Effects of Climate Change on Sea Level

Ole B. Andersen

Acknowledgement:

P. Knudsen, P. L. Svendsen

E. Leuliette(NOAA), G. Piccioni(TUM)

DTU Space
National Space Institute

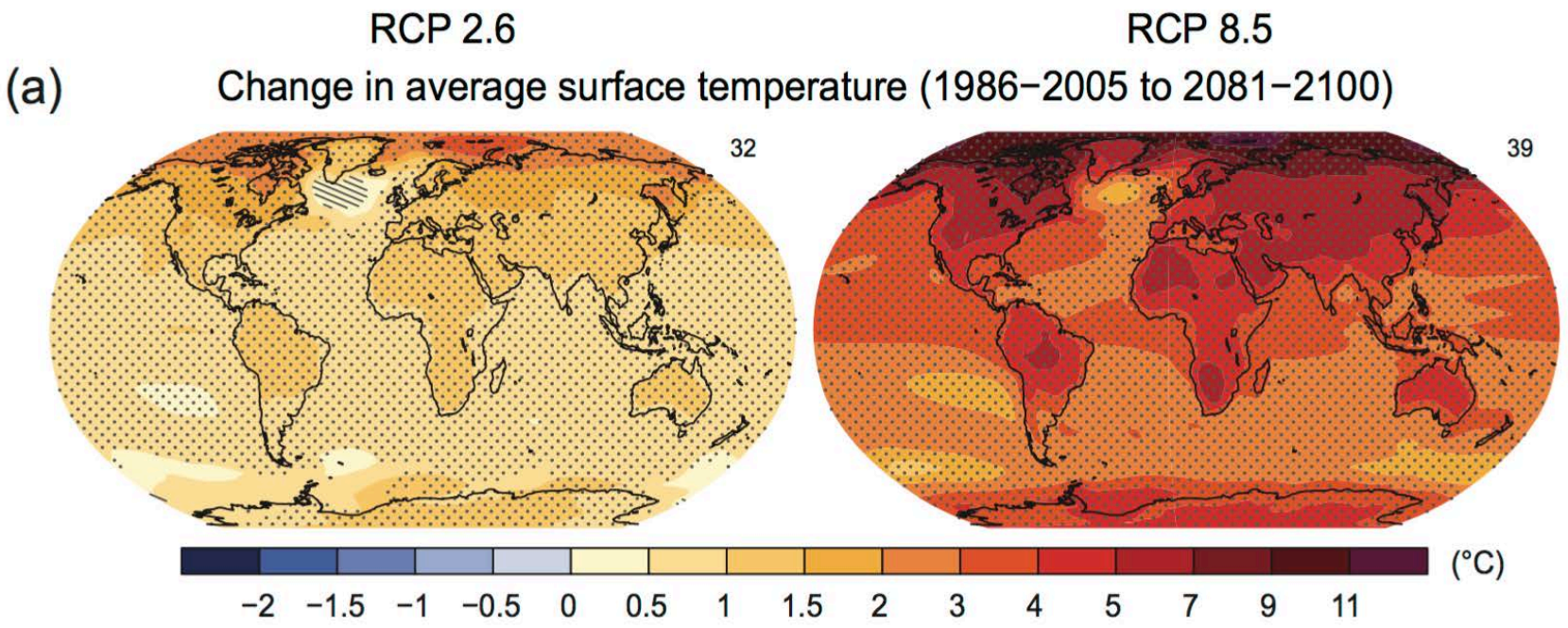
Outline

- Climate change, IPCC and sea level.
- Data behind the IPCC sea level estimates
  - Satellite altimetry and tide gauges.
- Global sea level change (shorter – longer times – sea level reconstruction)
- Explaining current sea level changes / Global sea level budget.
- Regional sea level change.

Arctic ocean.

Future of sea level research.

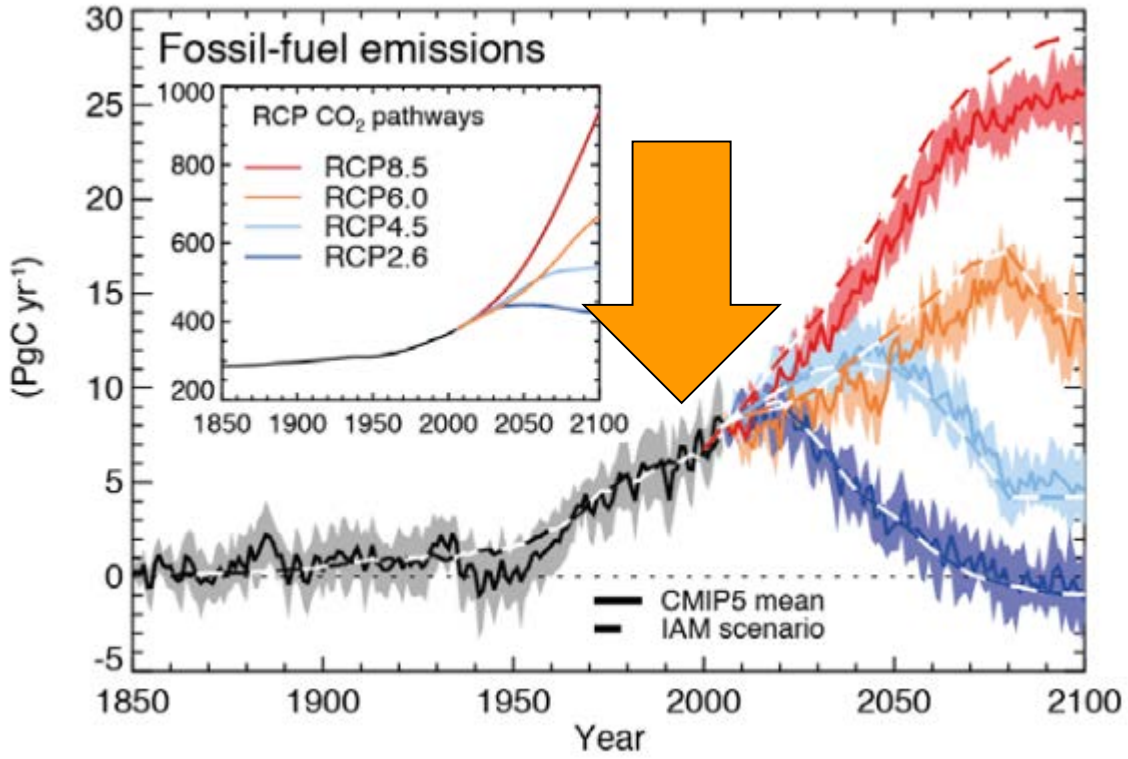
Future climate change



Climate Change

IPCC Assessment Report 5 provides a new assessment of sea level rise:

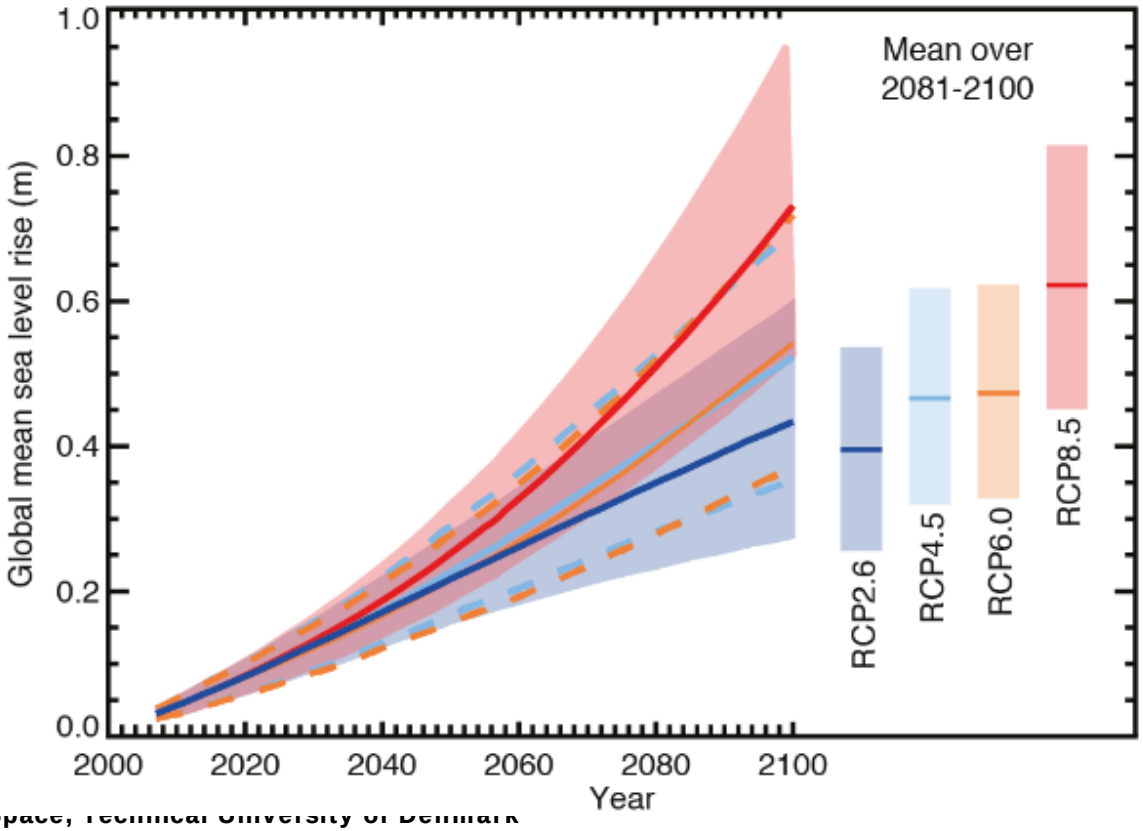
- Climate scenarios:

