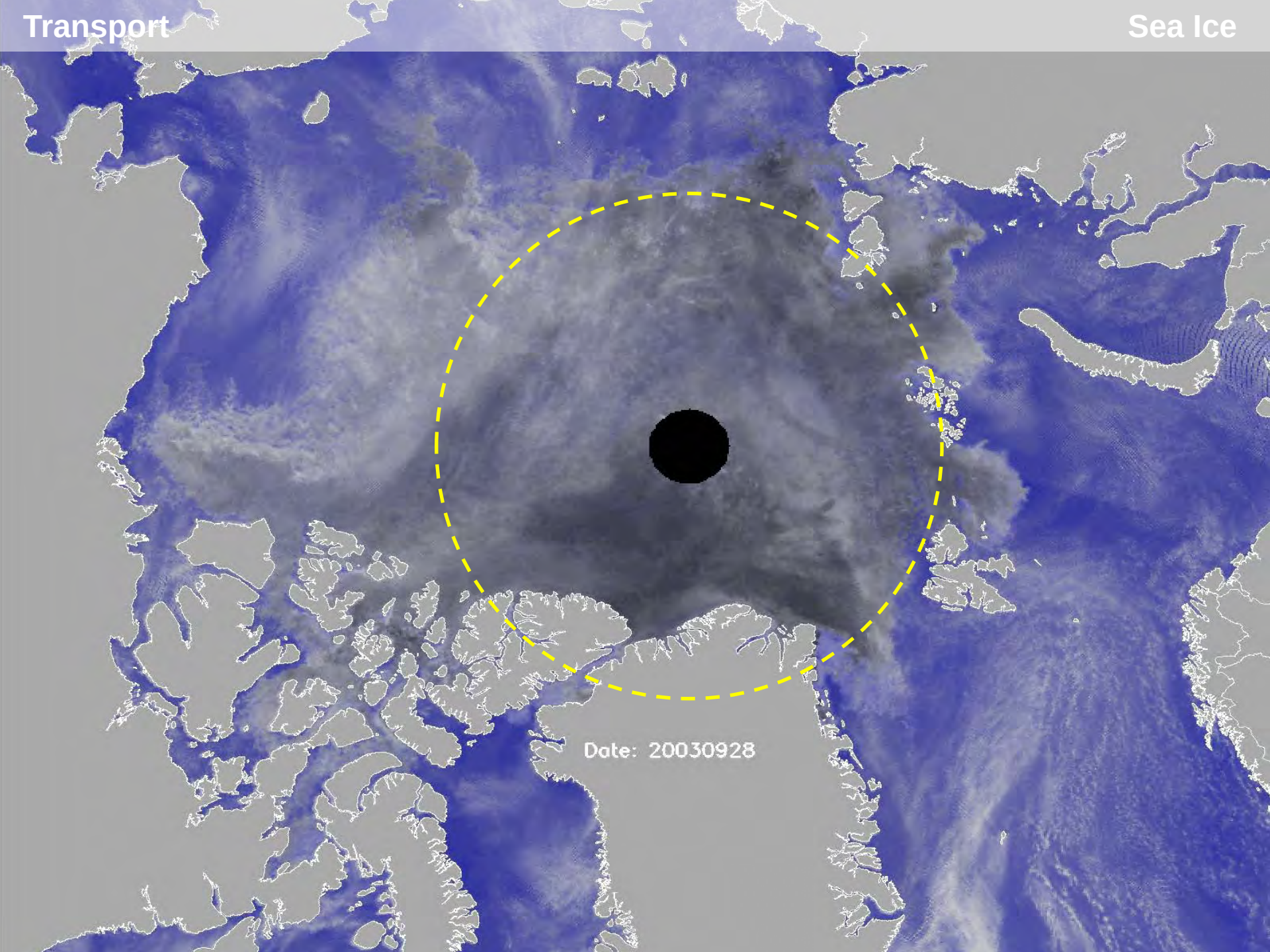
- SAR mode improves along track resolution, designed to pick out leads
- SARIn mode improves across track resolution, designed for rugged terrain

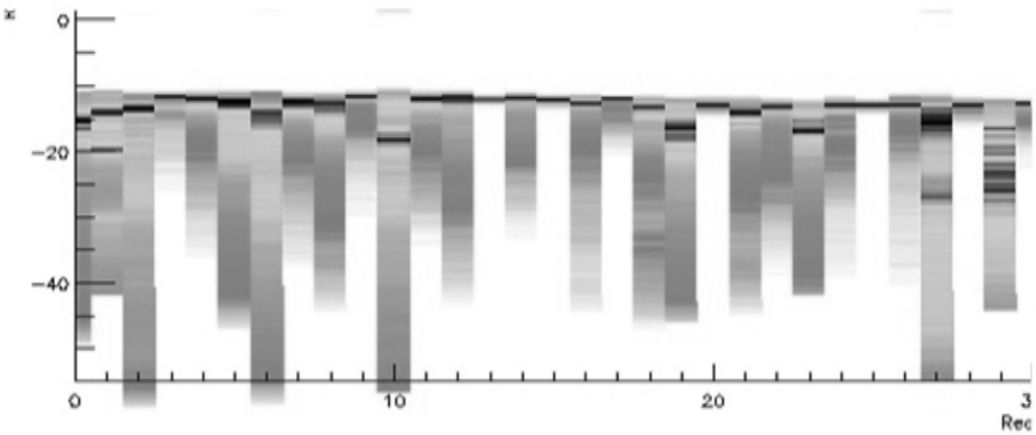


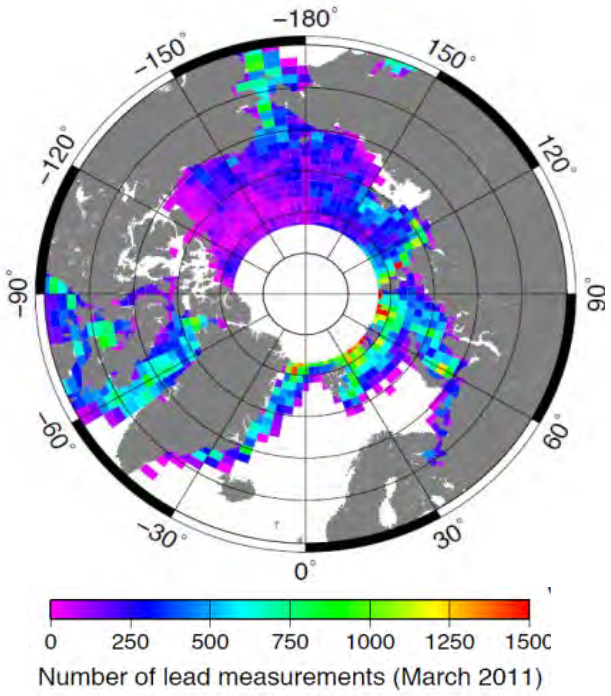
# Sea ice achievements

Credit: S. Hendricks, AWI

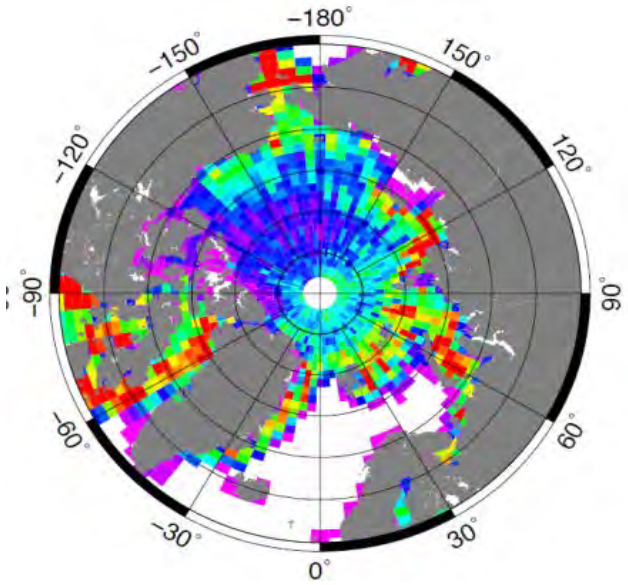

Transport
Sea Ice
Date: 20030928


Transport
Sea Ice
Date: 20030928

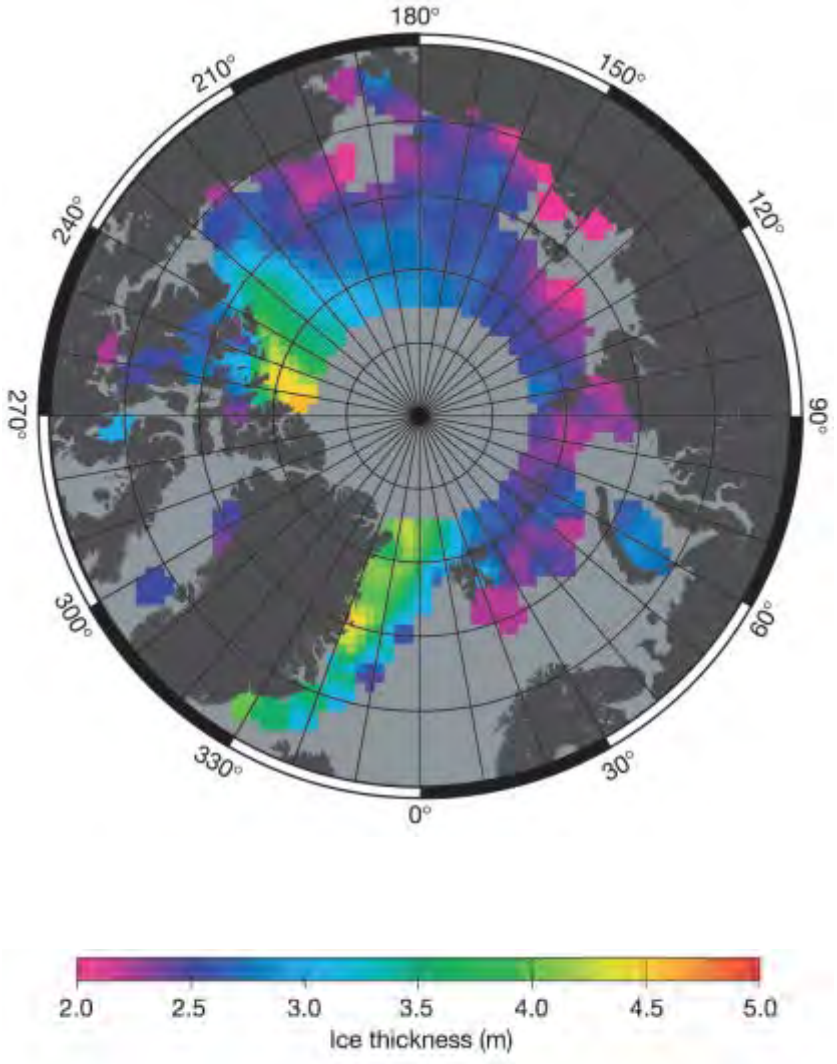

0
−20
−40
0
10
20


−180°
−150°
150°
−120°
120°
−90°
90°
−60°
60°
−30°
30°
0°
0
250
500
750
1000
1250
1500
Number of lead measurements (March 2011)

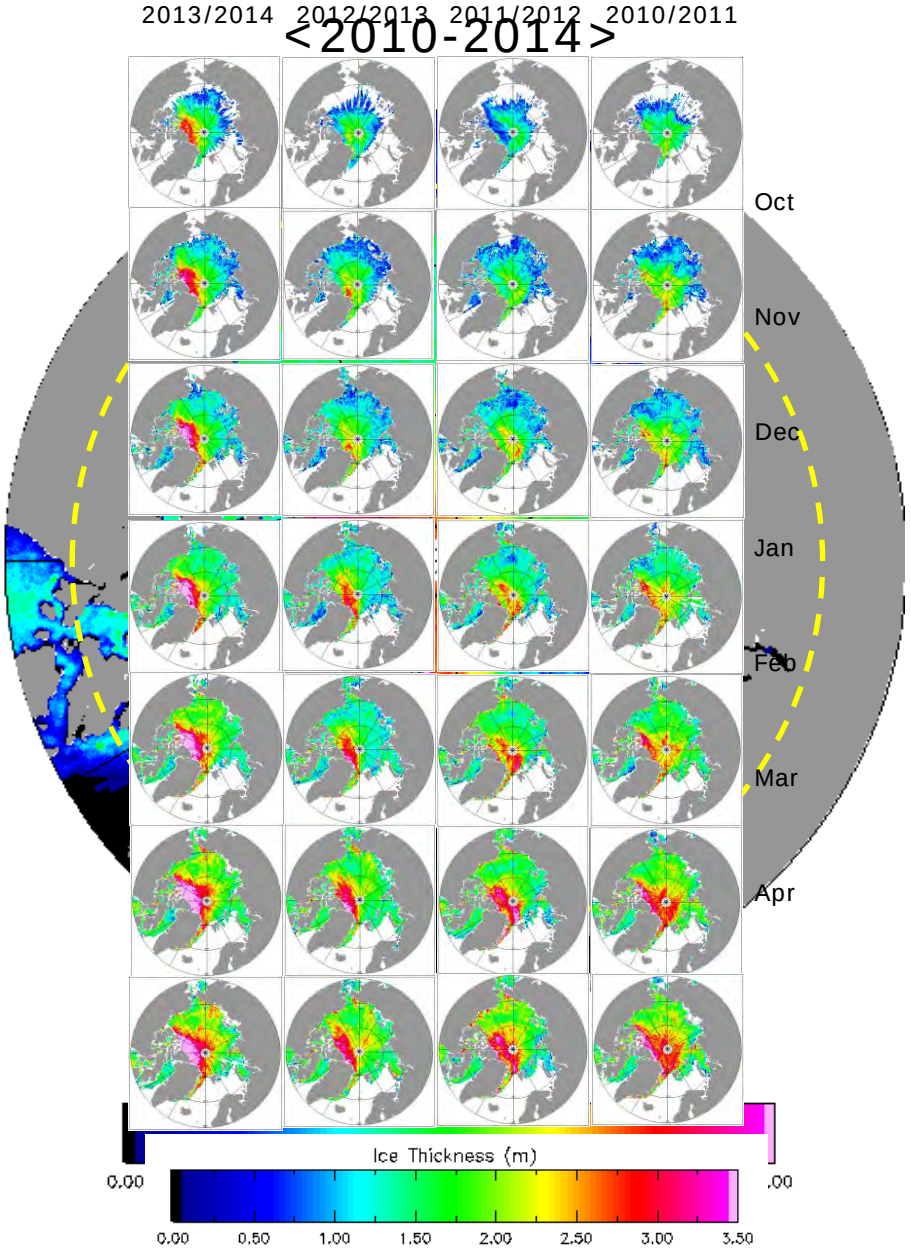

Relative elevation
0
−20
−40
−60


−180°
−150°
150°
−120°
120°
−90°
90°
−60°
60°
−30°
30°
0°

<1993-2001>

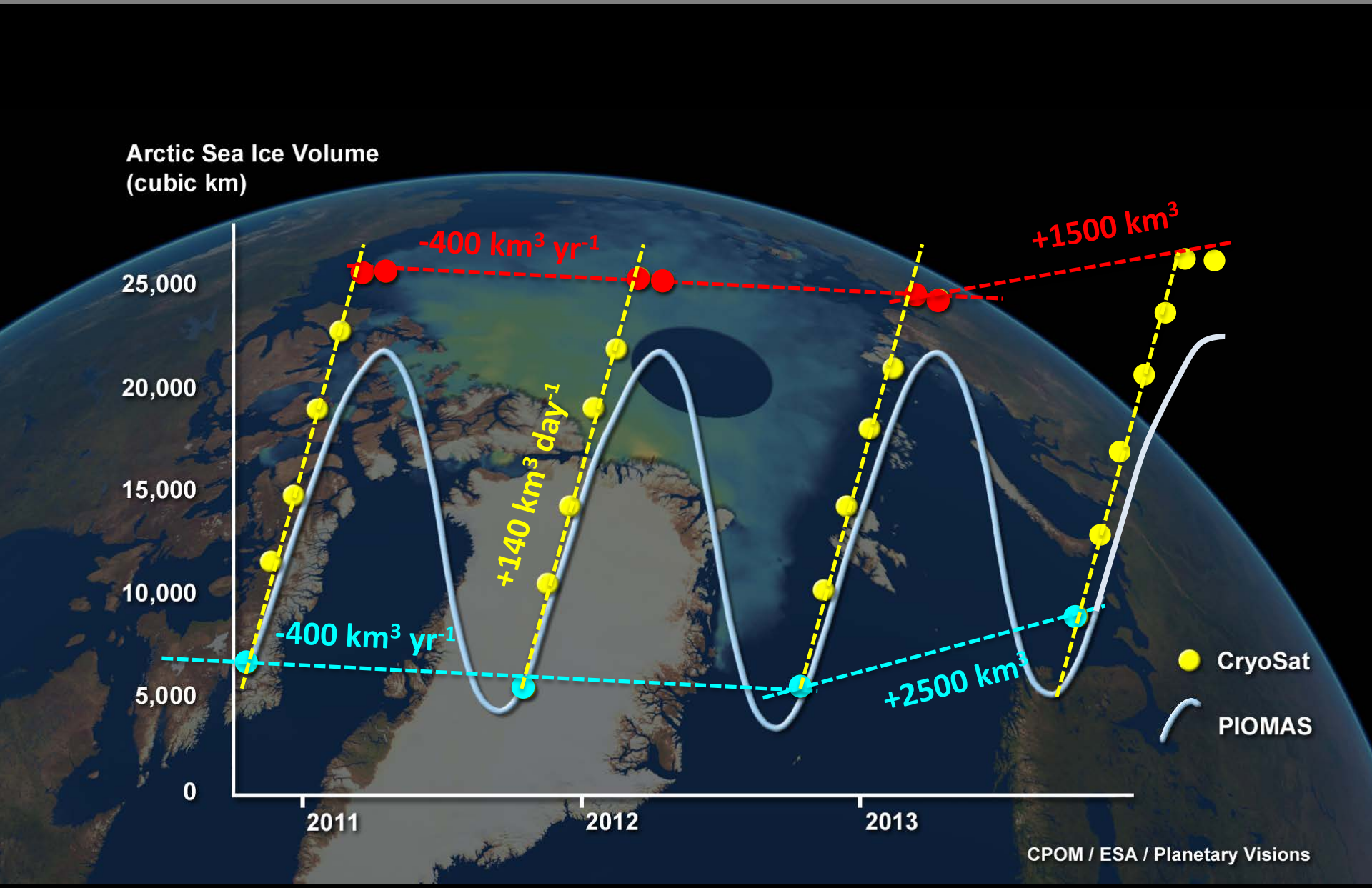


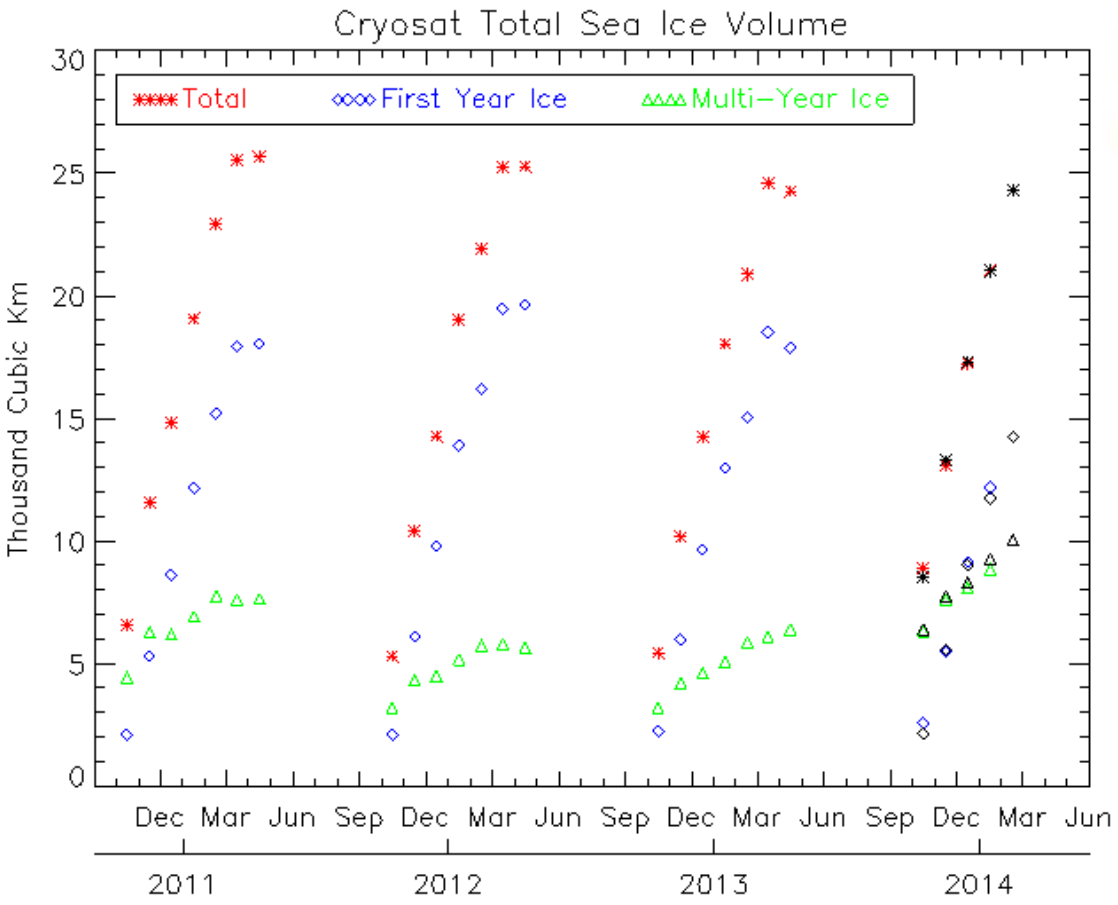

<2010-2014>

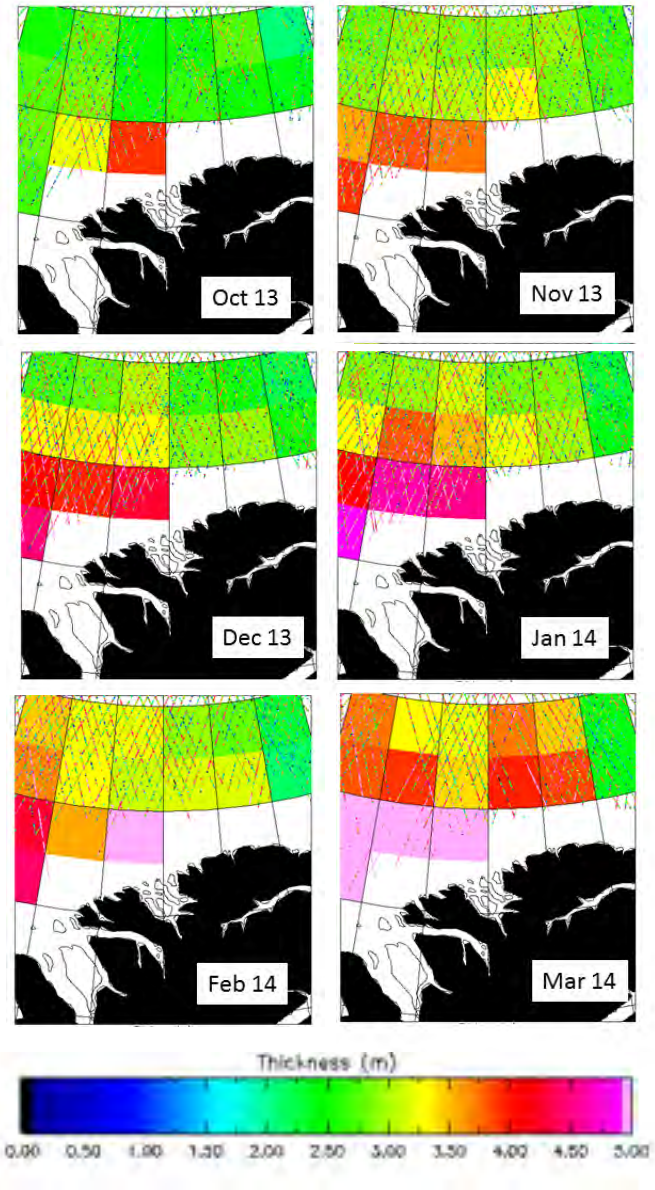


# CryoSat-2 sea ice volume trend



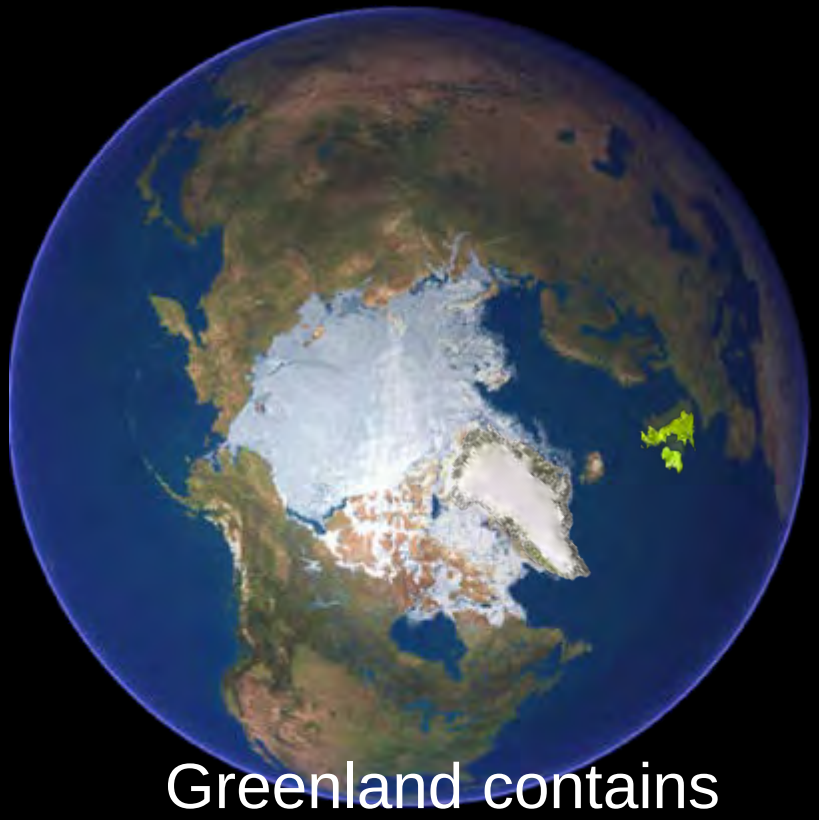