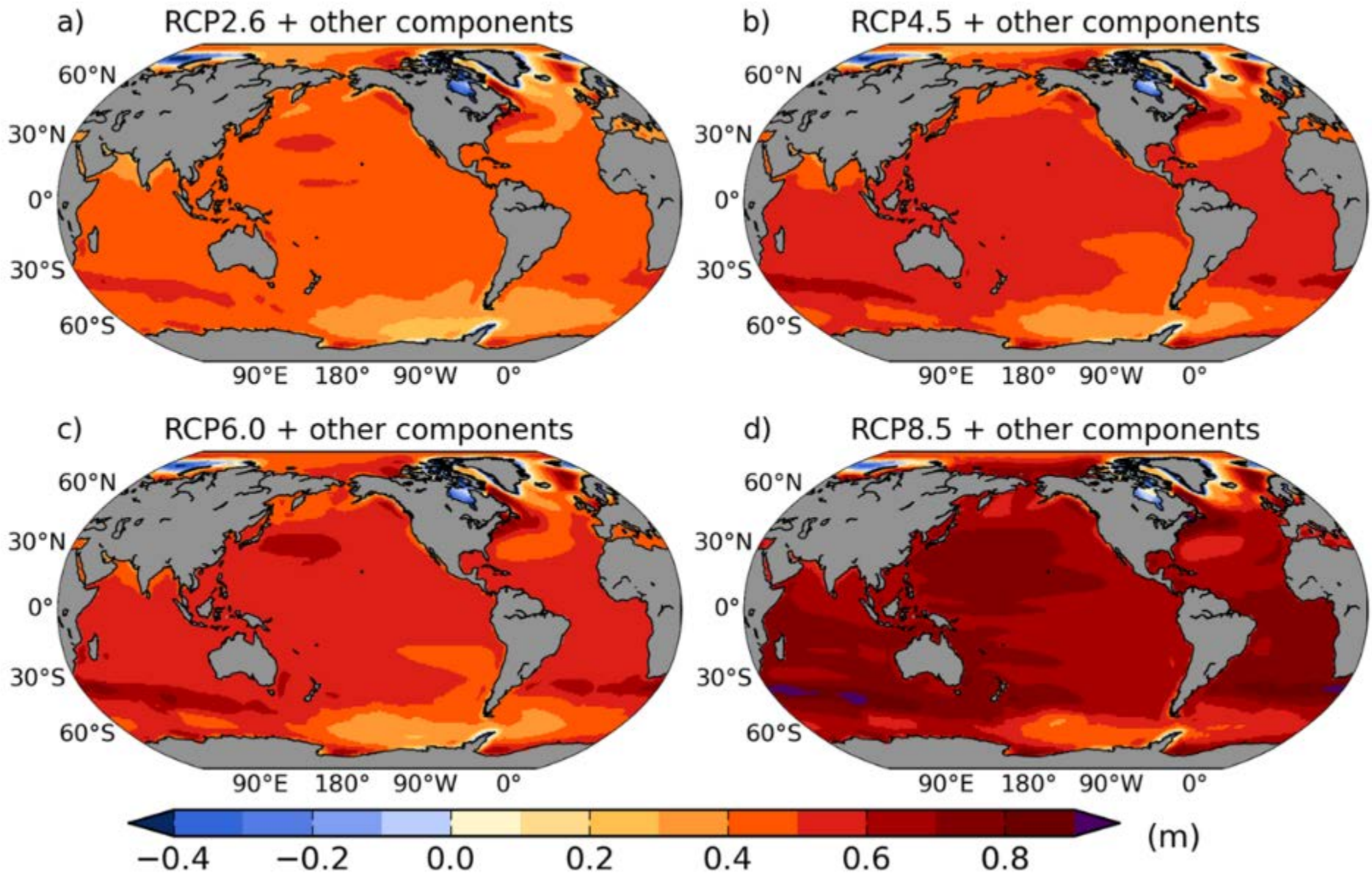


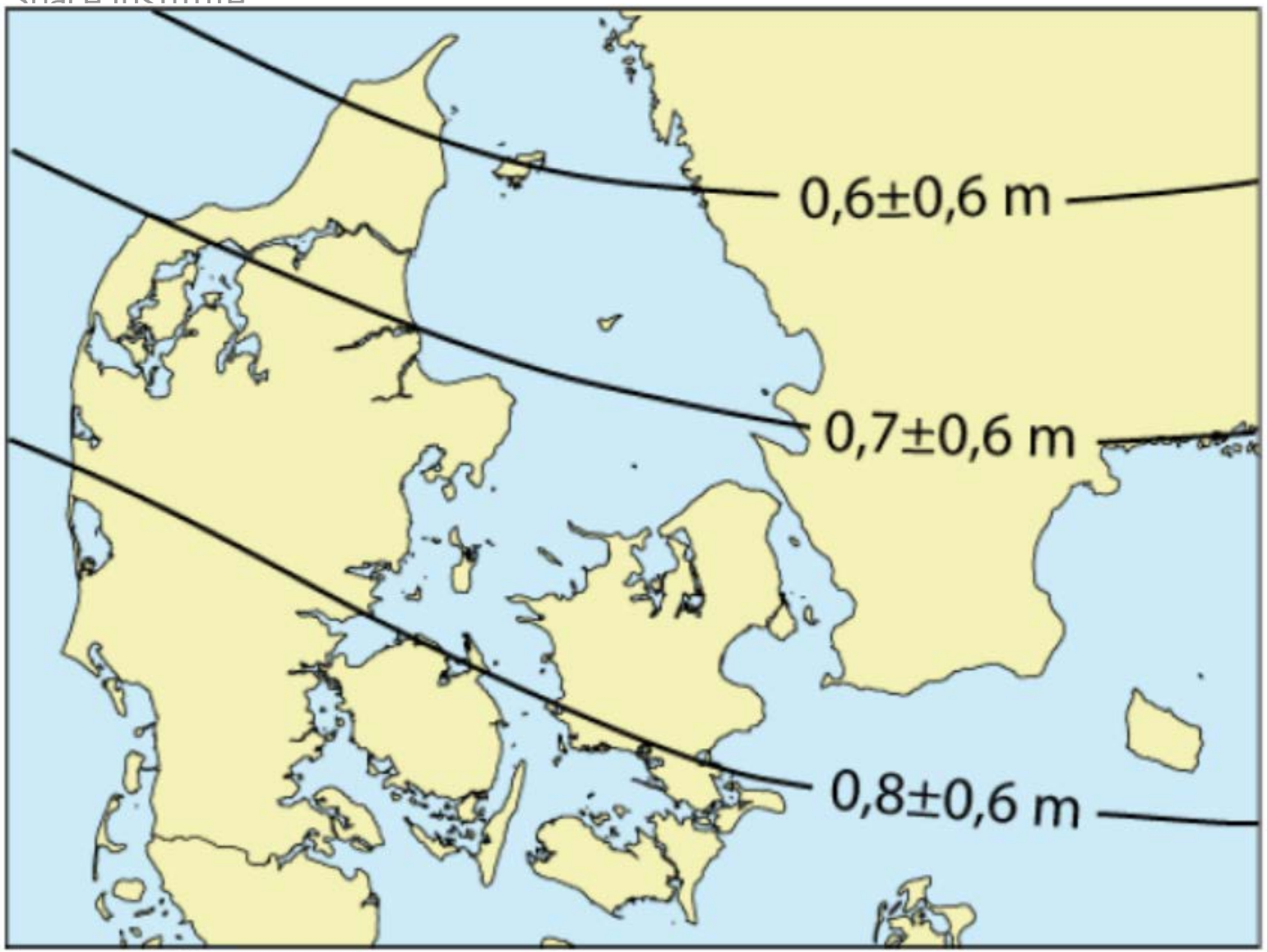
Climate Change

IPCC Assessment Report 5 provides a new assessment of sea level rise:

- Projections for 2013 - 2100

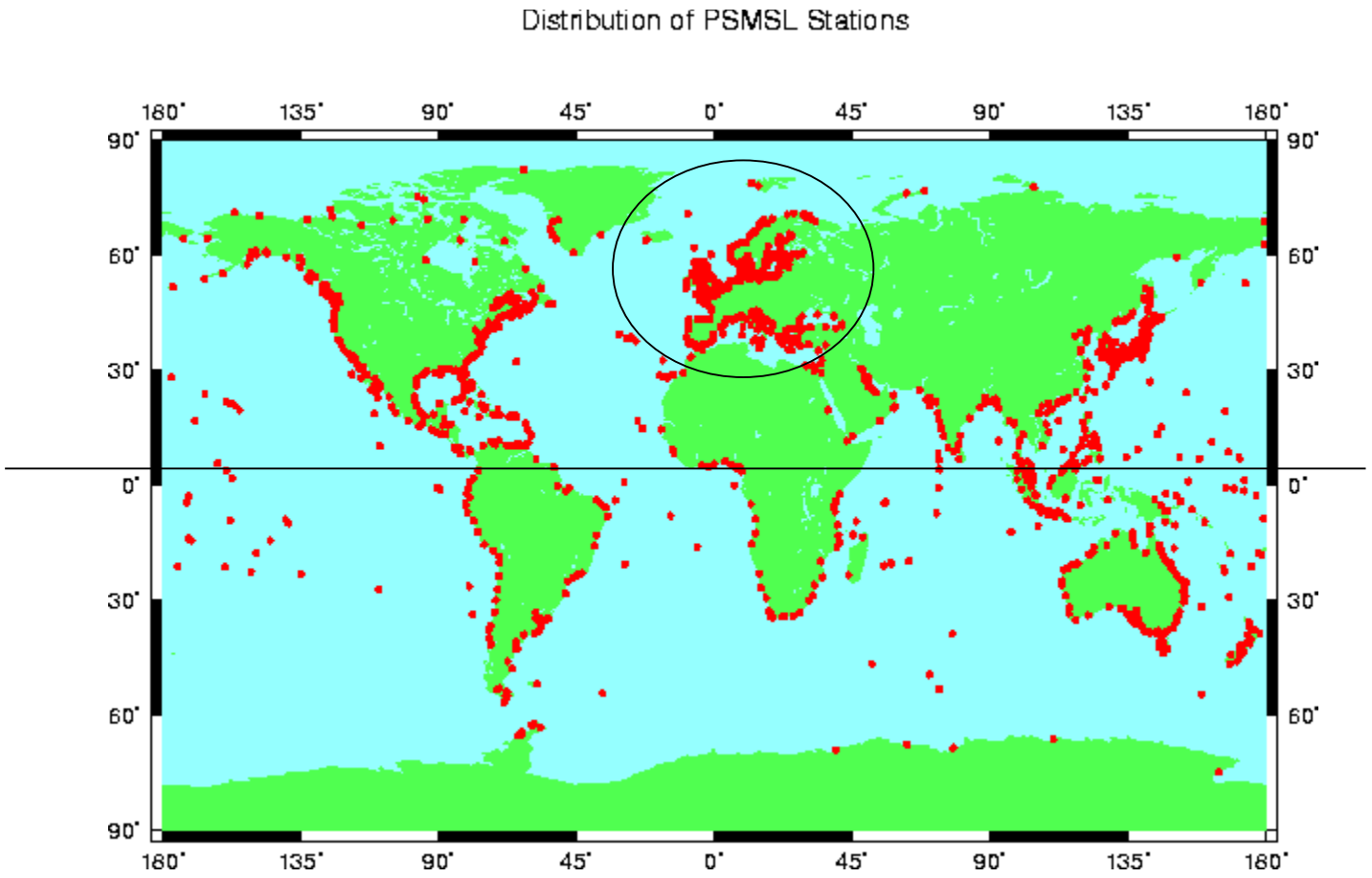



a) RCP2.6 + other components
b) RCP4.5 + other components
c) RCP6.0 + other components
d) RCP8.5 + other components
60°N
30°N
0°
30°S
60°S
90°E
180°
90°W
0°
−0.4
−0.2
0.0
0.2
0.4
0.6
0.8
(m)

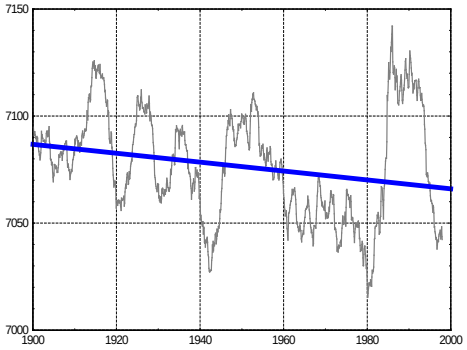


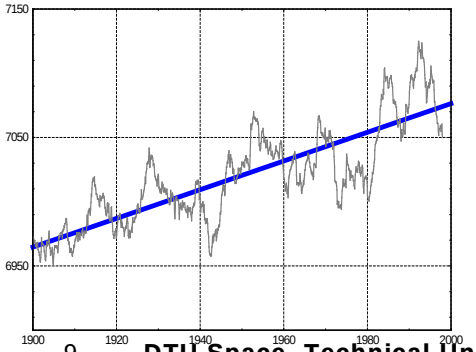
SEA LEVEL PROJECTIONS CURRENTLY HAVE LARGE UNCERTAINTIES……..

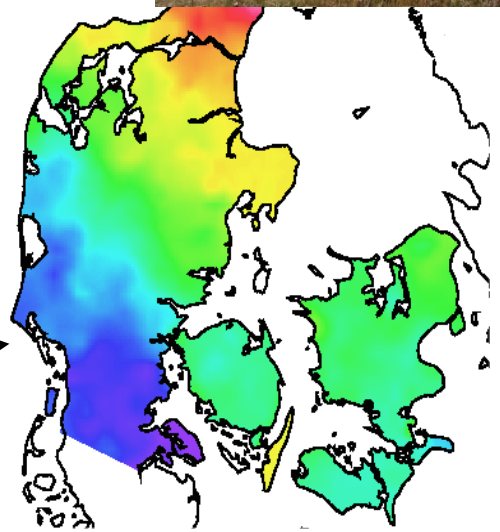
PSMSL tide gauges

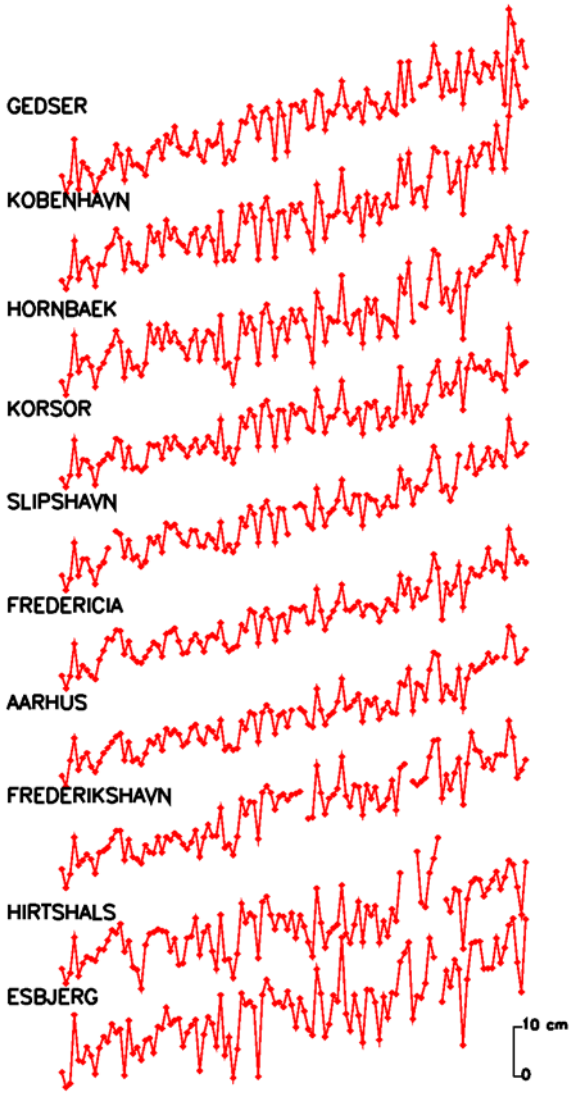


Tide gauges measures relative SL



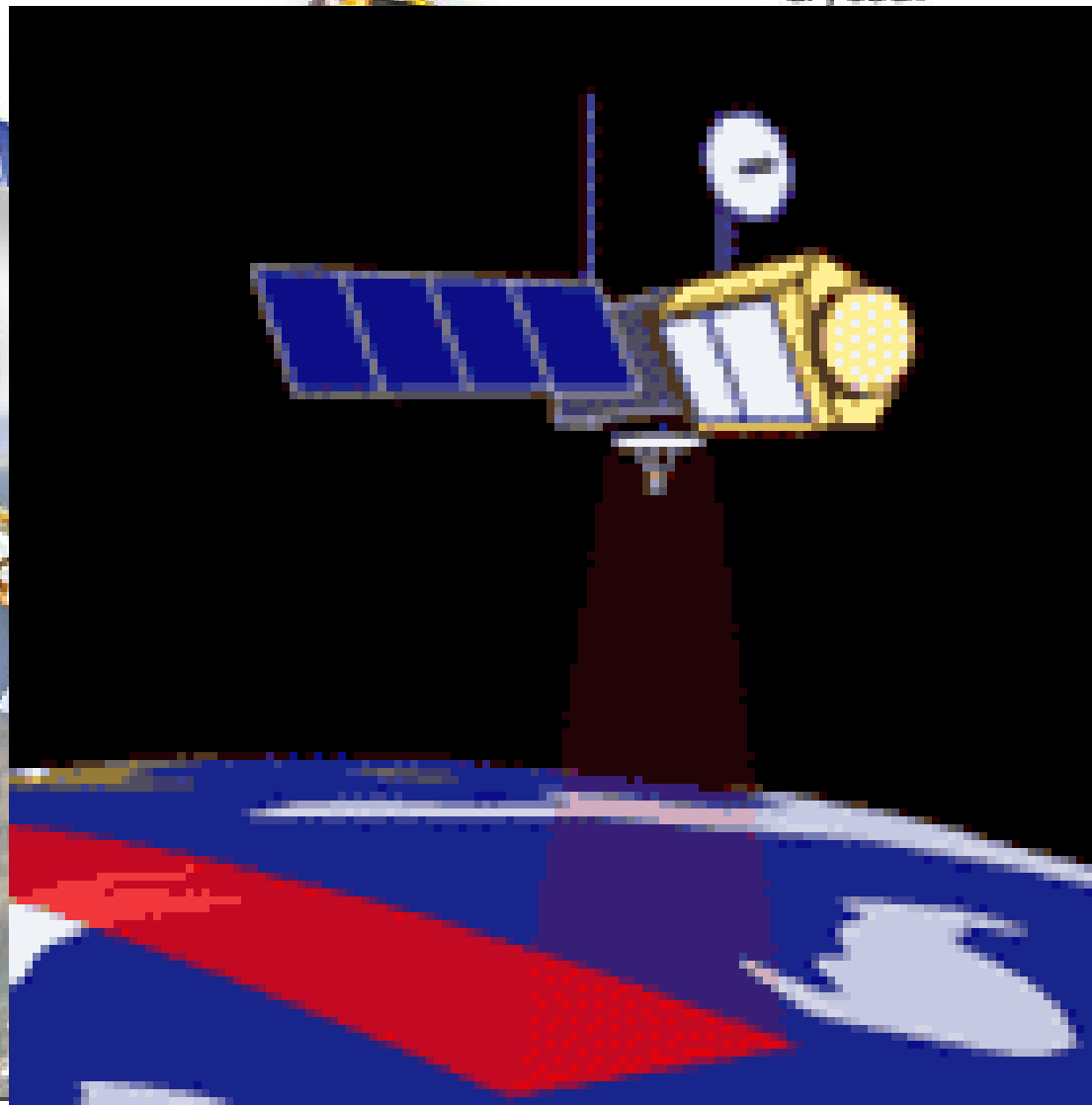




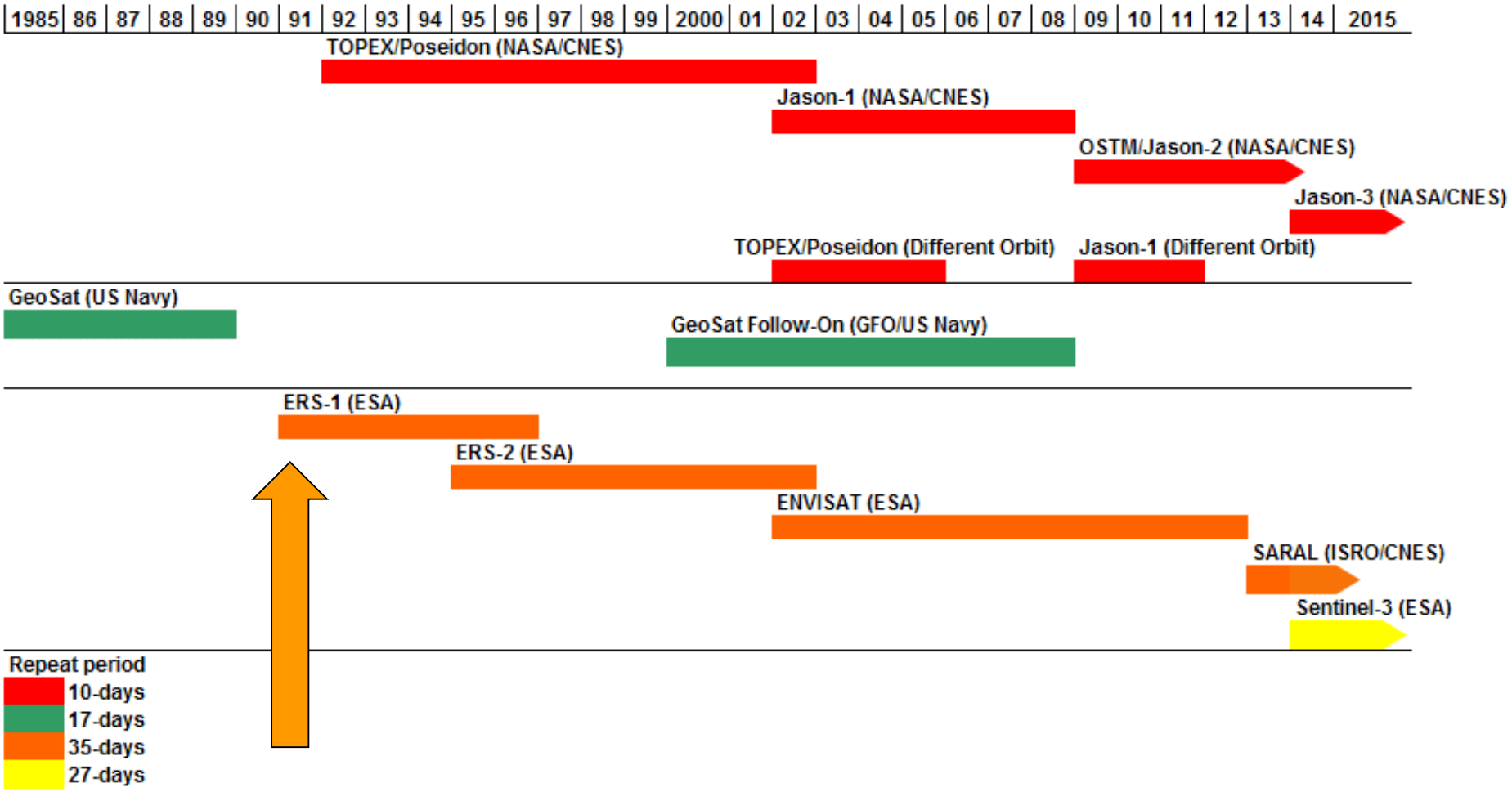


Bästad, Sweden, 2016

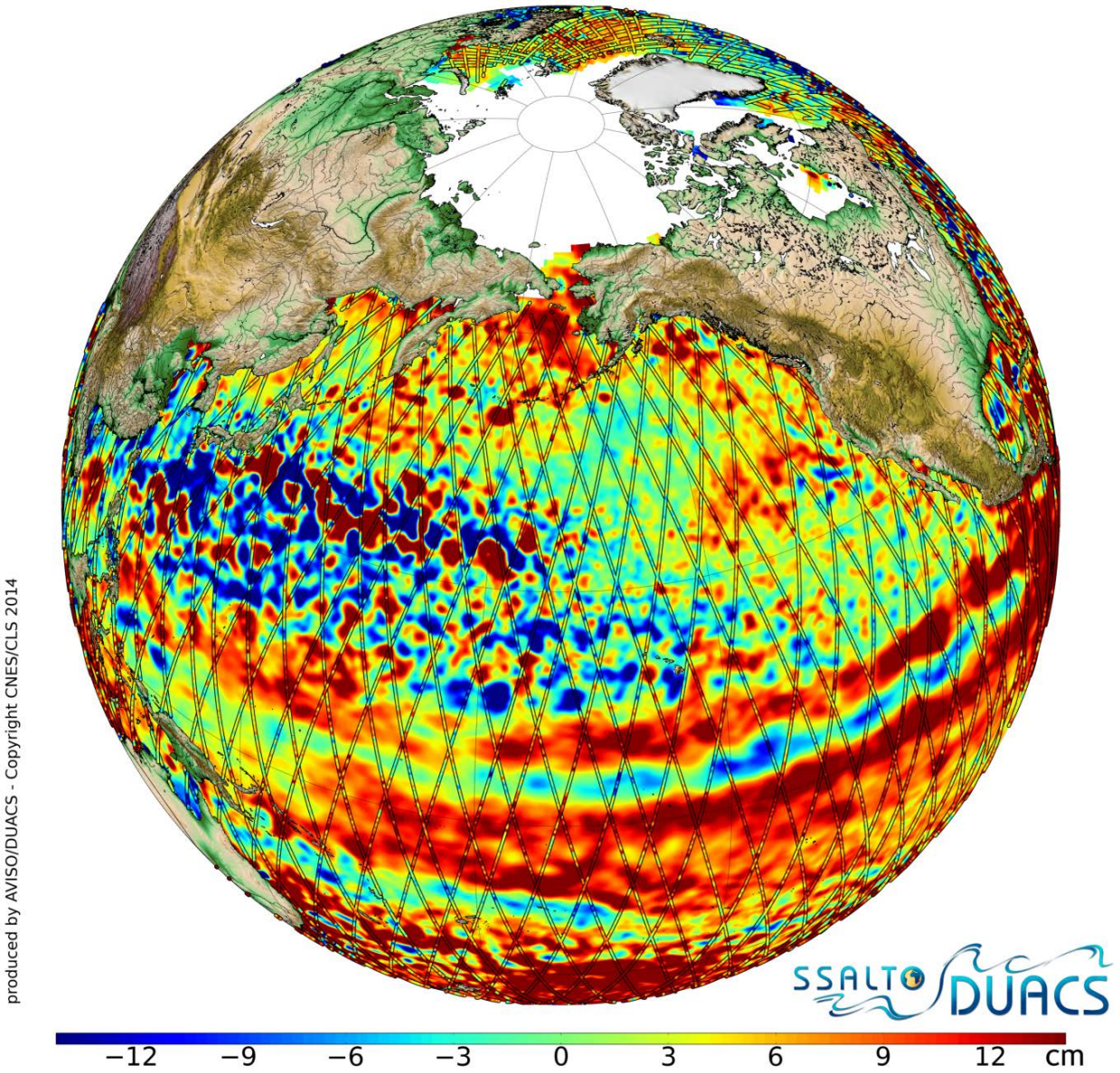
Satellite Altimetry measures geocentric sea level

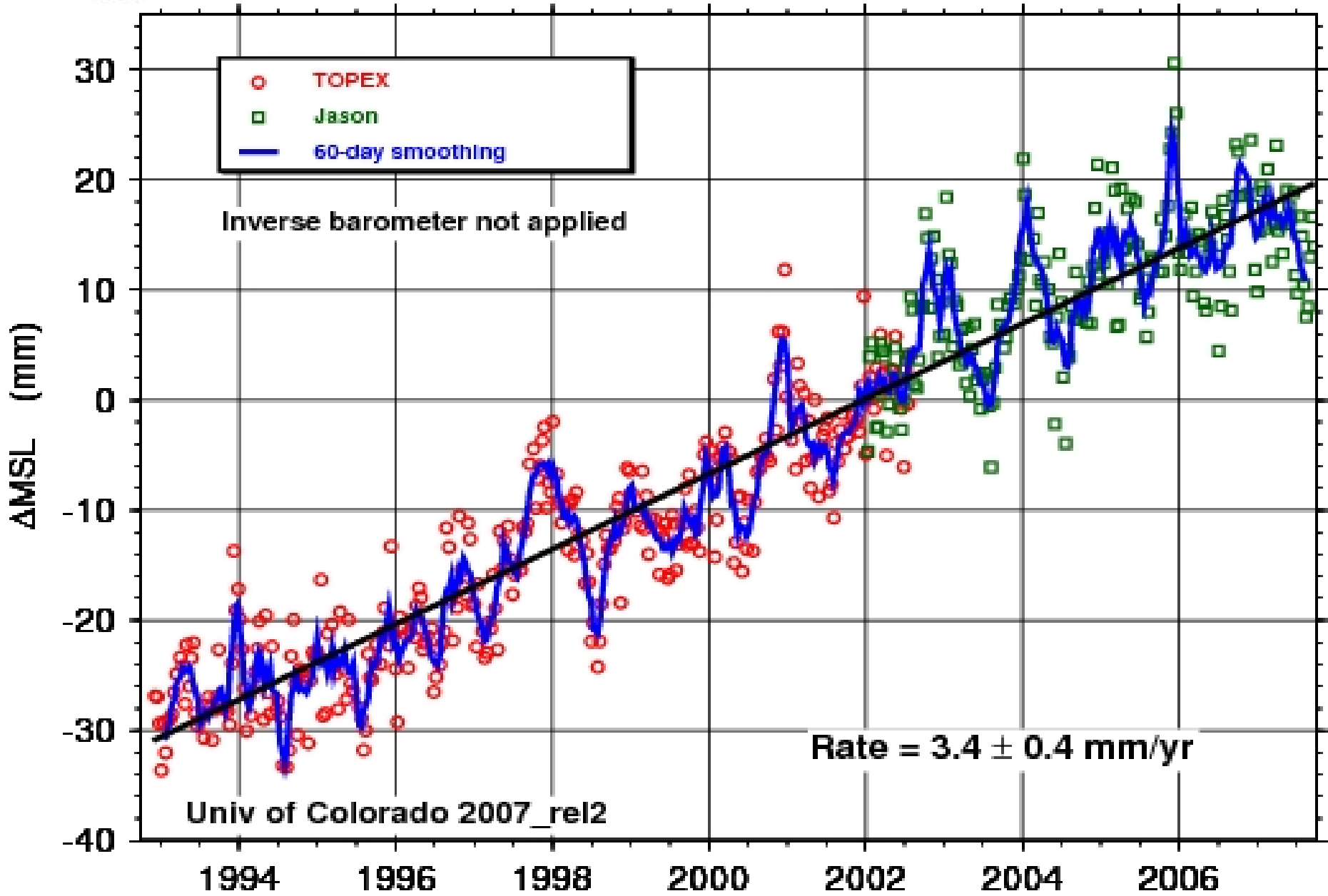


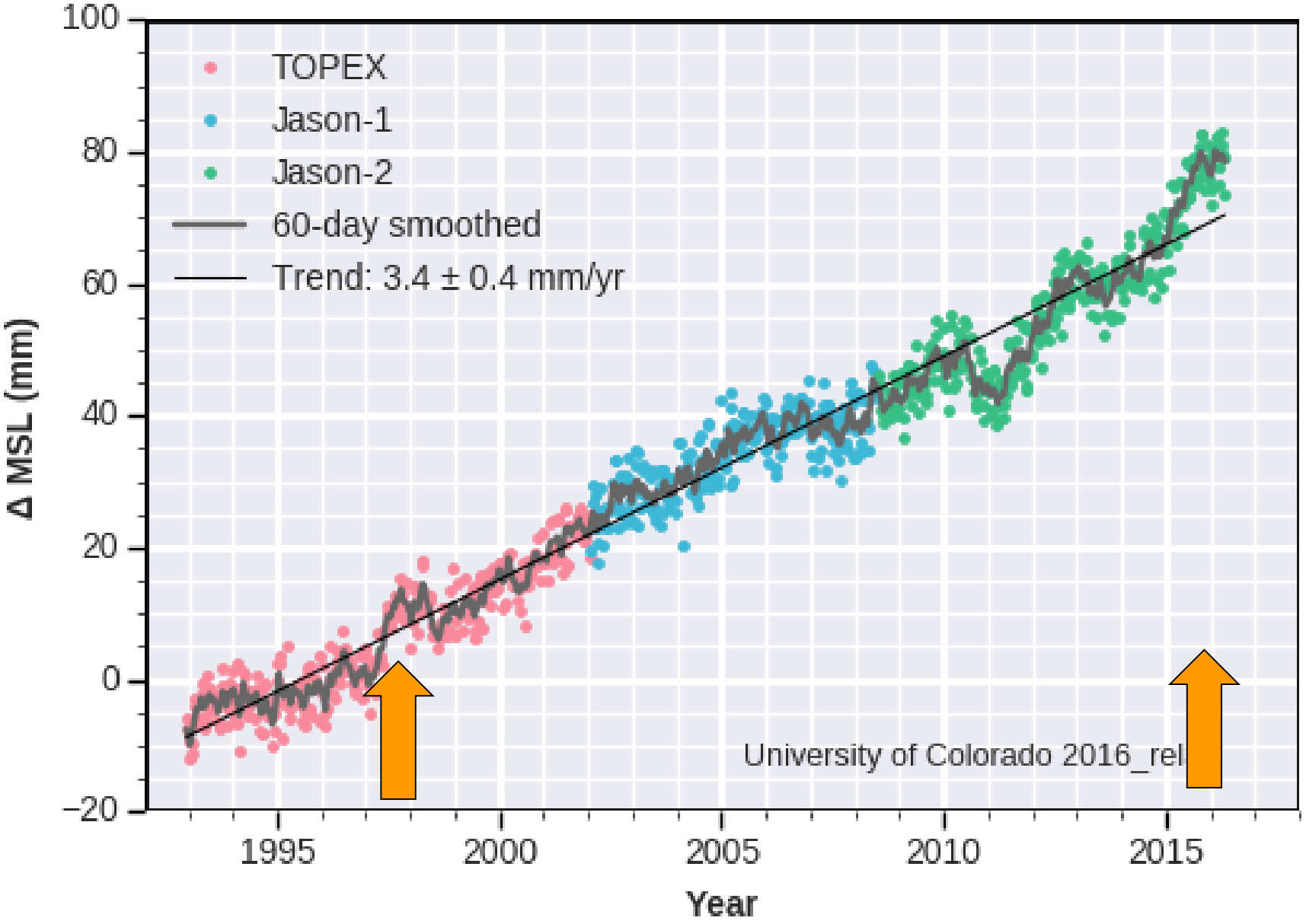
General Timeline for Satellite Radar Altimeters with Short Repeat Periods