Cryosat Total Sea Ice Volume
Total
First Year Ice
Multi-Year Ice
Thousand Cubic Km
0
5
10
15
20
25
30
Dec Mar Jun Sep Dec Mar Jun Sep Dec Mar Jun Sep Dec Mar Jun
2011
2012
2013
2014

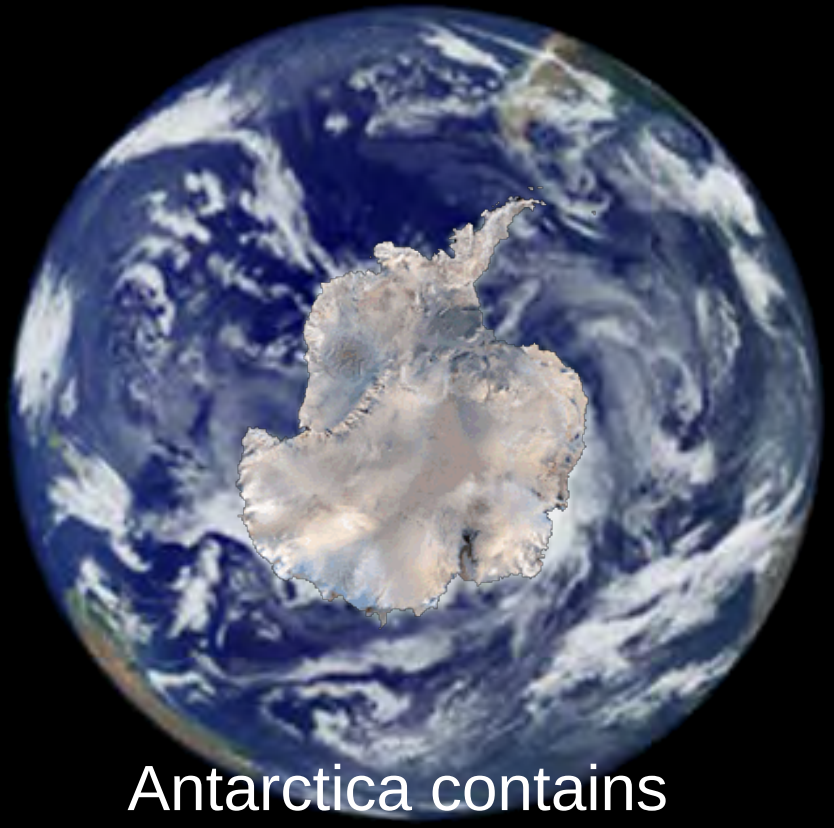

Oct 13
Nov 13
Dec 13
Jan 14
Feb 14
Mar 14
Thickness (m)
0.00 0.50 1.00 1.50 2.00 2.50 3.00 3.50 4.00 4.50 5.00