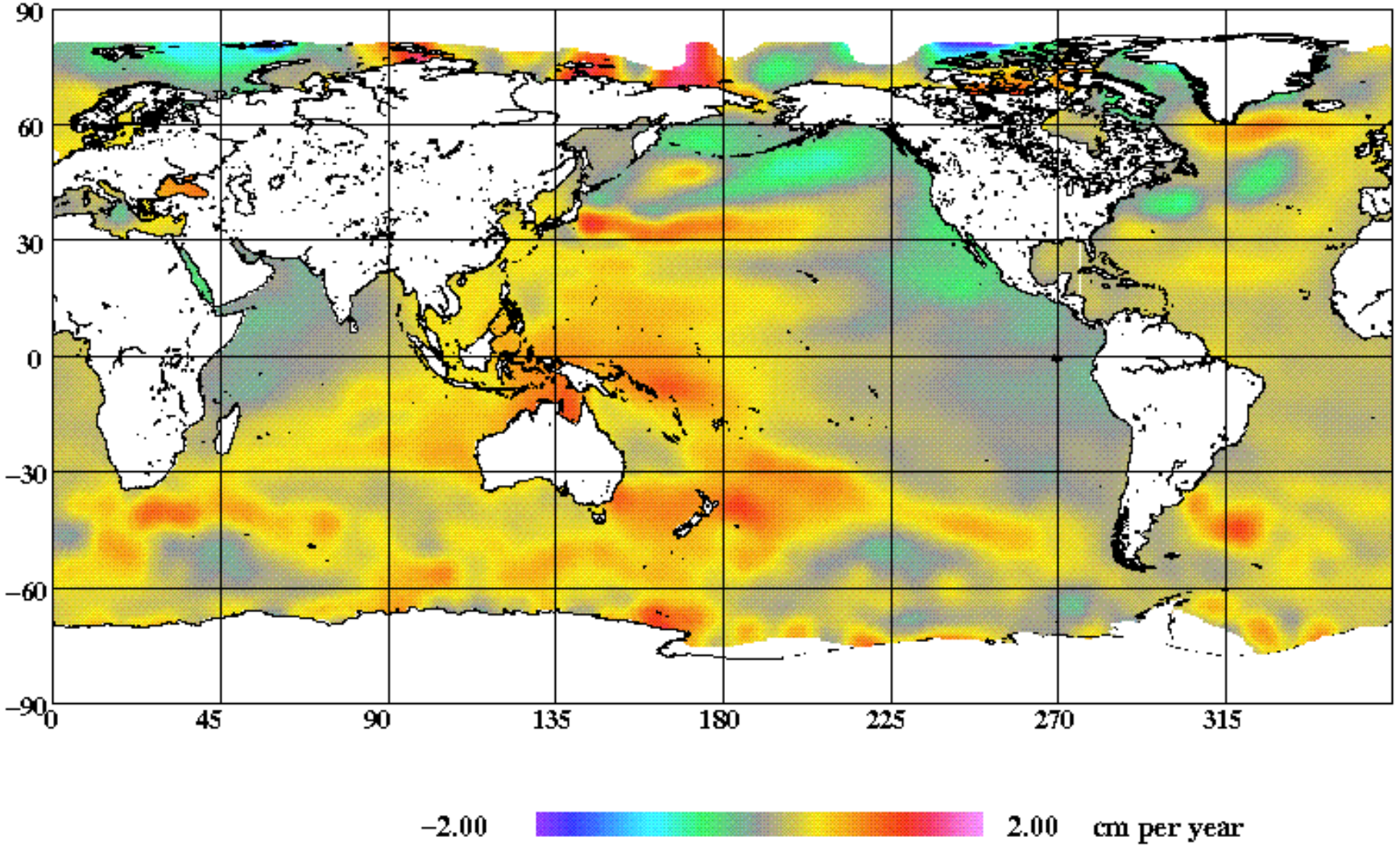


Global is only “global up to 65”

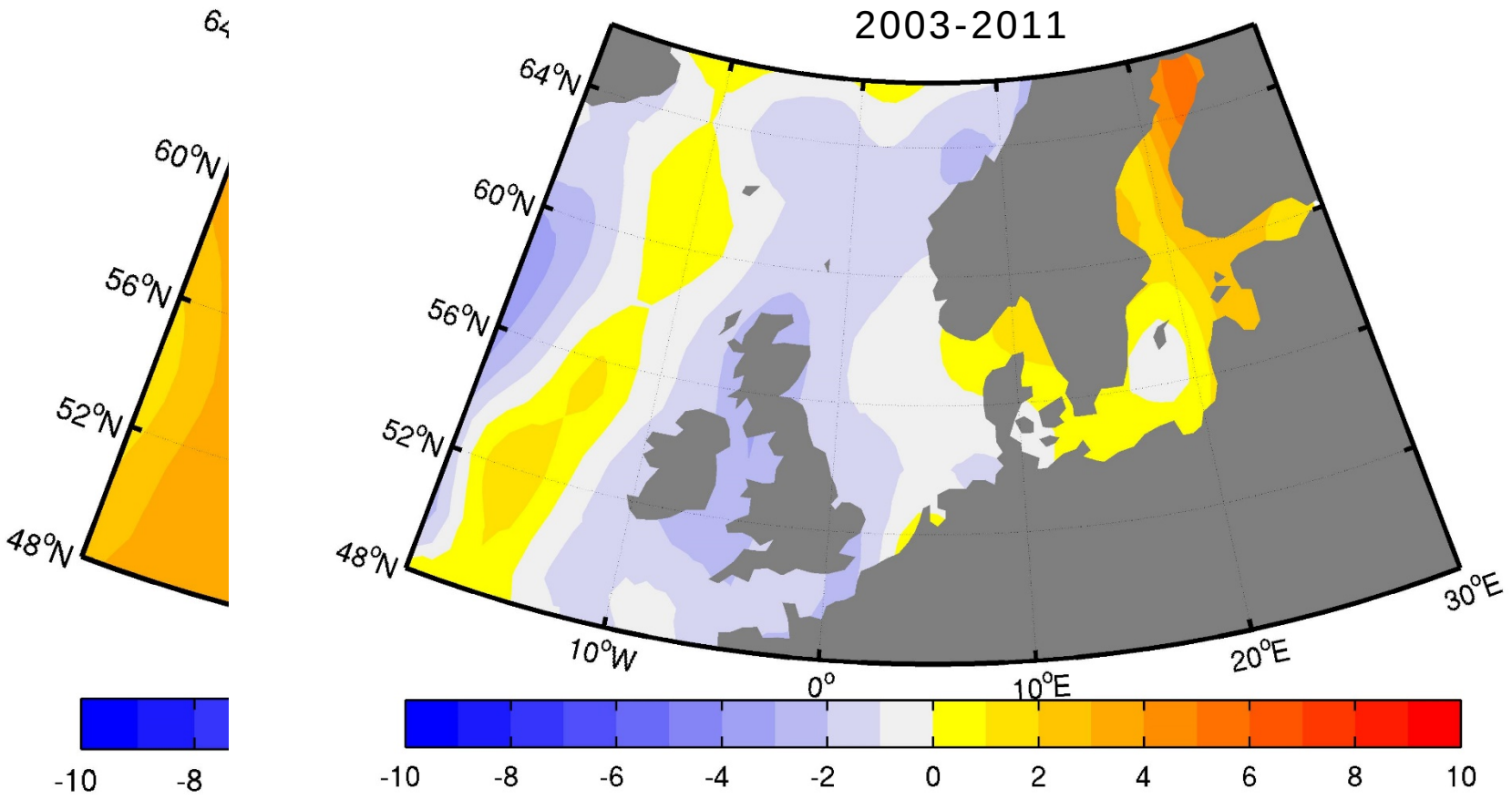



TOPEX
Jason
60-day smoothing
Inverse barometer not applied
ΔMSL (mm)
30
20
10
0
-10
-20
-30
-40
1994
1996
1998
2000
2002
2004
2006
Rate = 3.4 ± 0.4 mm/yr
Univ of Colorado 2007_rel2


TOPEX
Jason-1
Jason-2
60-day smoothed
Trend: 3.4 ± 0.4 mm/yr
Δ MSL (mm)
100
80
60
40
20
0
-20
1995
2000
2005
2010
2015
Year
University of Colorado 2016_rel

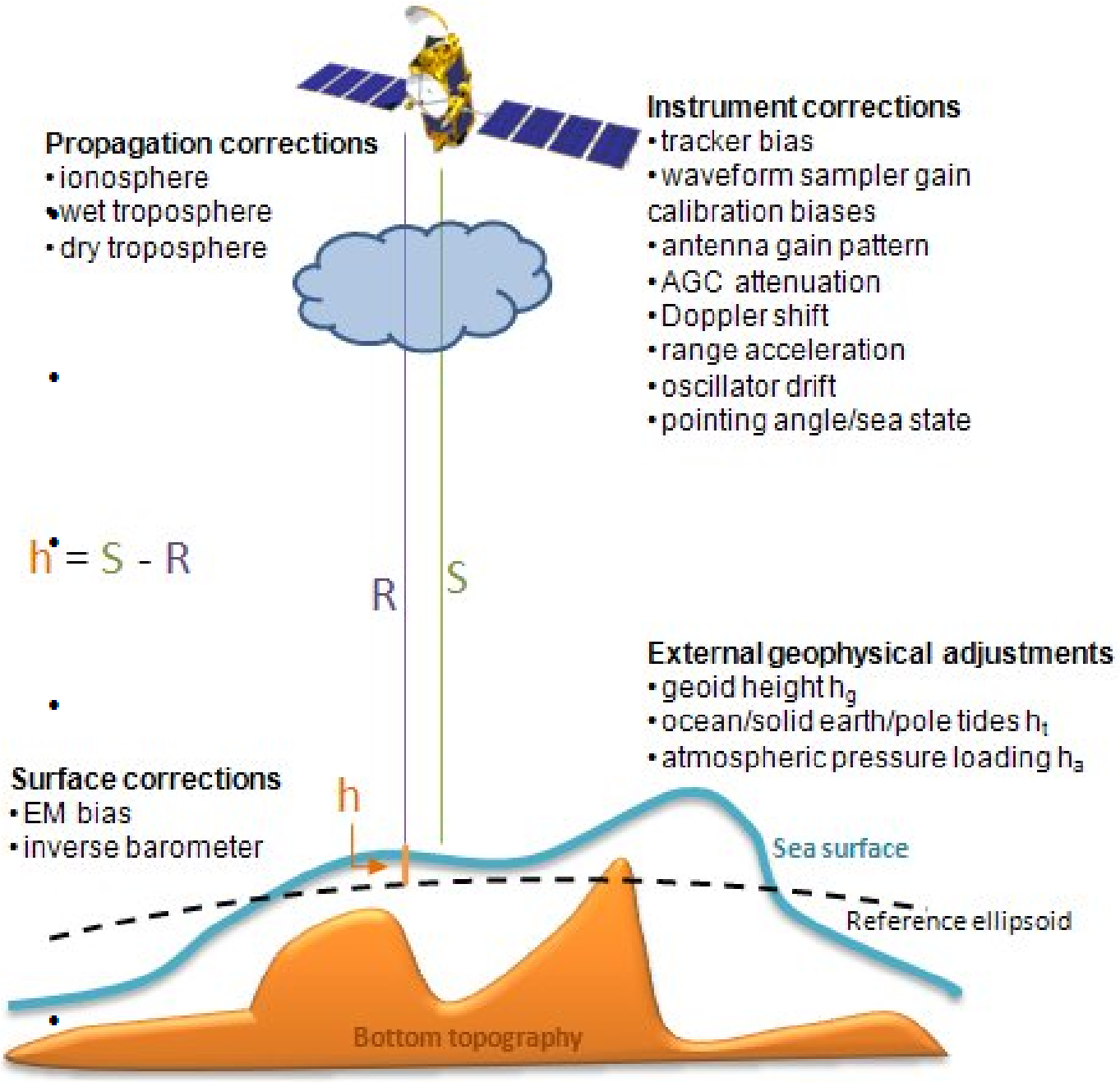

90
60
30
0
−30
−60
−90
0
45
90
135
180
225
270
315
−2.00
2.00
cm per year

Regional sea level change (1993-2011)

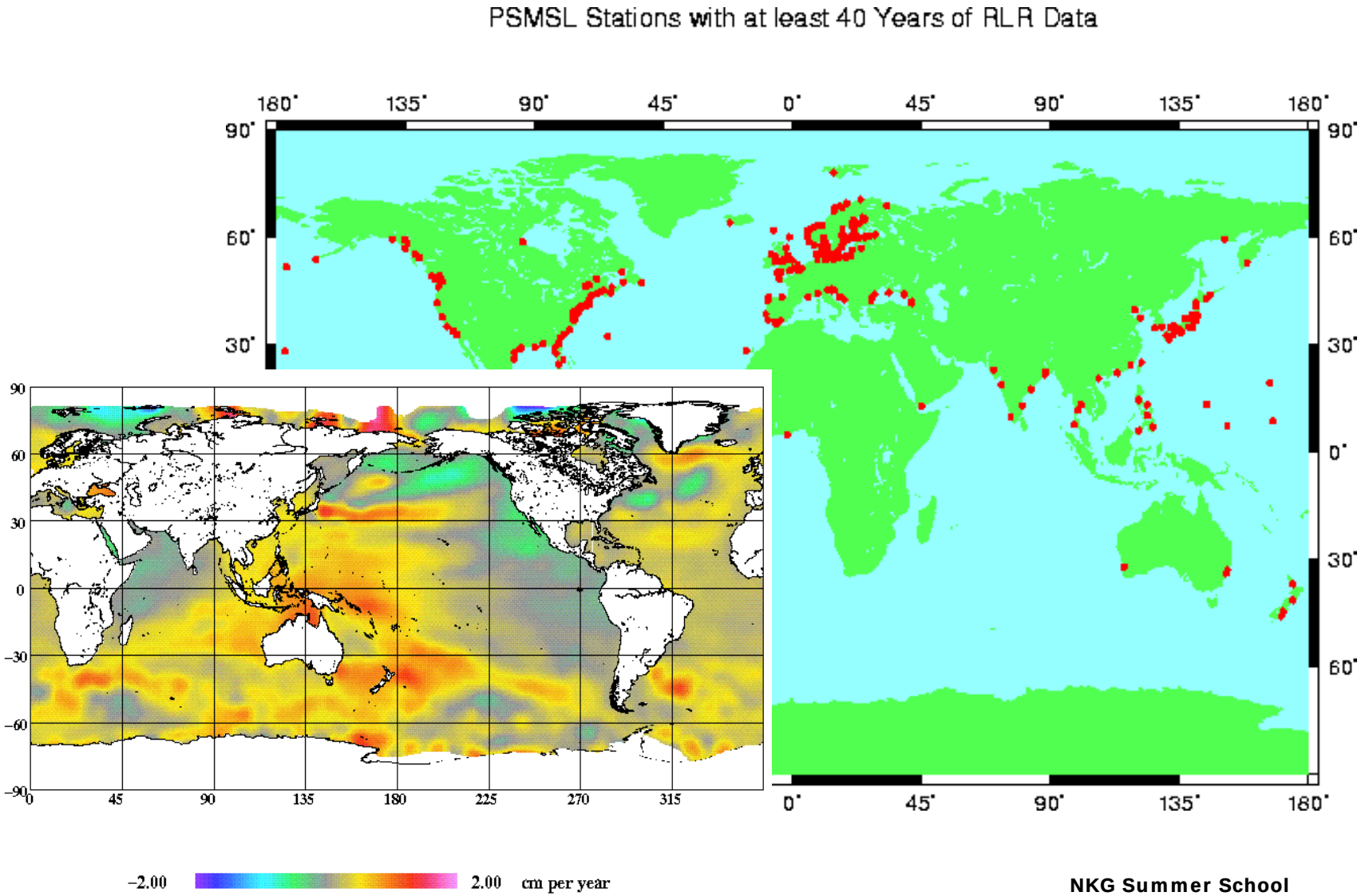


Errors.

Orbit:Cnes	
Radiometer Wet	
Dynamical atmosph	
Sigma0 drift	
Bias uncertain	
Total error budget	



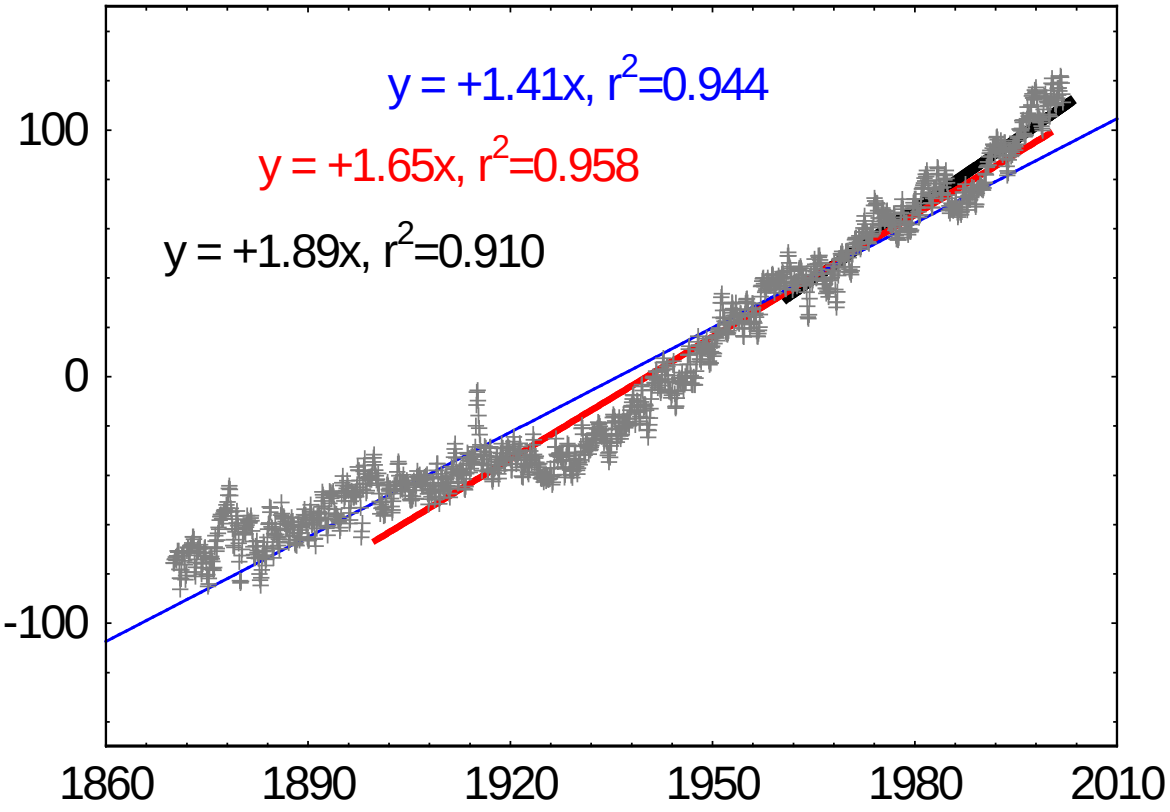
Longer time series. Beyond the altimeter era



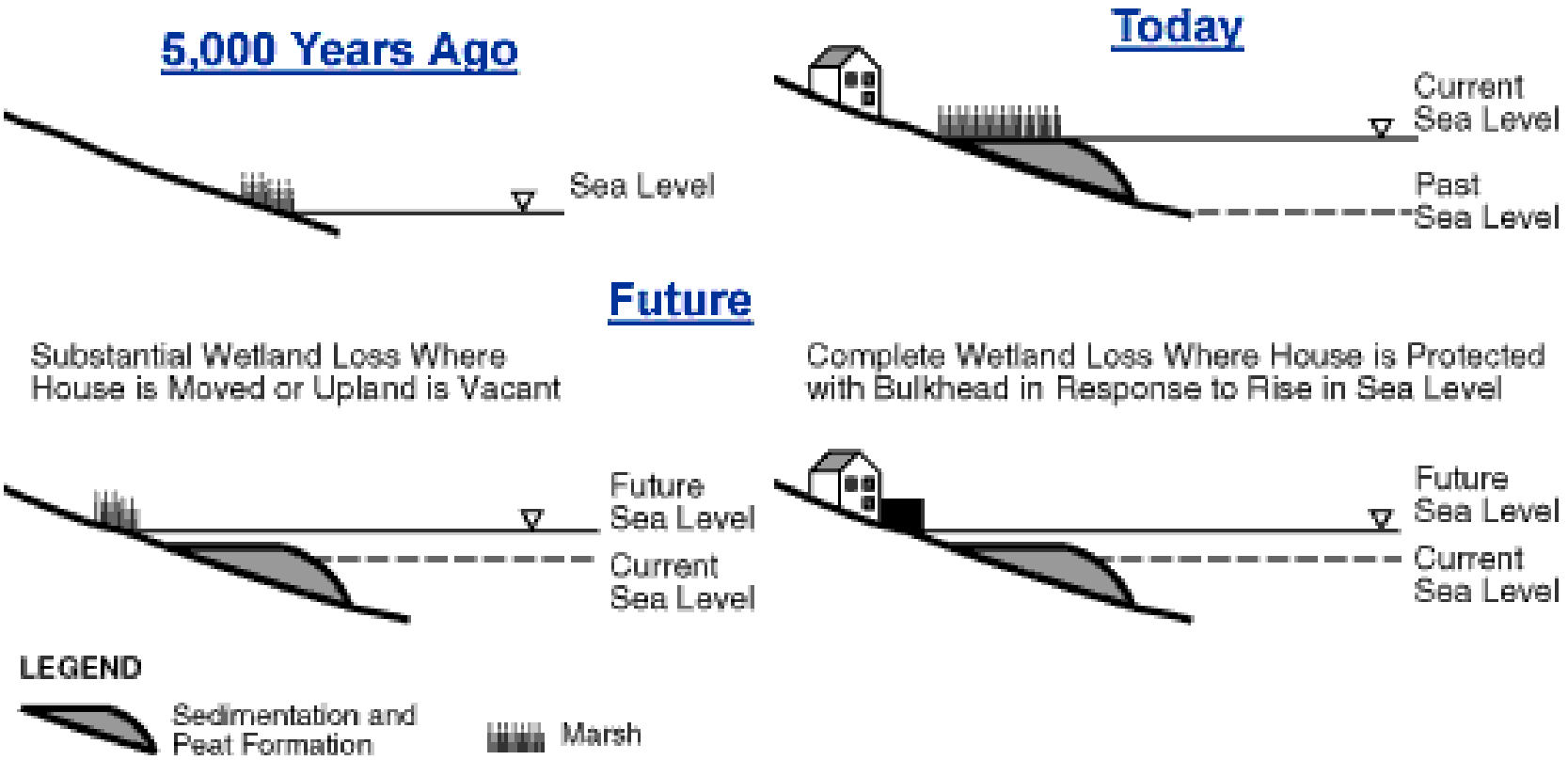
Tide Gauge analyses

Global reconstructed sea level

Church & White



Evolution of a Marsh as Sea Level Rises



Coastal marshes have kept pace with the slow rate of sea level rise that has characterized the last several thousand years. Thus, the area of marsh has expanded over time as new lands have been inundated. If in the future, sea level rises faster than the ability of the marsh to keep pace, the marsh area will contract. Construction of bulkheads to protect economic development may prevent new marsh from forming and result in a total loss of marsh in some areas.

Understanding Sea level change
The Sea Level Budget

What changes sea level

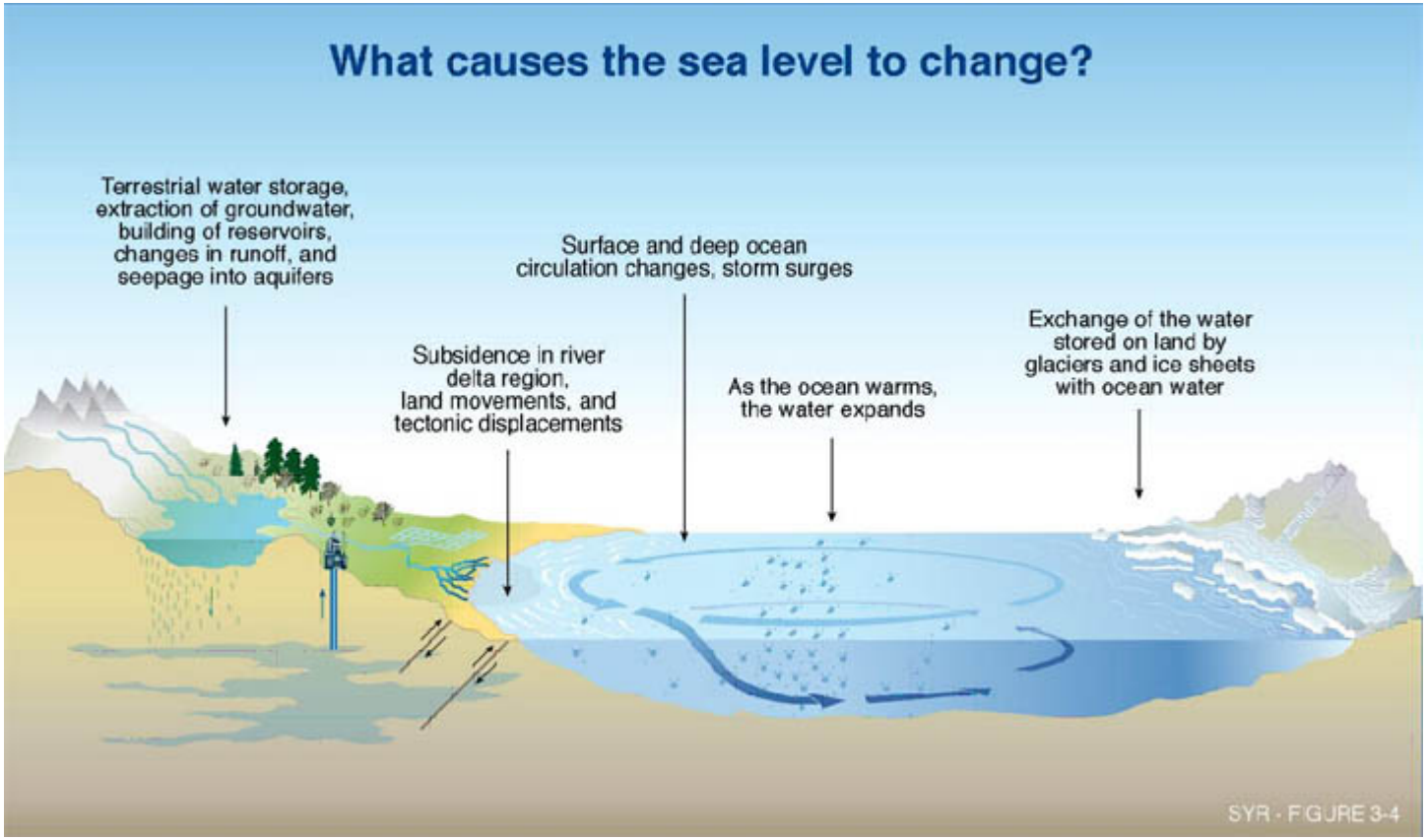
1) Heatig water

   (Steric expansion->height)