# Land ice achievements

**Land ice achievements:** *Past missions & science gap*

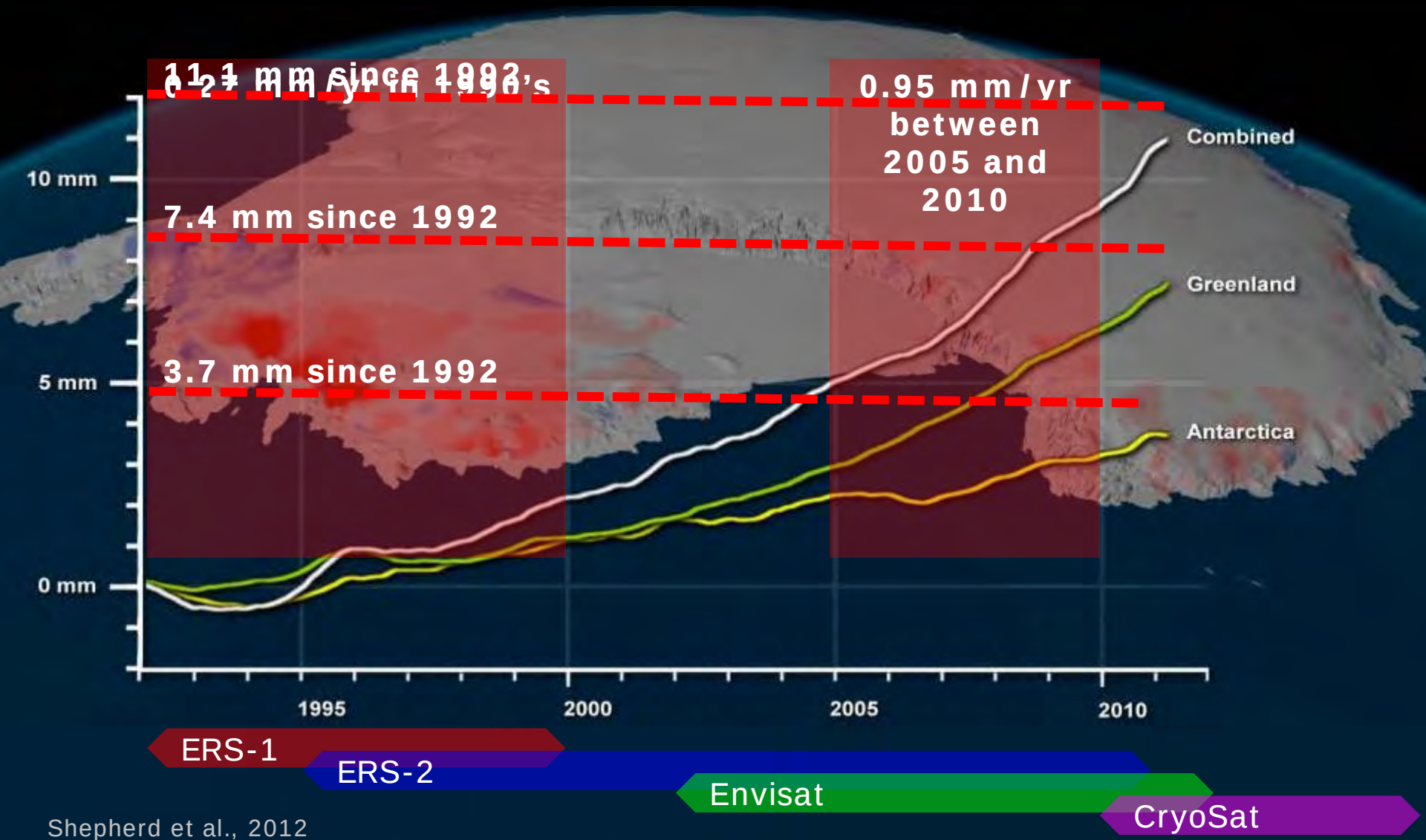


Greenland contains enough ice to raise sea levels by 7m

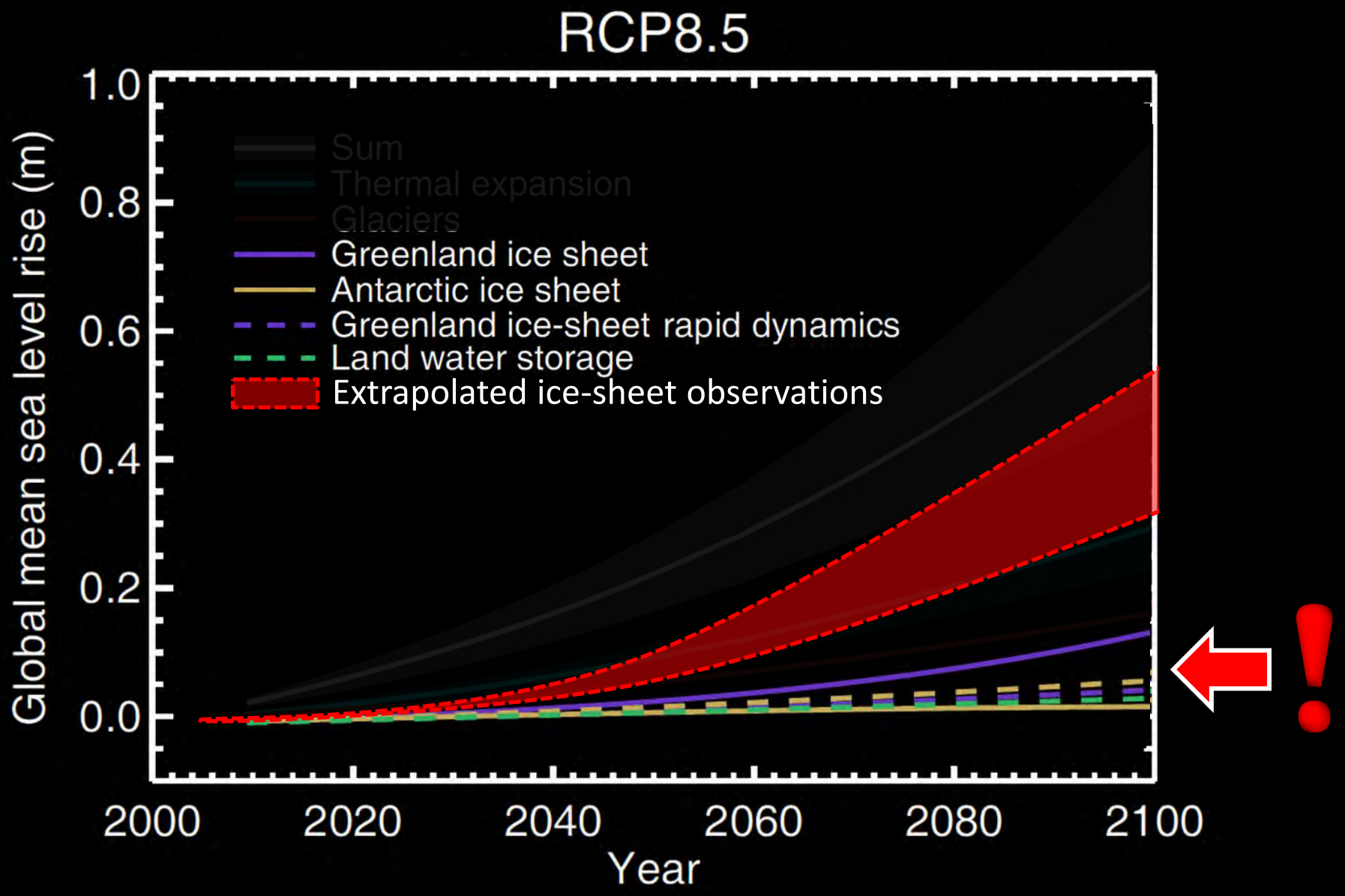


Antarctica contains enough ice to raise sea levels by 57m

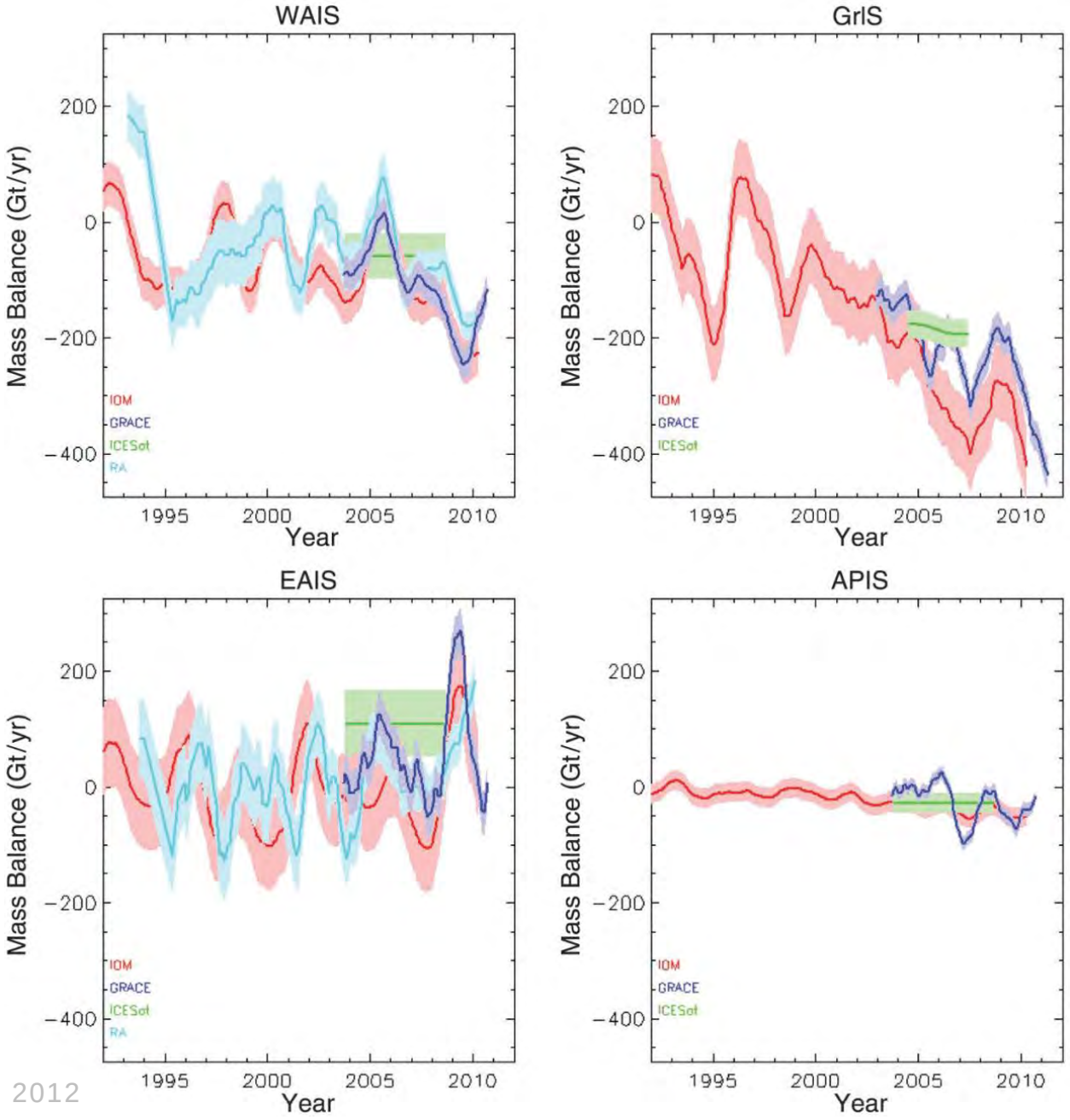
**Land ice achievements:** *Past missions & science gap*



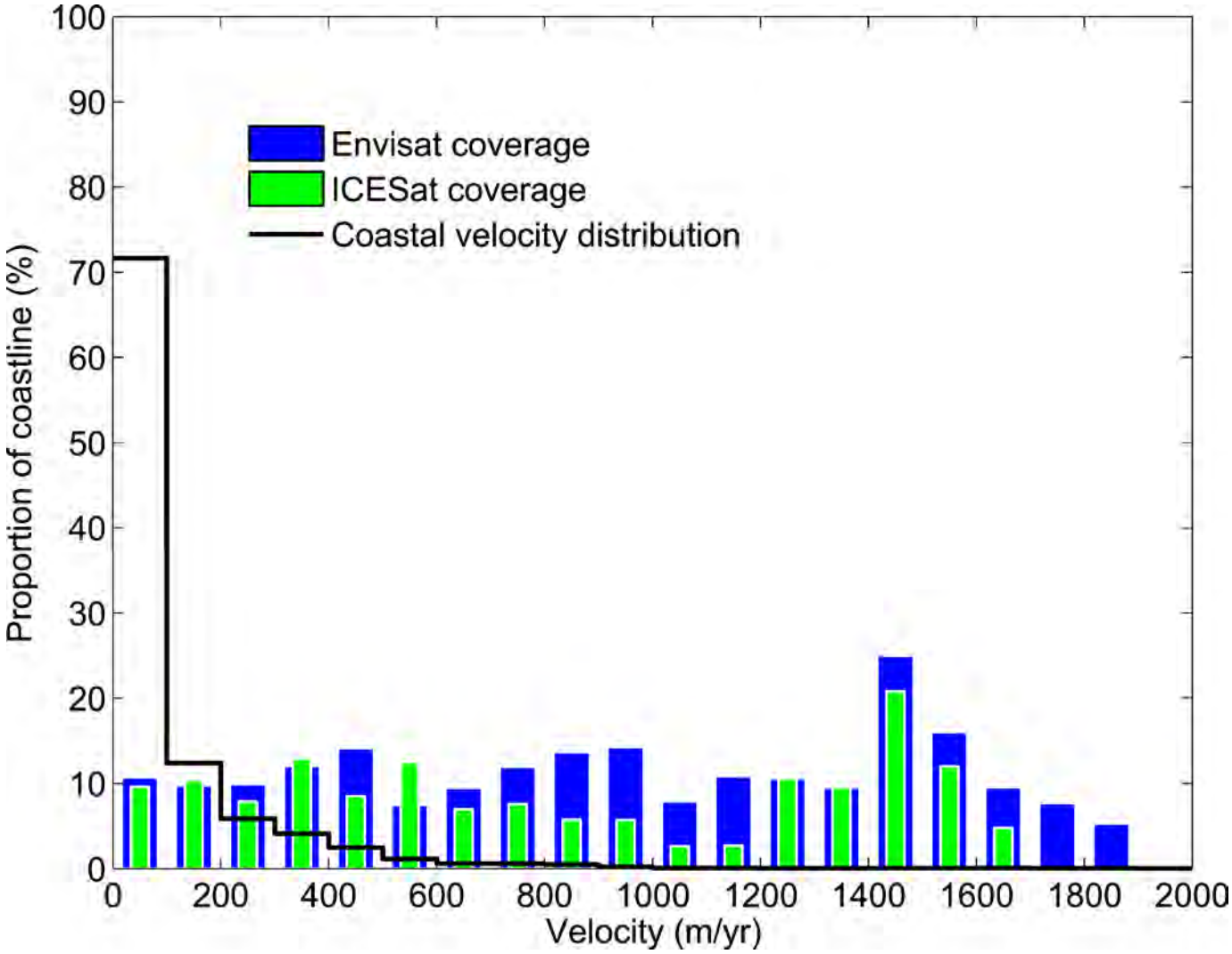

Shepherd et al., 2012


RCP8.5
Global mean sea level rise (m)
1.0
0.8
0.6
0.4
0.2
0.0
Sum
Thermal expansion
Glaciers
Greenland ice sheet
Antarctic ice sheet
Greenland ice-sheet rapid dynamics
Land water storage
Extrapolated ice-sheet observations
2000
2020
2040
2060
2080
2100
Year