1) Adding water (ocean Mass)

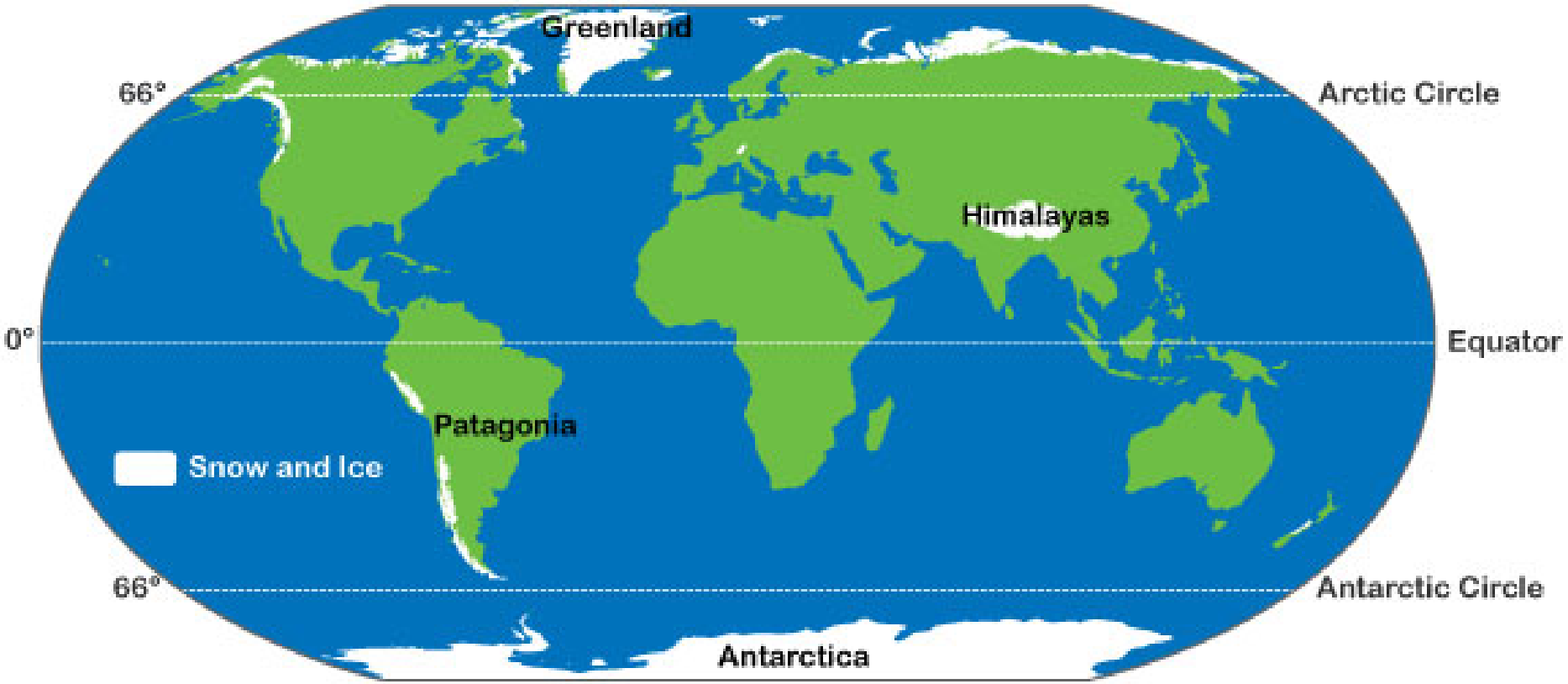
$$\Delta SSH = \Delta SH + \Delta OM$$

Little more sophisticated version.



$$\Delta SSH = \Delta SH + \Delta OM + \Delta Circulation + \Delta \text{Shape}$$

Large Ice bodies on the Earth.



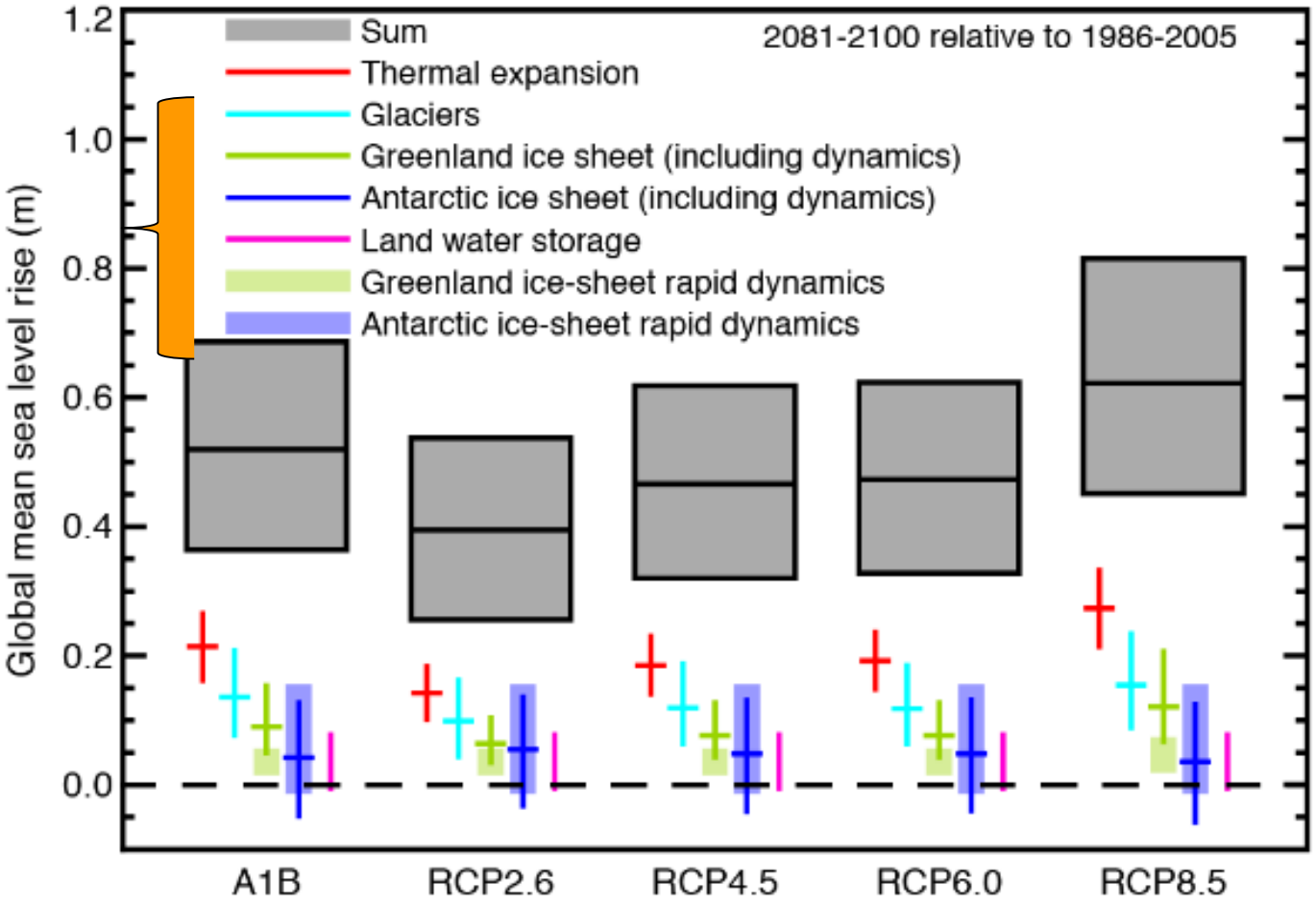
Climate Change

IPCC Assessment Report 5 provides a new assessment of sea level rise:

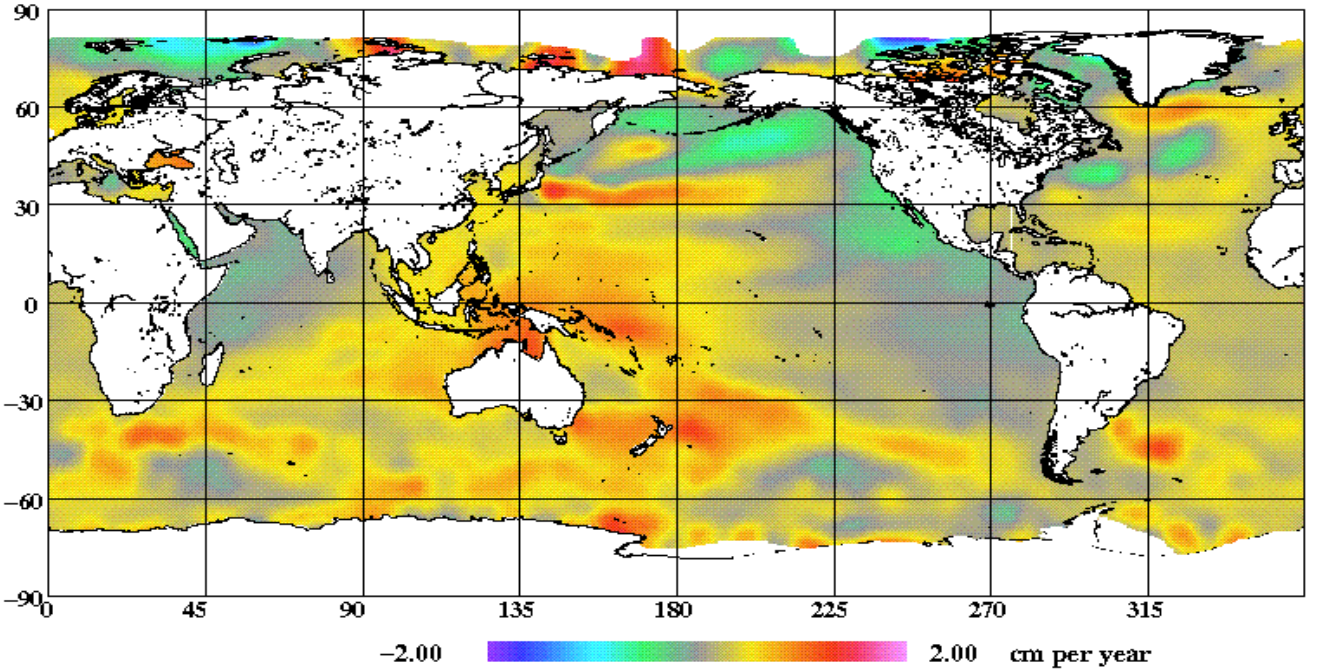
- Global sea level budget:

Source	1993–2010
Observed contributions to GMSLR	
Thermal expansion	1.1 [0.8 to 1.4]
Glaciers except in Greenland and Antarctica	0.76 [0.39 to 1.13]
Glaciers in Greenland[a]	0.10 [0.07 to 0.13]
Greenland ice sheet	0.33 [0.25 to 0.41]
Antarctic ice sheet	0.27 [0.16 to 0.38]
Land water storage	0.38 [0.26 to 0.49]
Total of contributions	2.8 [2.3 to 3.4]
Observed GMSLR	3.2 [2.8 to 3.6]

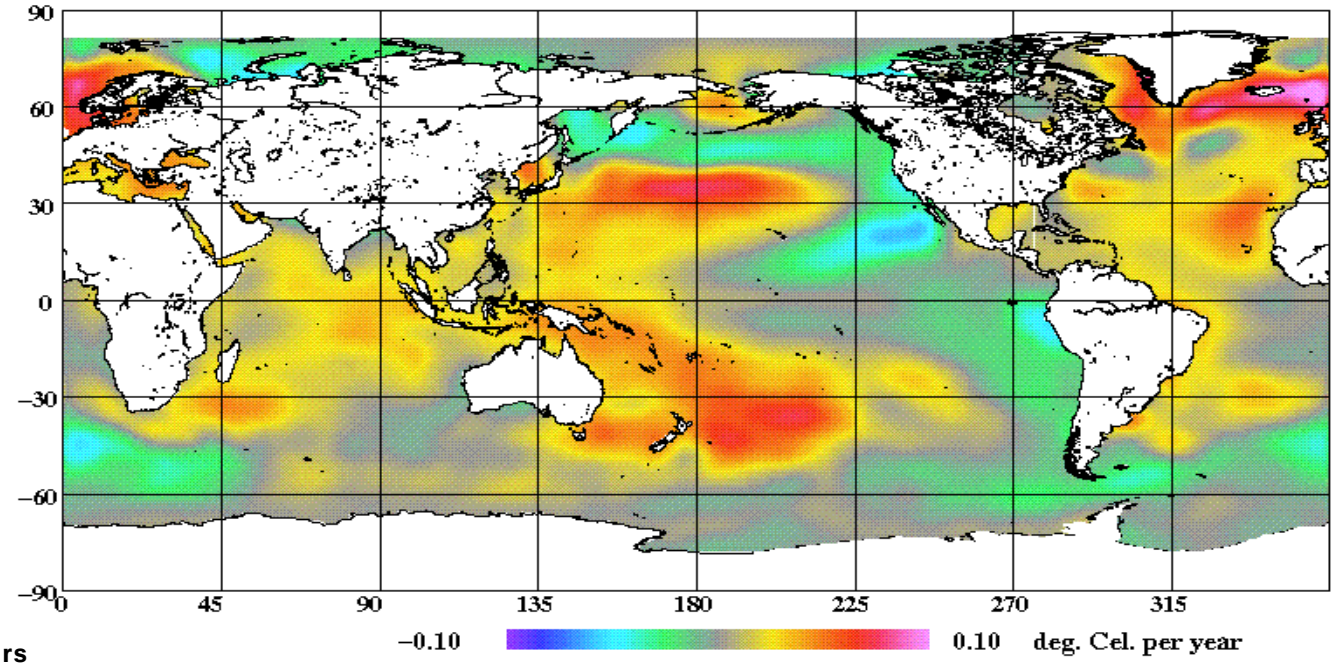
Table 13.1: Global mean sea level budget (mm yr^{-1}) over different time intervals from observations and from model-based contributions. Uncertainties are 5–95%. The AOGCM historical integrations end in 2005; projections for RCP4.5 are used for 2006–2010. The modelled thermal expansion and glacier contributions are computed from the CMIP5 results, using the model of Marzeion et al. (2012a) for glaciers. The land water contribution is due to anthropogenic intervention only, not including climate-related fluctuations.