# Partial surveys



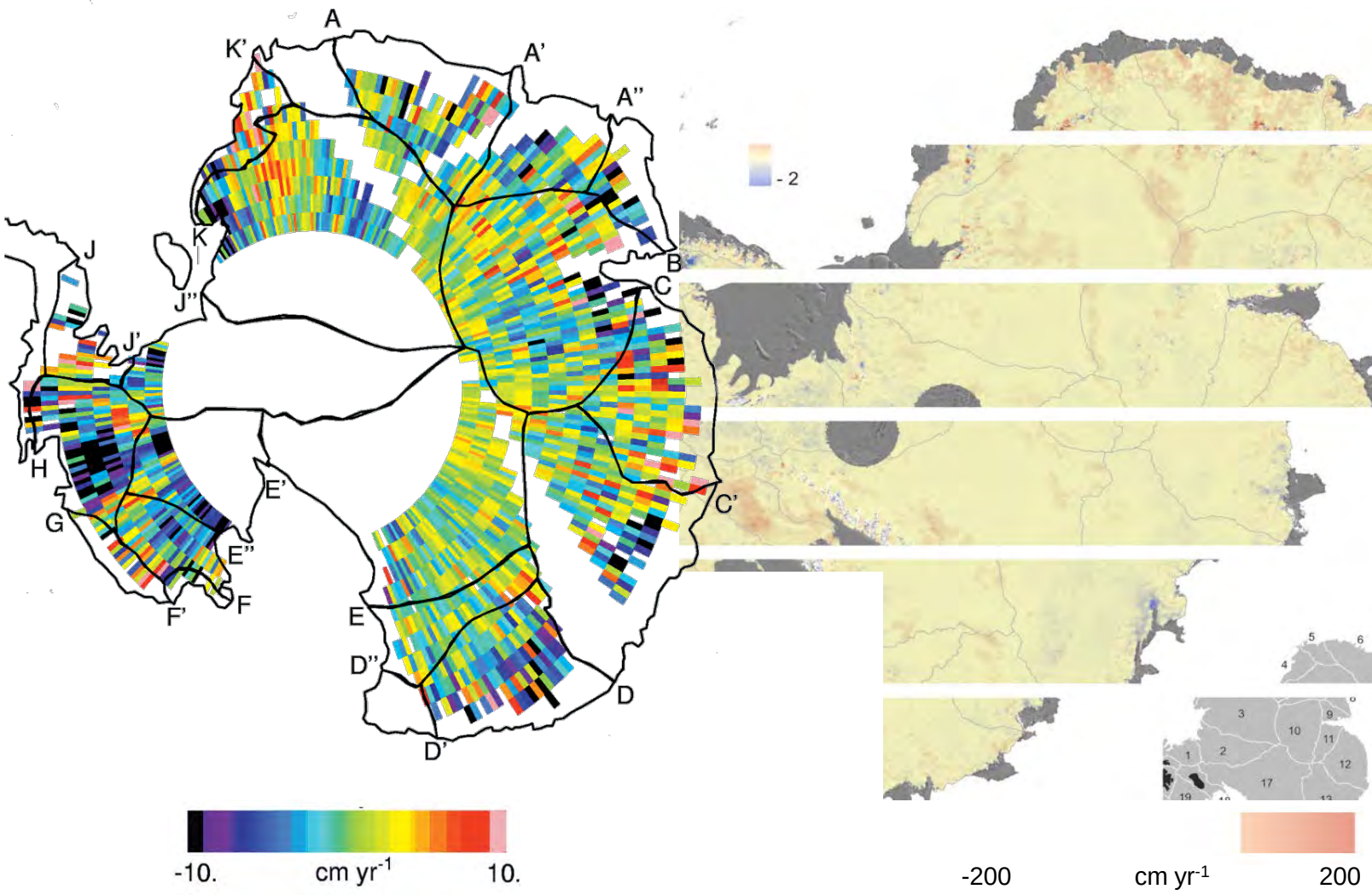

Shepherd t al., 2012

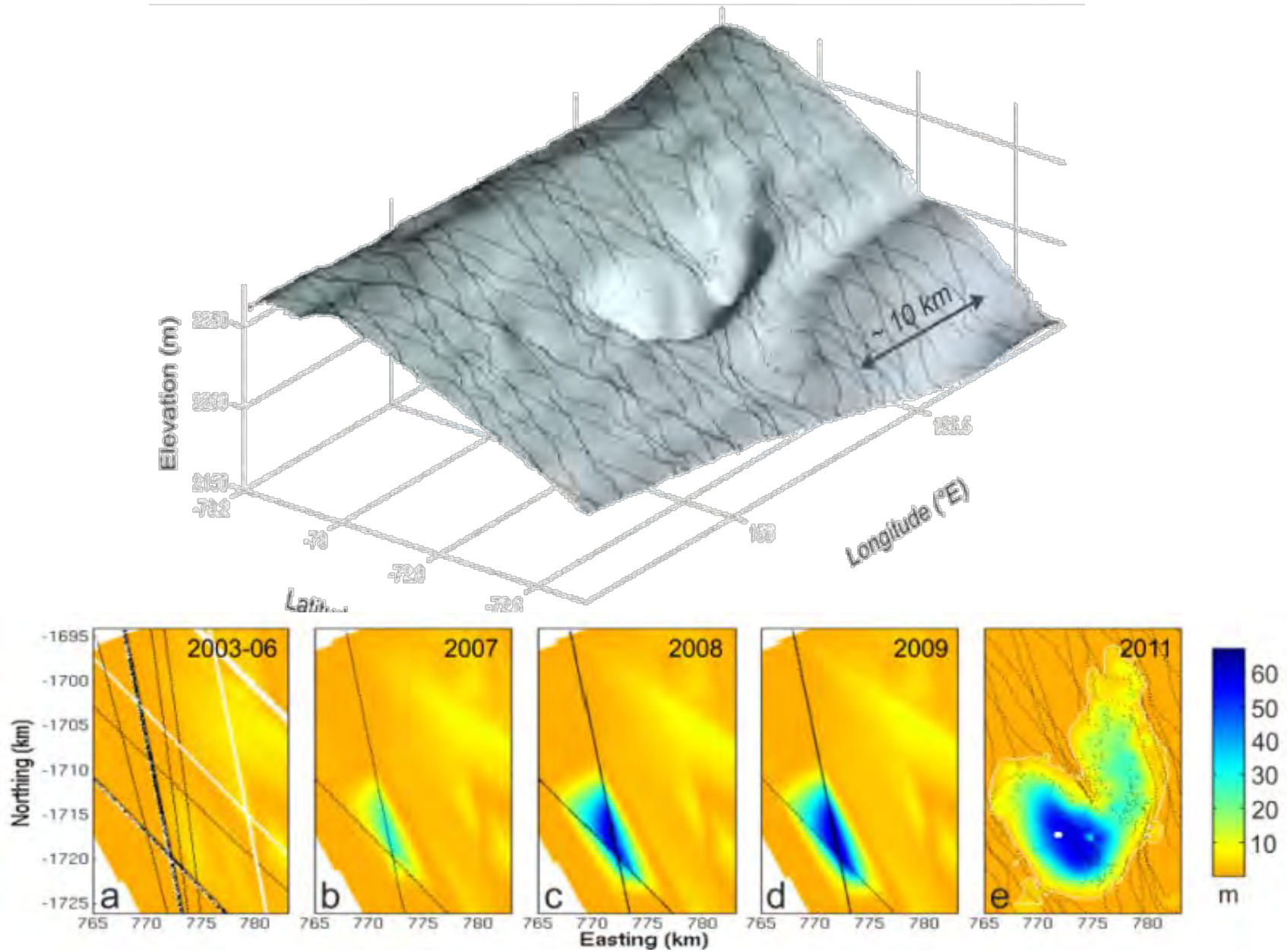



McMillan et al., 2014

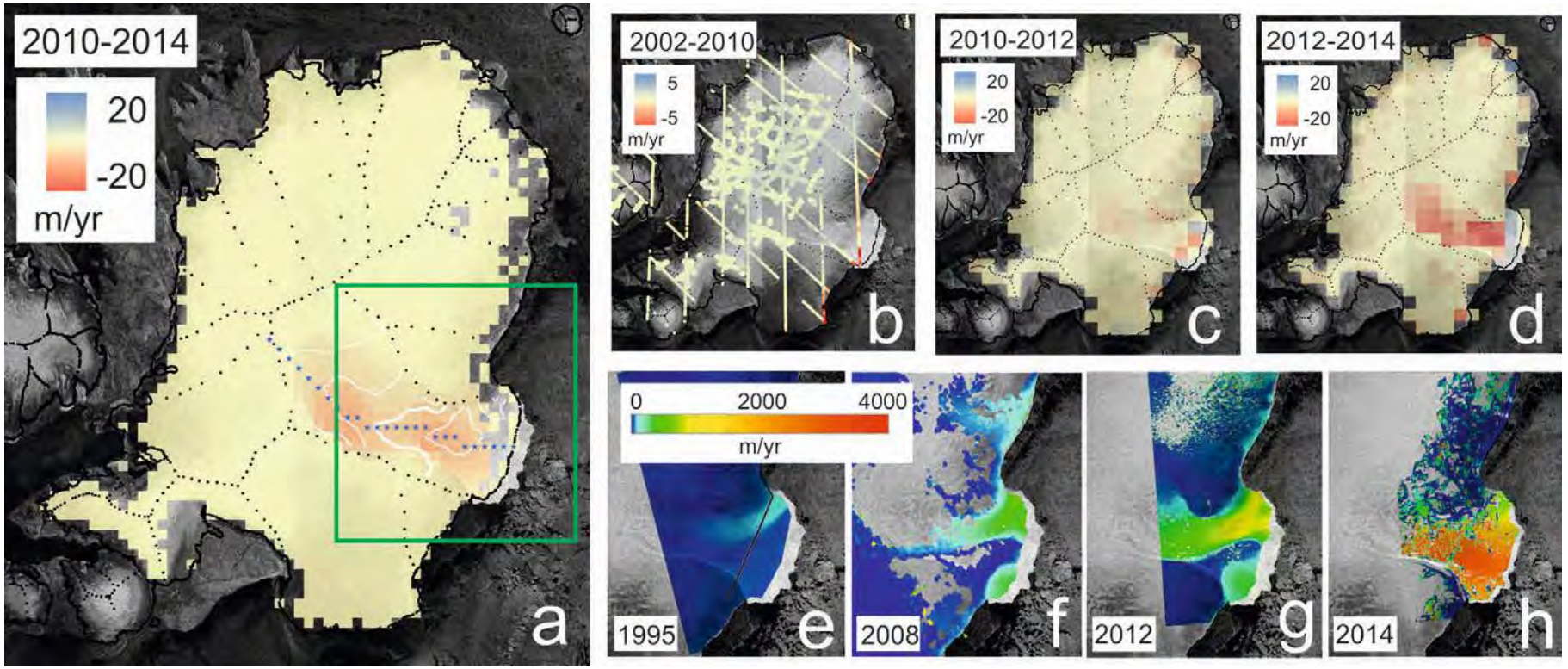
<1992-1996>

<2010-2014>

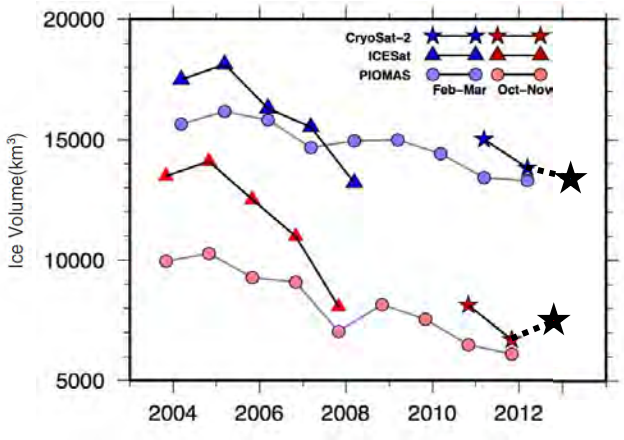




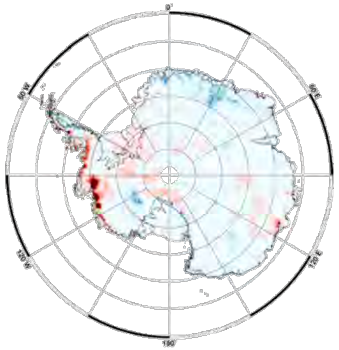

McMillan et al., 2013

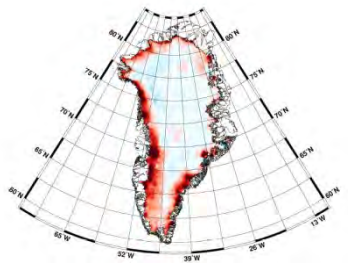

2010-2014
20
-20
m/yr
a
2002-2010
5
-5
m/yr
b
2010-2012
20
-20
m/yr
c
2012-2014
20
-20
m/yr
d
0
2000
4000
m/yr
1995
e
2008
f
2012
g
2014
h

## P1 Trends in Arctic sea ice thickness

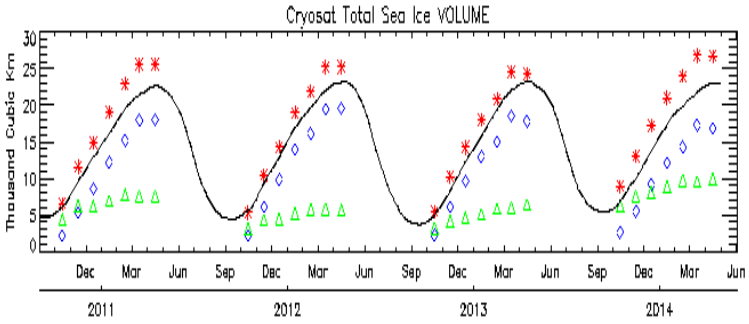



## P2 Ice sheet contribution to sea level

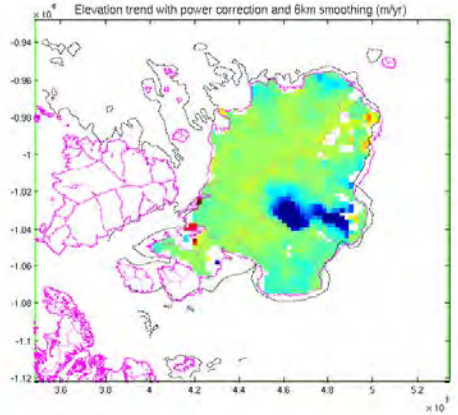




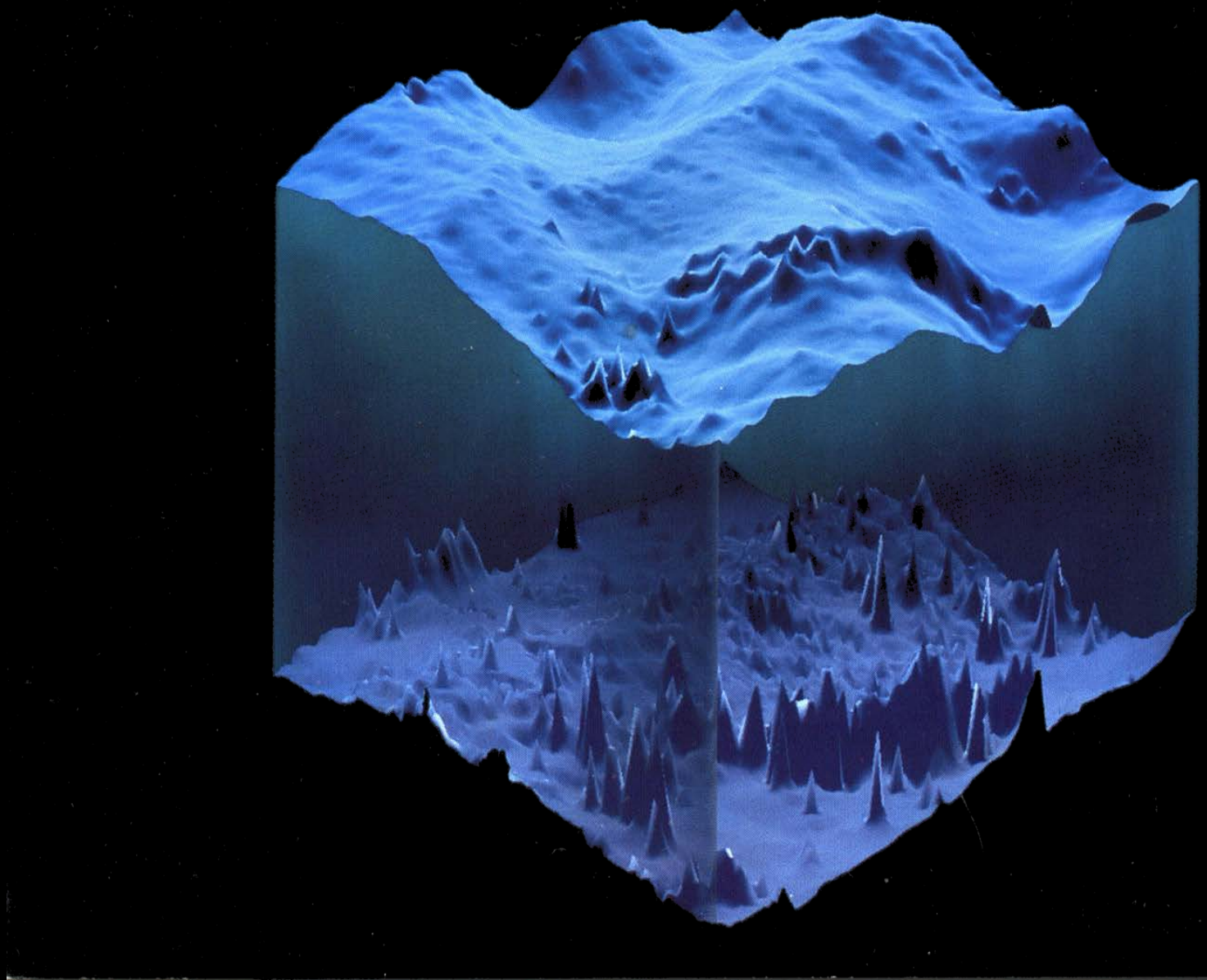
## S1 Arctic & Antarctic sea ice cycle

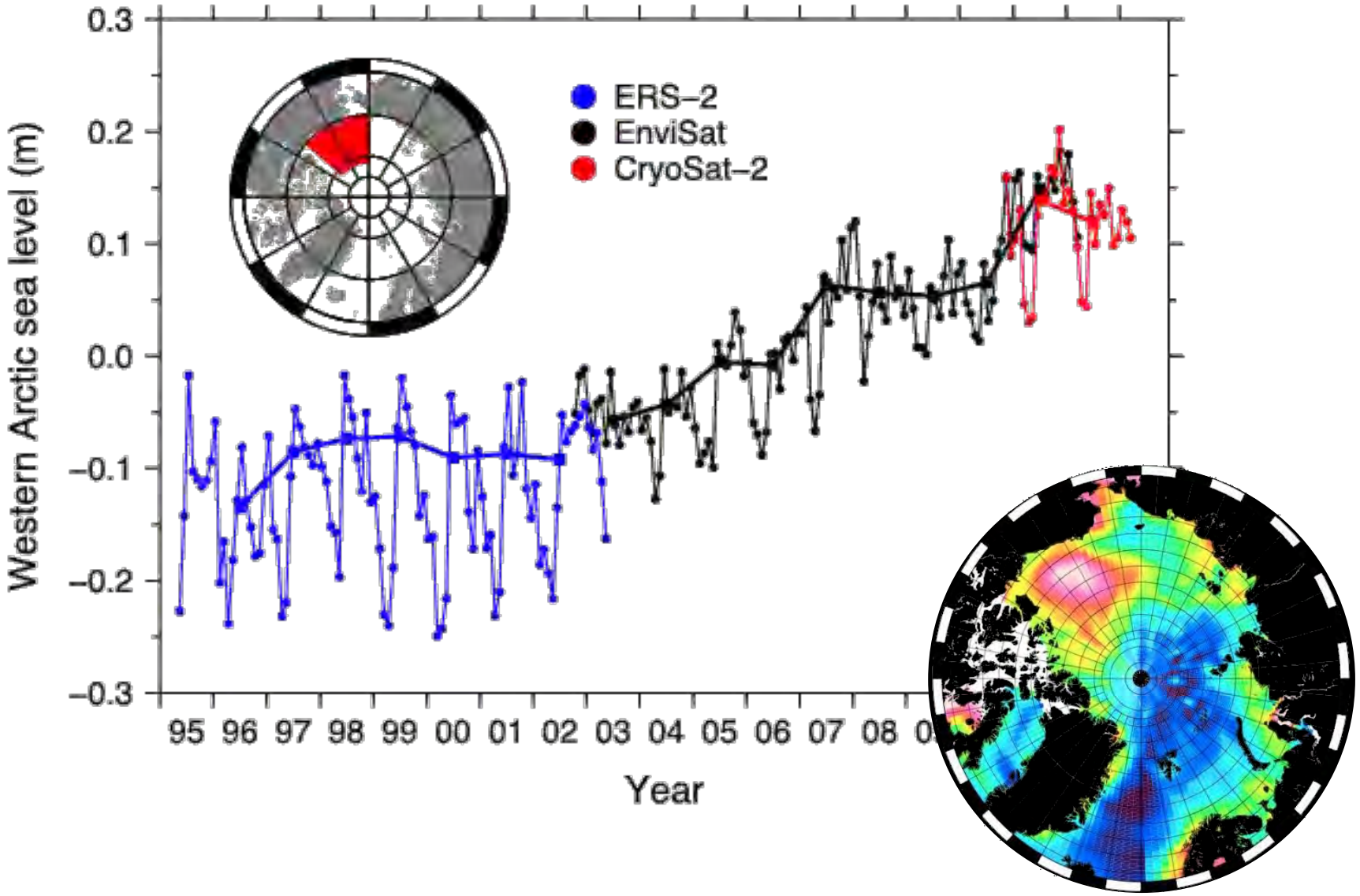


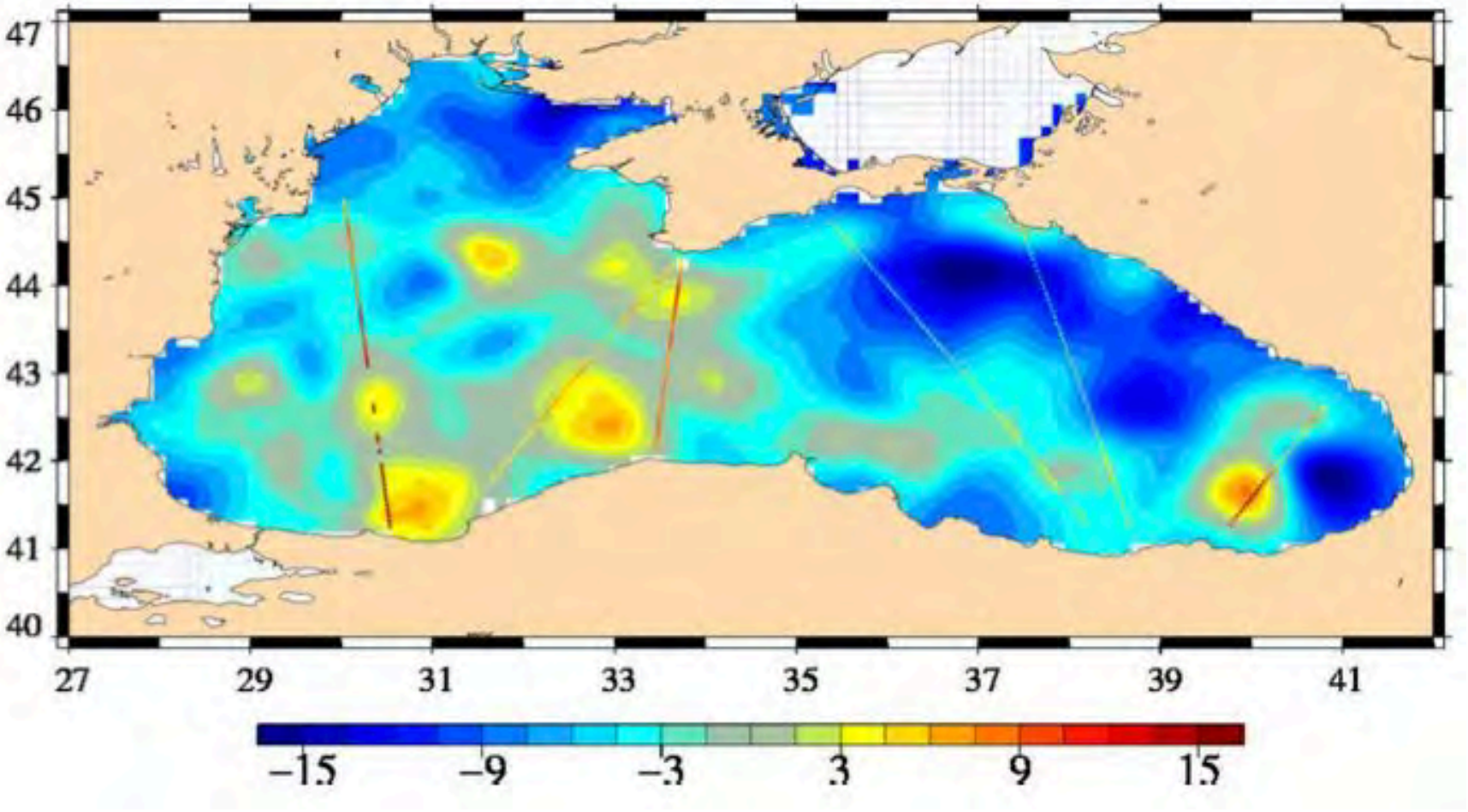