TS.21: Projections from process-based models with *likely* ranges and median values for global mean sea level its contributions in 2081–2100 relative to 1986–2005 for the four RCP scenarios and scenario SRES A1B used



High spatial correlation.



Closing the budget. What can altimetry, GRACE, and Argo tell us?

The sea level budget **2005-2015** may be expressed as height changes from the main components of sea level change:

$$\Delta SSH = \Delta SH + \Delta OM$$

SSH = sea surface height, SH = steric height, *OM* = ocean mass

Argo measures temperature and salinity short of the abyssal ocean (roughly 44 to 75% of Argo profiles are from 2000m).

$$\Delta SH = \Delta SH_{(0-2000m)} + \Delta SH_{(2000m-\infty)}$$

We can estimate a residual from observations:

$$\Delta SL_{residual} = \Delta SSH - \Delta SH_{(0-2000m)} - \Delta OM$$

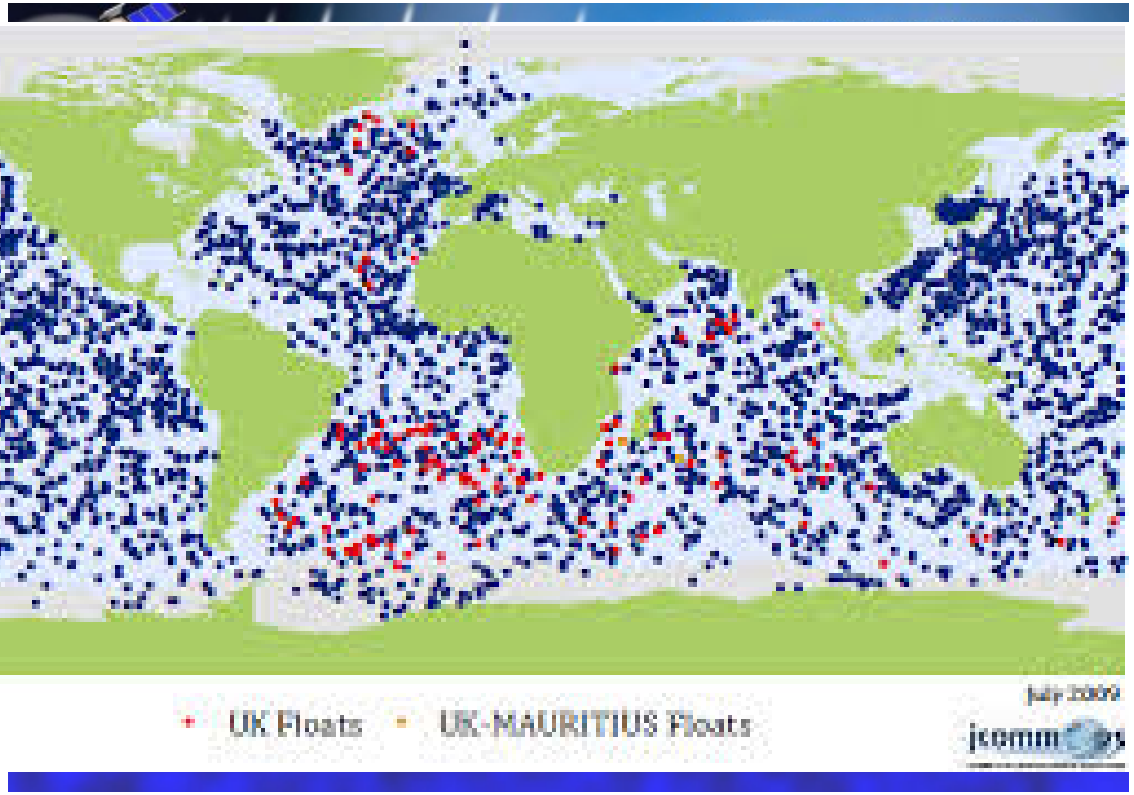
$$\Delta SL_{residual} = \Delta SH_{(2000m-\infty)} + Error$$

GRACE and ARGO

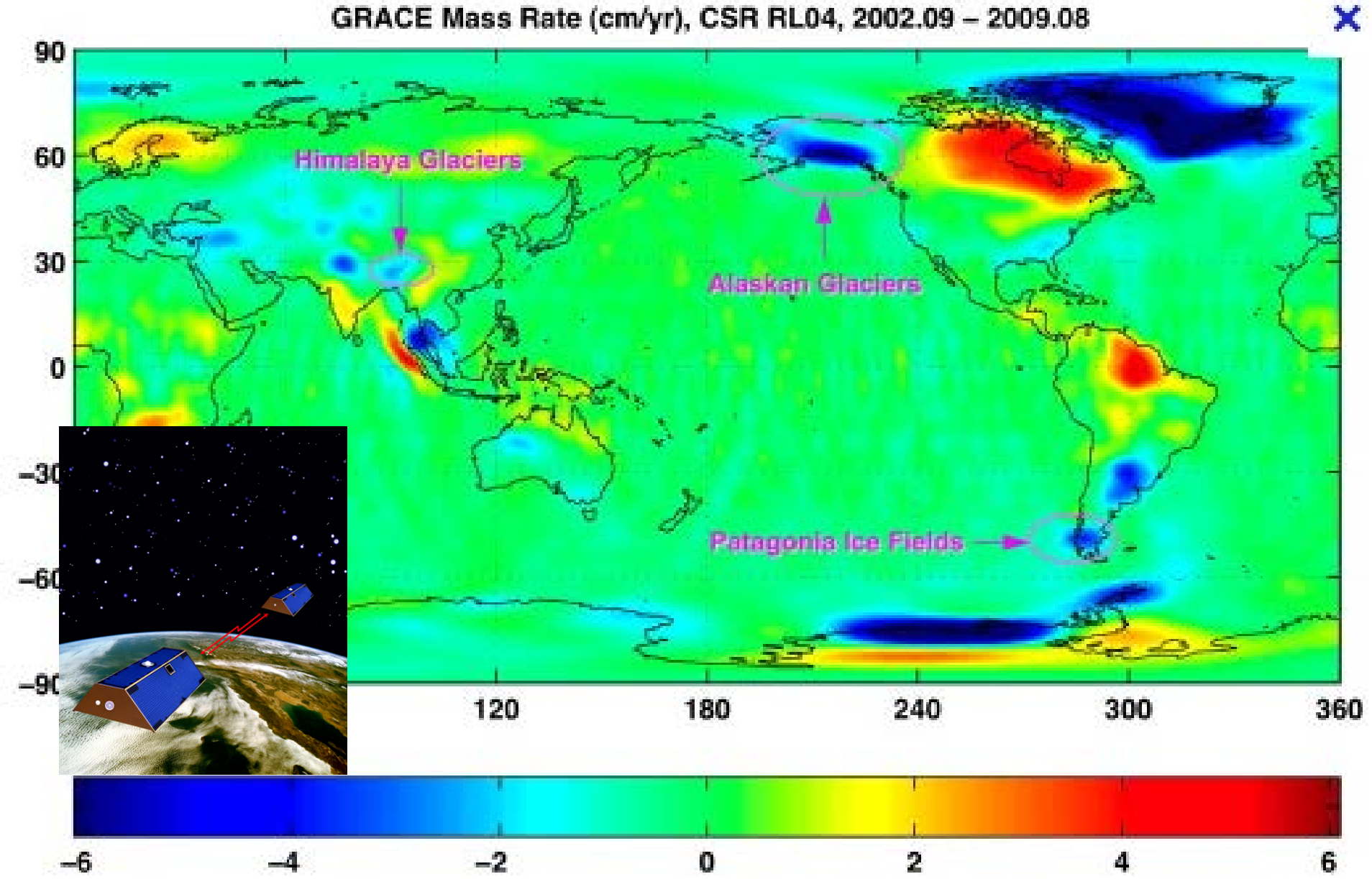
Satellites (MERIS on ENVISAT etc etc

WILL ONLY GIVE YOU SEA SURFACE temperature

You need to DIVE INTO THE ocean to get ”correct steric contribution”



GRACE measure how gravity is changing because shape of our planet is changing.

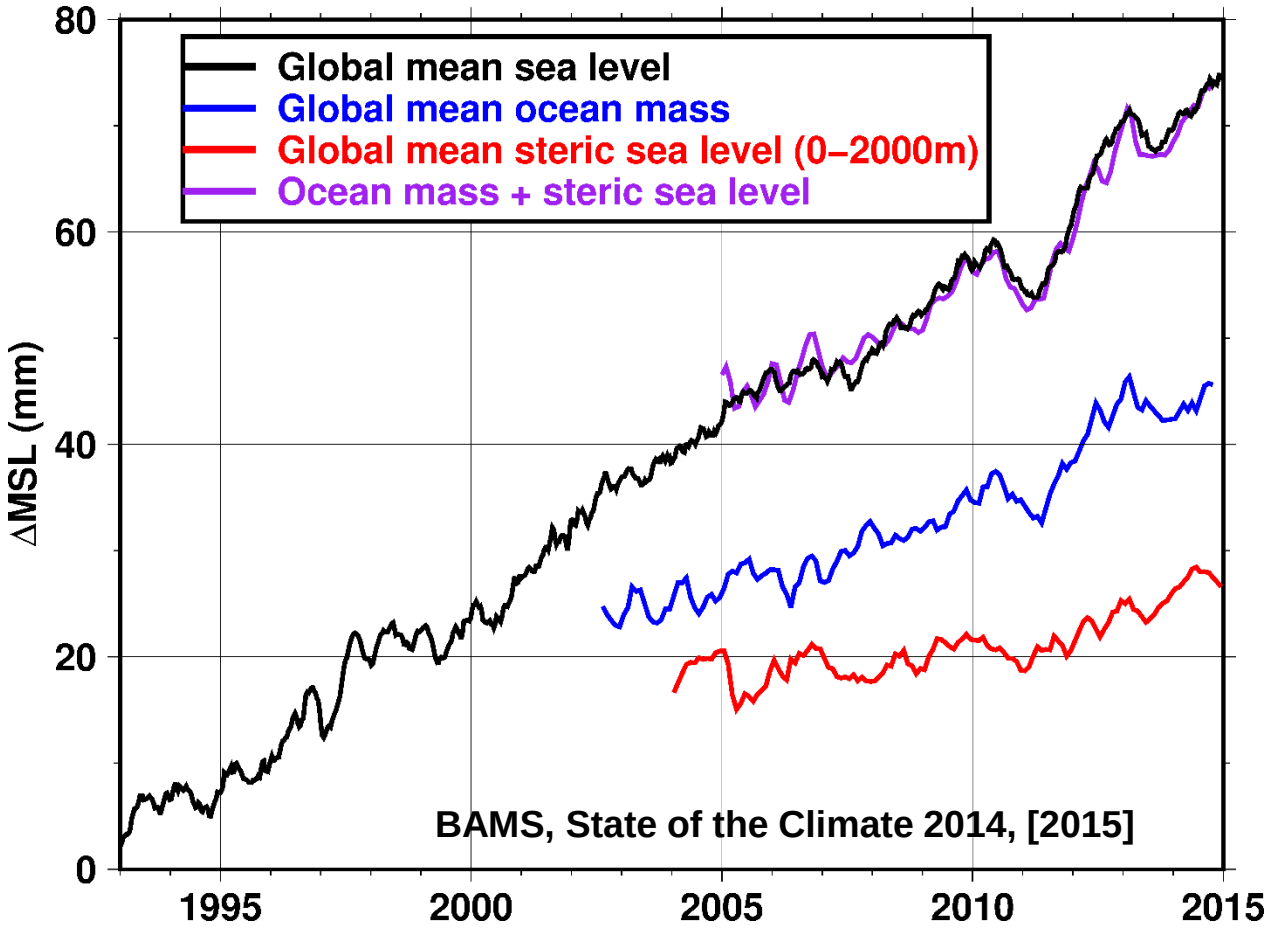


Global and regional sea level budgets

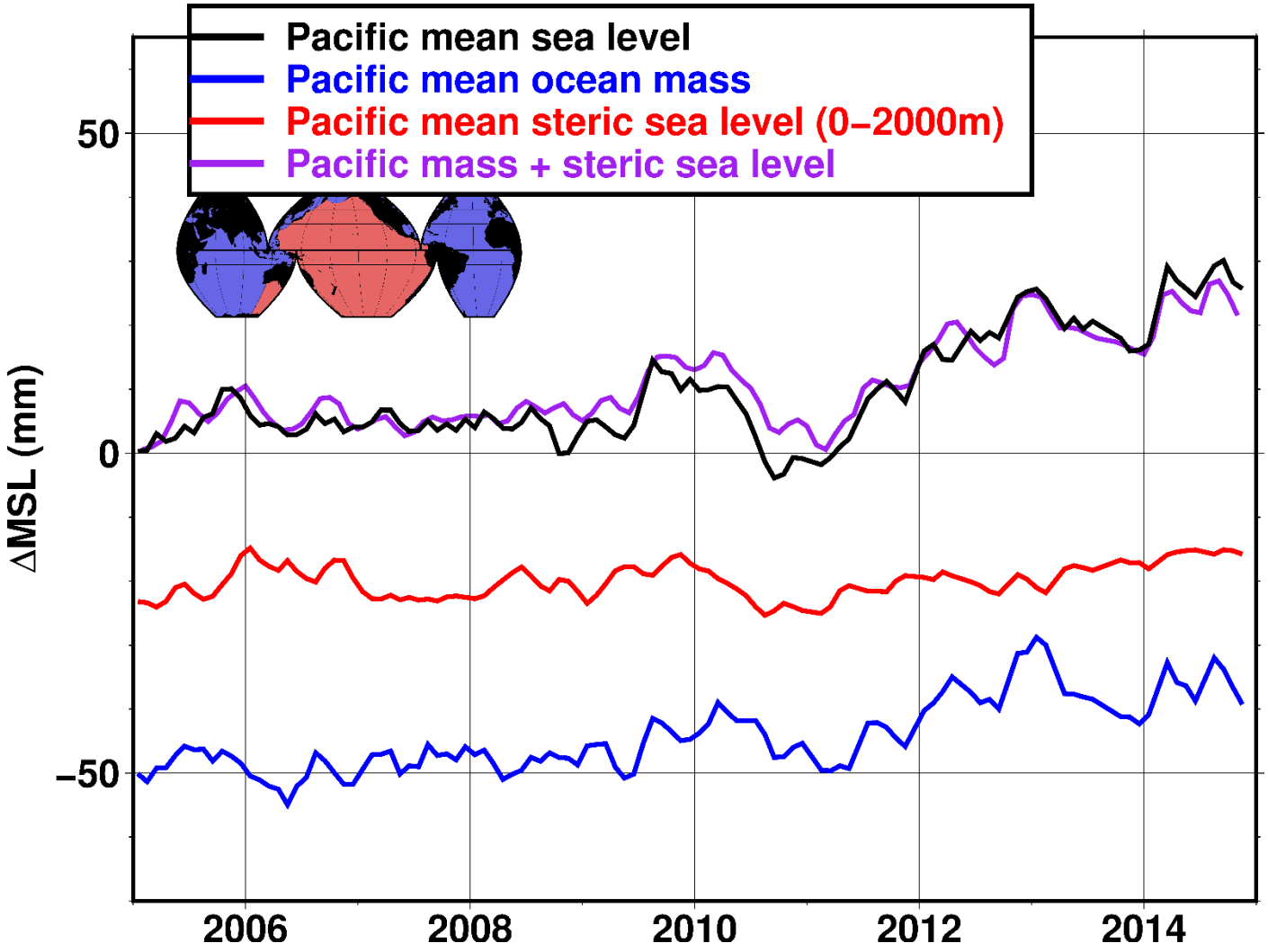
Global sea level budgets can be closed within the estimated errors