## S2 Ice caps and glaciers

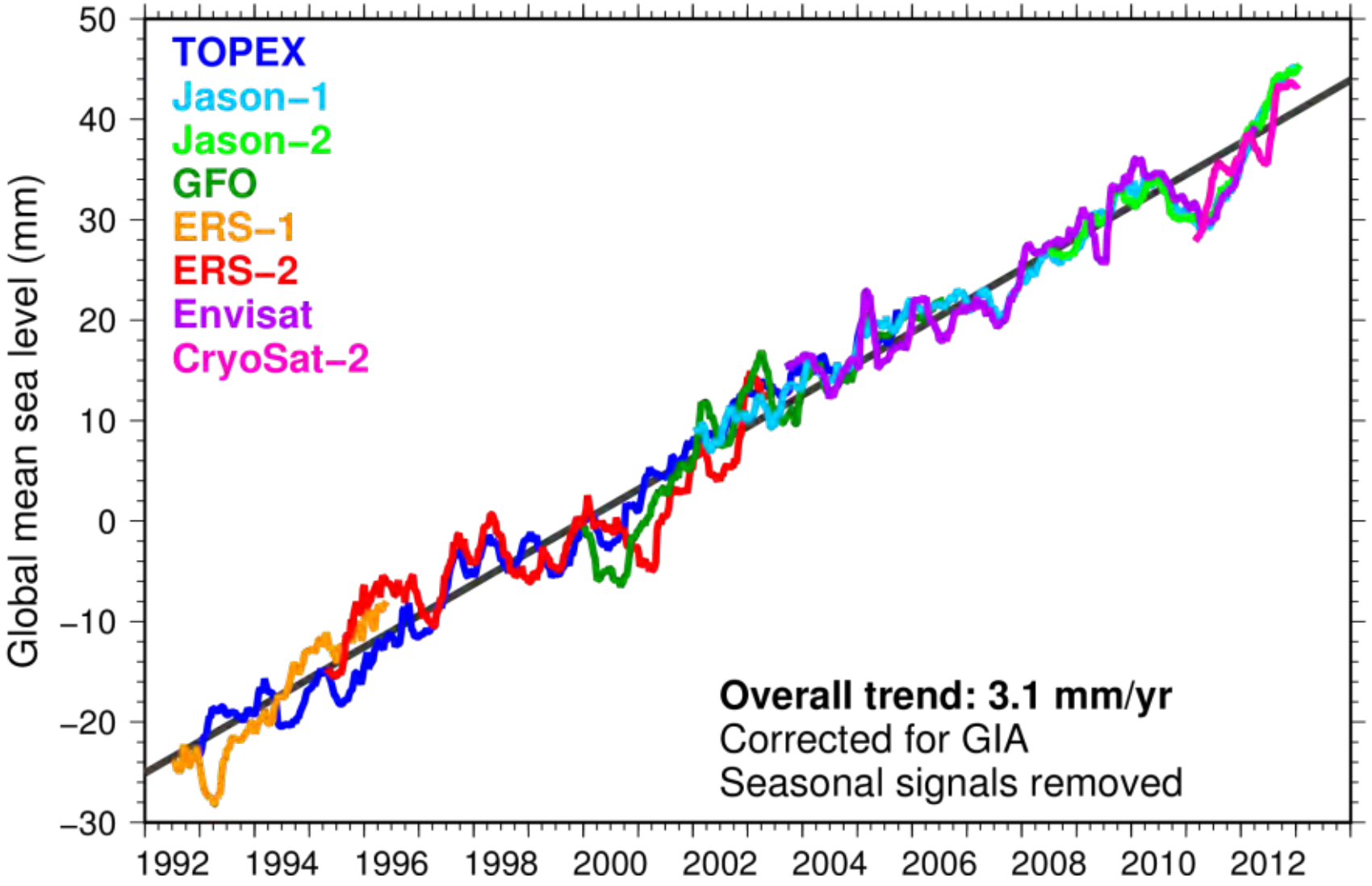


# Wider scientific achievements

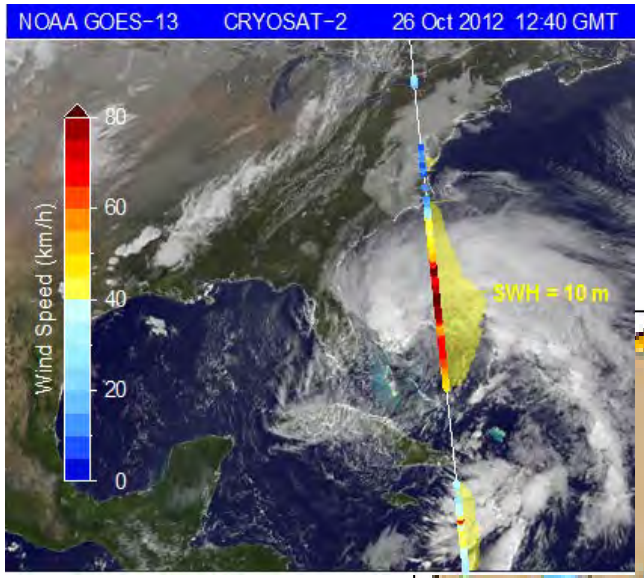


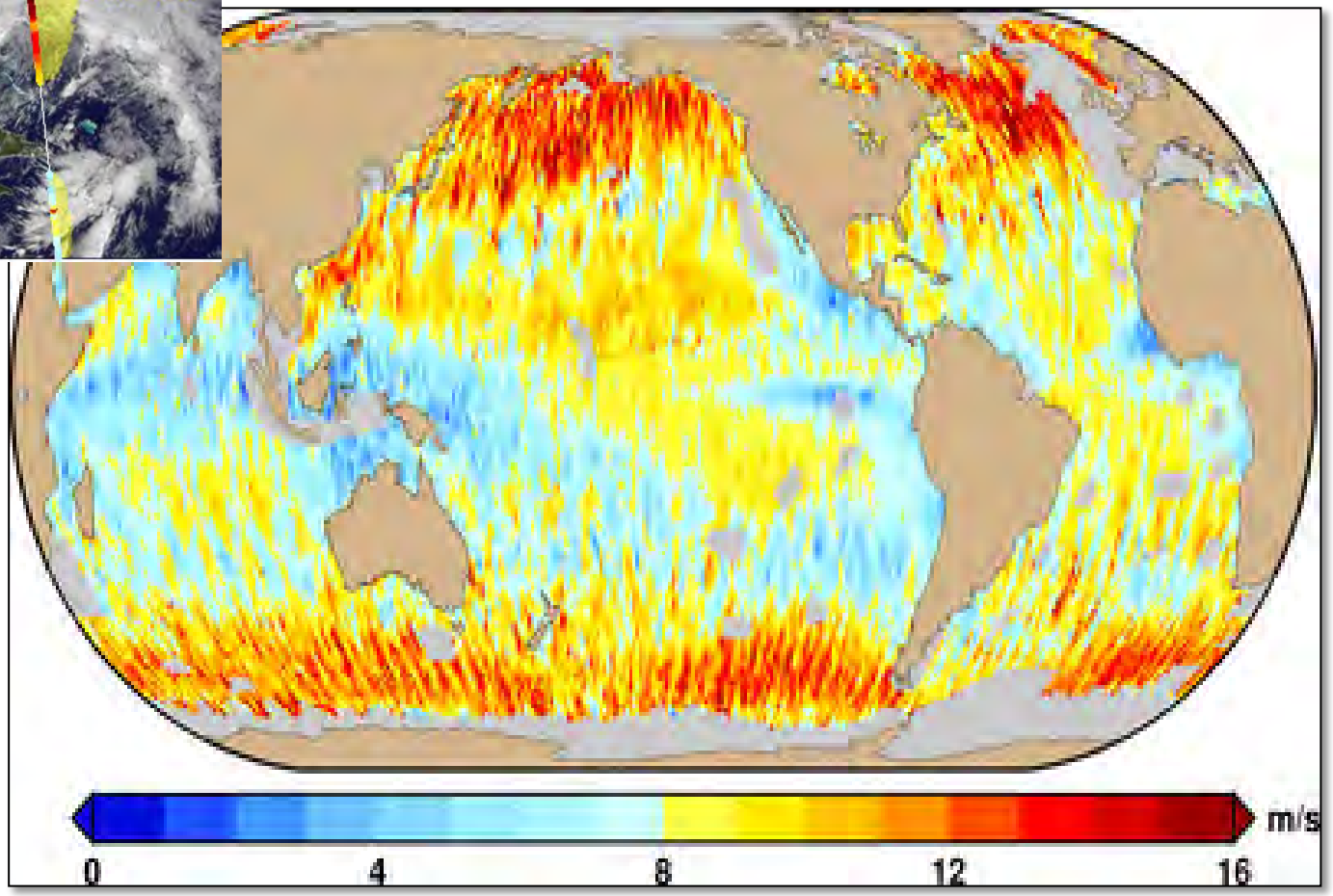

ERS–2
EnviSat
CryoSat–2
Western Arctic sea level (m)
0.3
0.2
0.1
0.0
–0.1
–0.2
–0.3
95 96 97 98 99 00 01 02 03 04 05 06 07 08
Year


47
46
45
44
43
42
41
40
27
29
31
33
35
37
39
41
−15
−9
−3
3
9
15

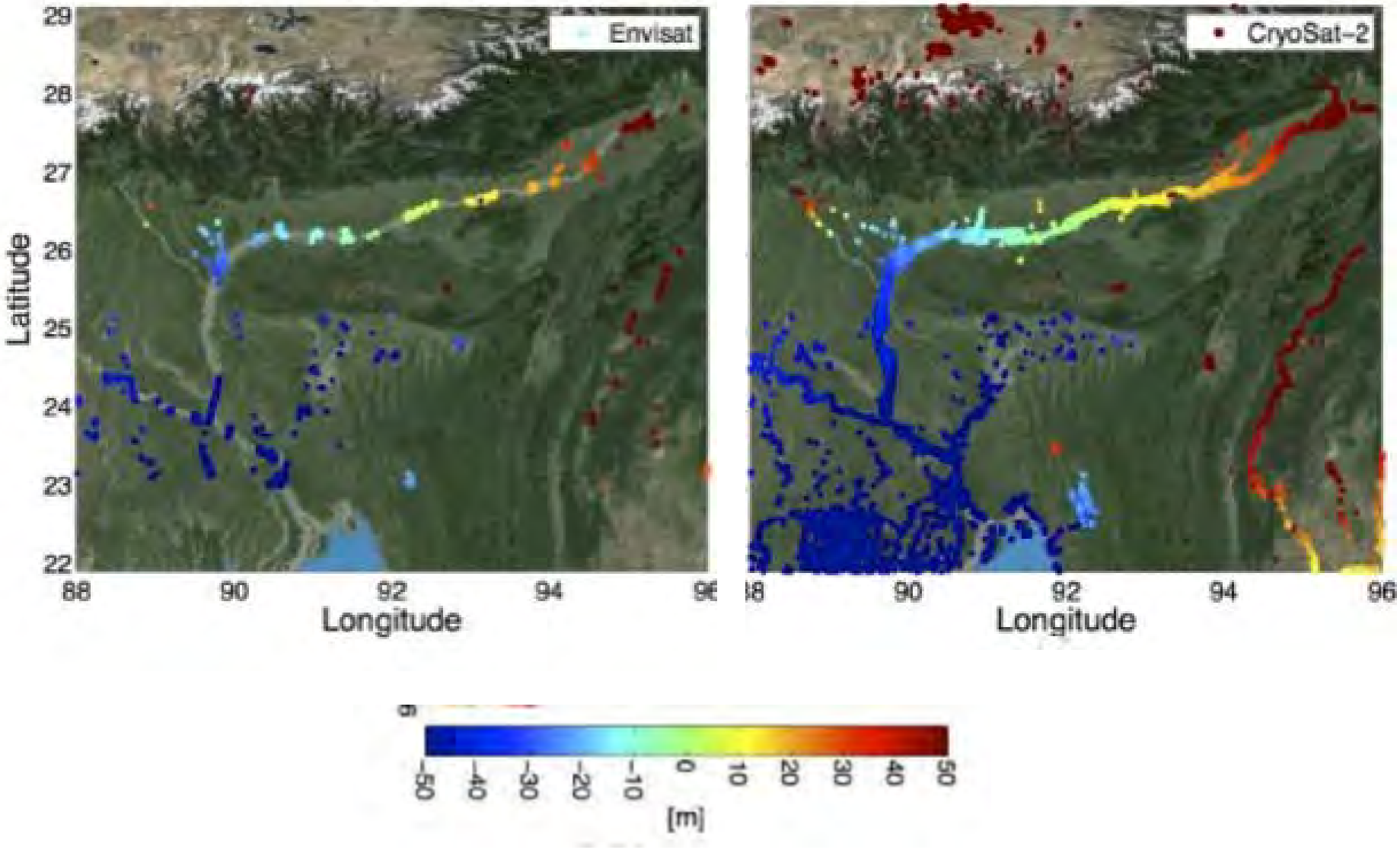


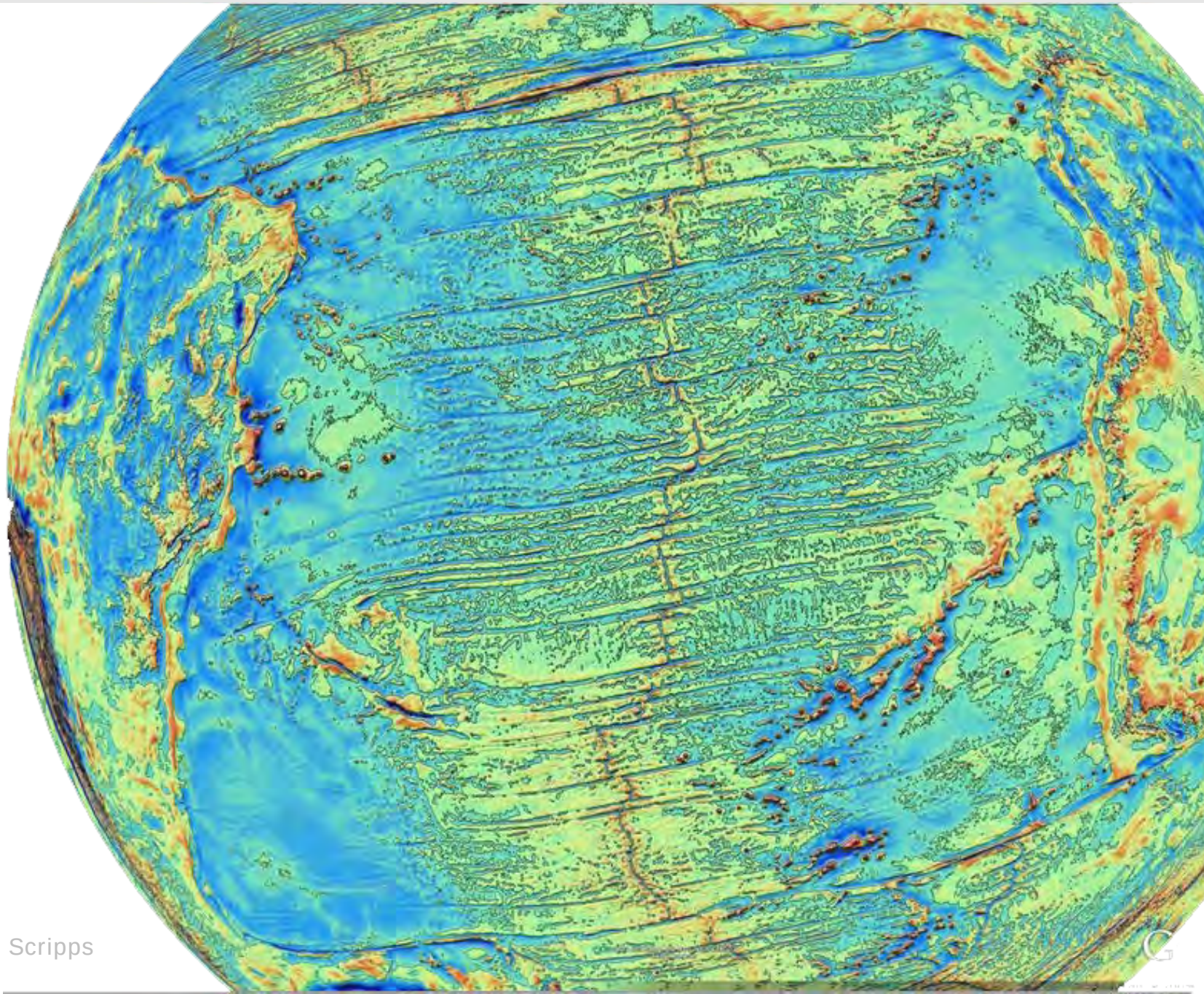

R. Scharoo, Eumetsat


NOAA GOES-13
CRYOSAT-2
26 Oct 2012 12:40 GMT
Wind Speed (km/h)
80
60
40
20
0
SWH = 10 m

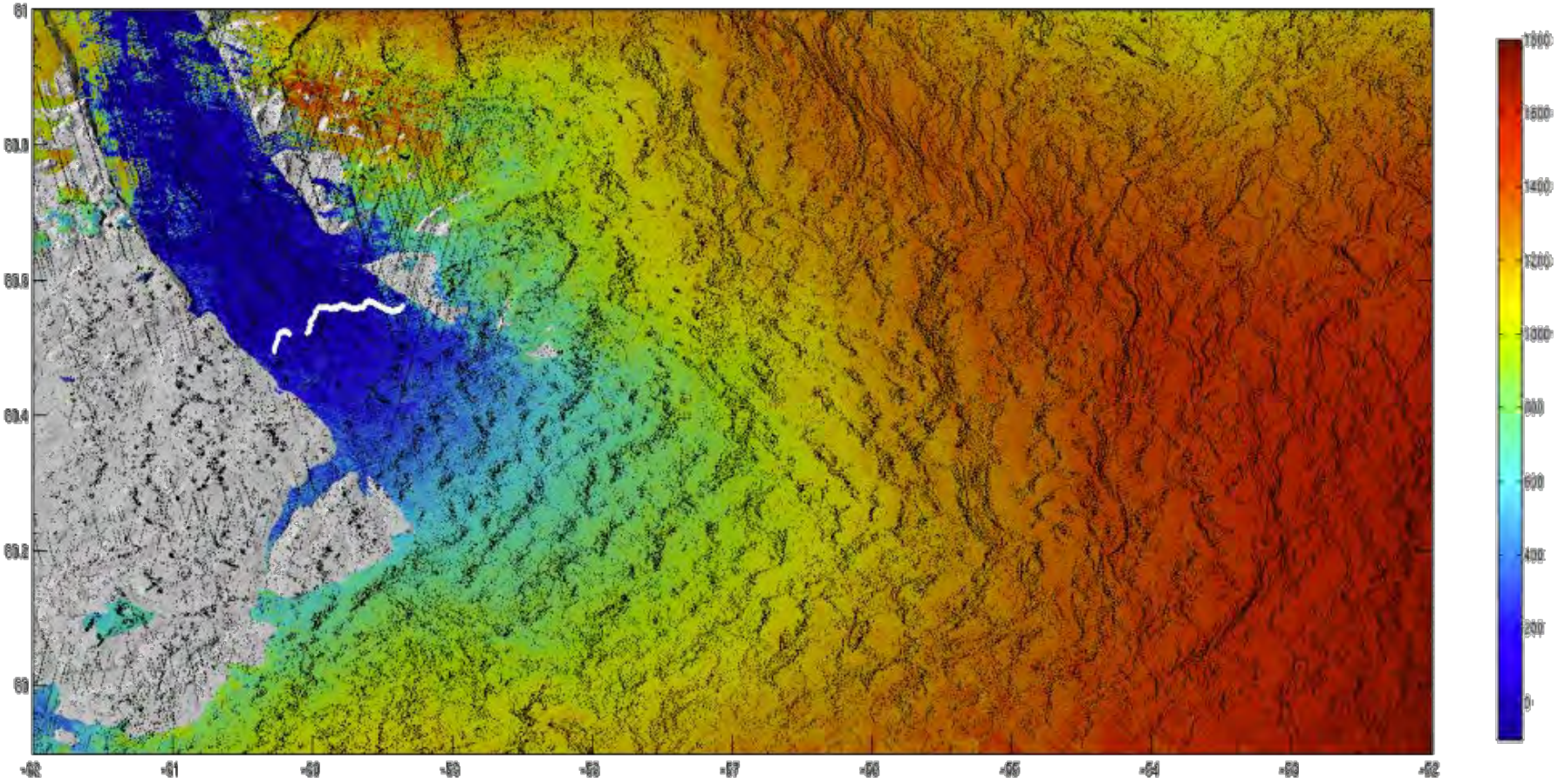

m/s
0
4
8
12
16

W. Smith, NOAA


Envisat
CryoSat-2
Latitude
Longitude
Longitude
29
28
27
26
25
24
23
22
88
90
92
94
90
92
94
96
-50
-40
-30
-20
-10
0
10
20
30
40
50
[m]



D. Sandwell, Scripps



Gourmelen, 2013

- Primary and secondary mission objectives met

| Requirements | Sea Ice $10^5$ Km$^2$ | Ice Sheets $13.8 \cdot 10^6$ Km$^2$ |
|---|---|---|
| Science requirement | 3.5 cm/yr | 0.76 cm/yr |
| Observed | 3.0 cm/yr | 0.2 cm/yr |

- Fivefold improvement in sampling of ice sheet margins
- Tenfold improvement in capacity to detect leads
- First assessment of entire Antarctic and Greenland ice sheet
- First assessment of entire Arctic sea ice
- Demonstrates conventional altimetry prone to omission bias
- Mass loss from AIS and GrIS has increased over time
- Recovery in Arctic sea ice volume in 2014


Elevation change (m/y)
-1
+1