Bounds size of deep (> 2000 m) ocean warming (e.g. Llovel et al. 2014)

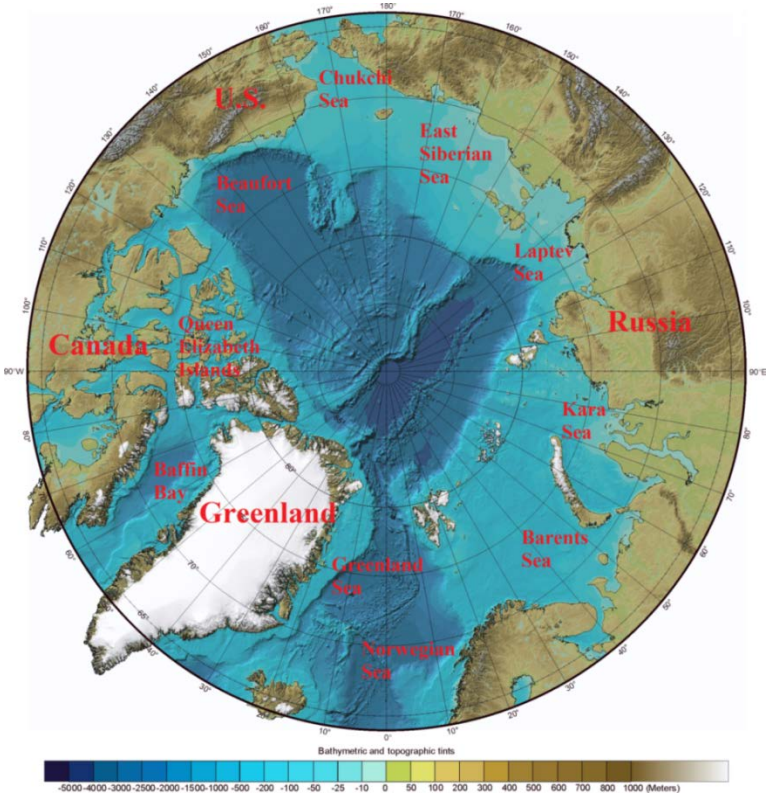
What do regional sea level budgets tell us?



Pacific Ocean sea level budget



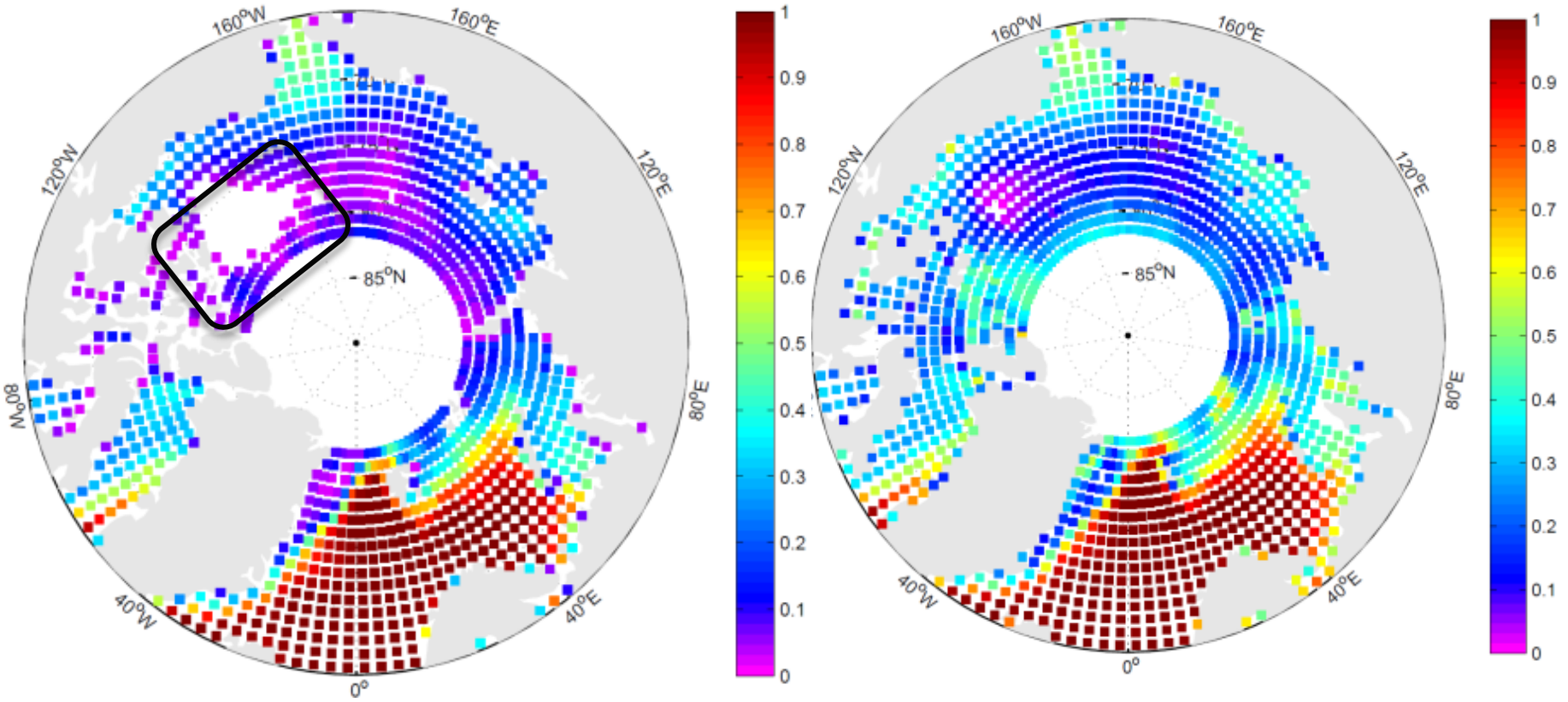
Arctic Ocean



Arctic Ocean problems:
Seasonal to permanent ice cover
Ocean tide models less accurate (sun-syncronous ERS/ENVISAT/C2/S3)
range corrections affected by ice, retracking is challenging
residual orbit errors

DTU Space
National Space Institute

Altimetry – new re-processed 23Y dataset (ESA-CCI2)

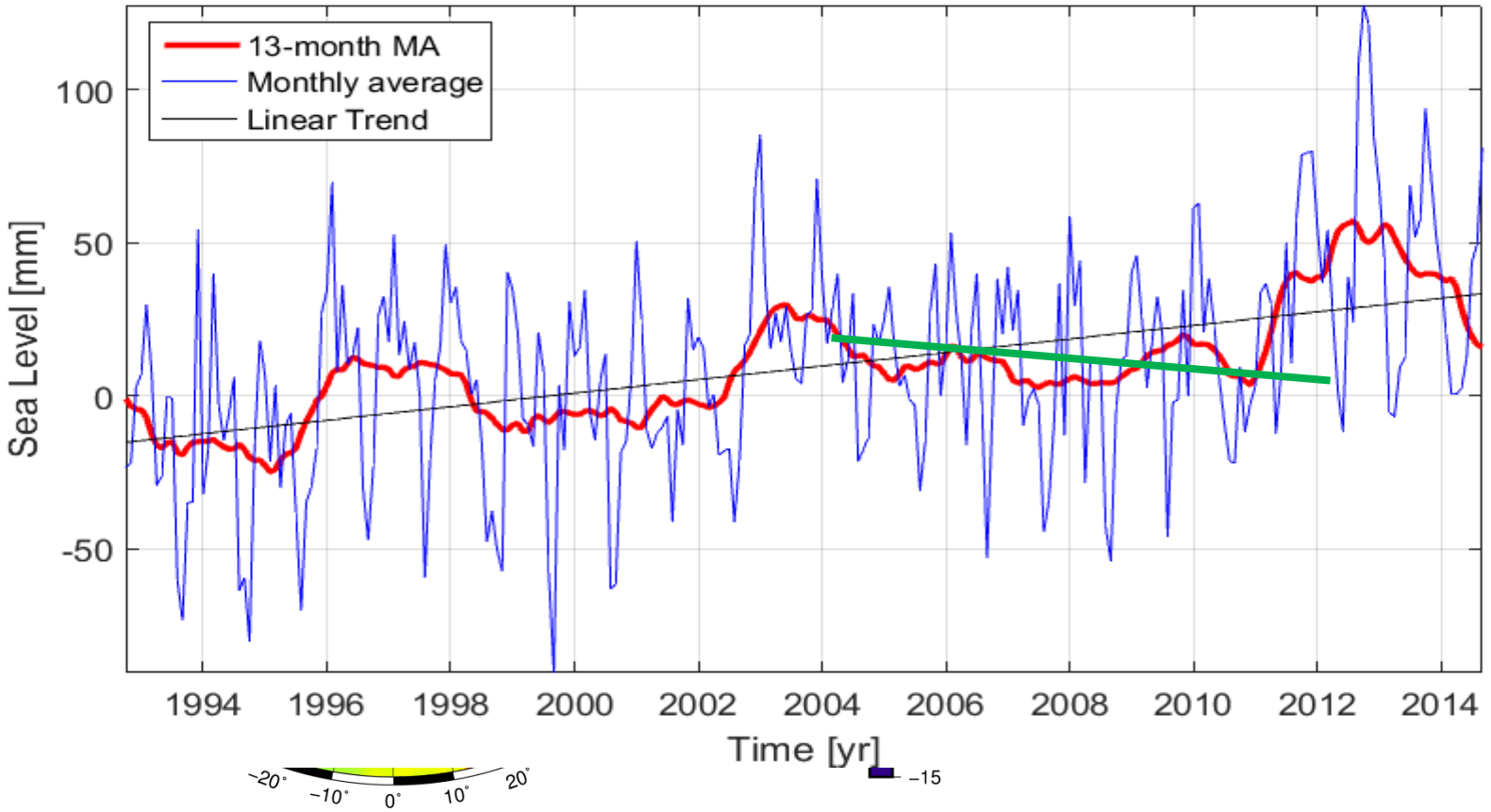


Data availablility:
RADS standard along-track products relative to DTU13 MSS

Data availablility:
Re-processed along-track products relative to DTU13 MSS

Western Arctic/Beaufort: average data increases of 383 %.
(74N-80.5N, 130W-180W) on average data increase of 130 %

23 Years Linear Sea Level trend (1993-2015)

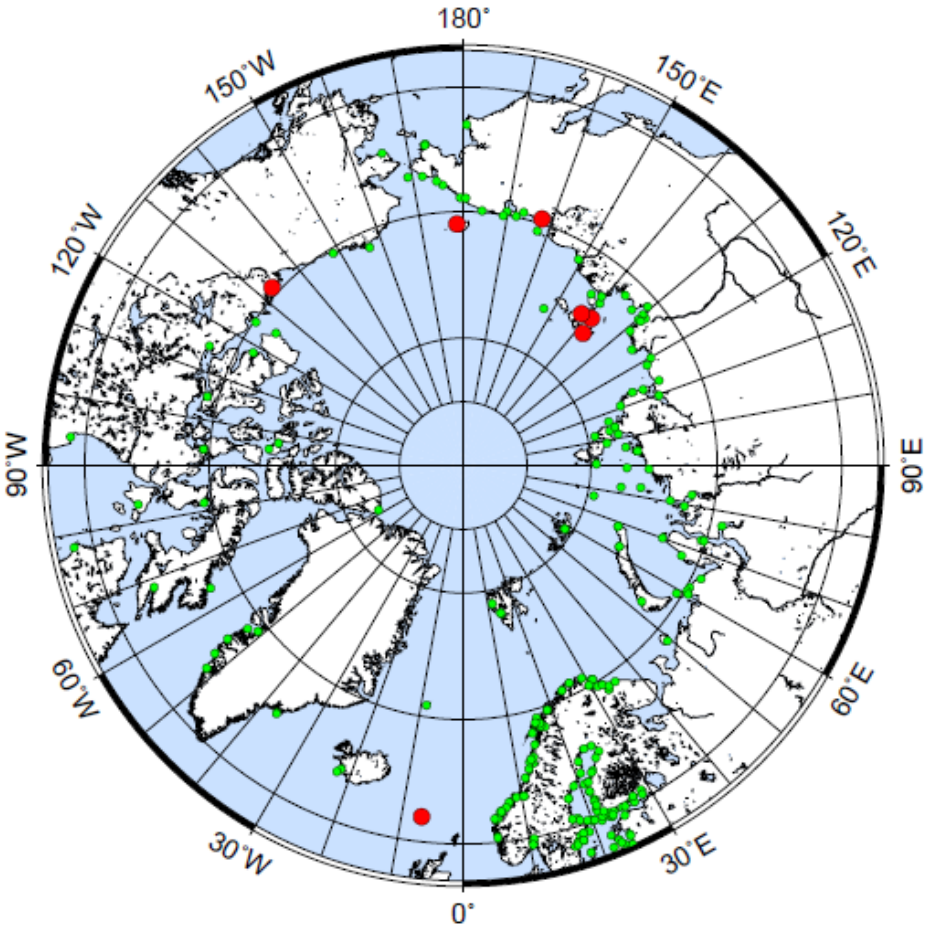


Average linear trend 2.2 mm/year but large inter-annual variations

Sea level change over past 60 years.

Arctic sea level reconstruction

106 PSMSL Tide Gauges

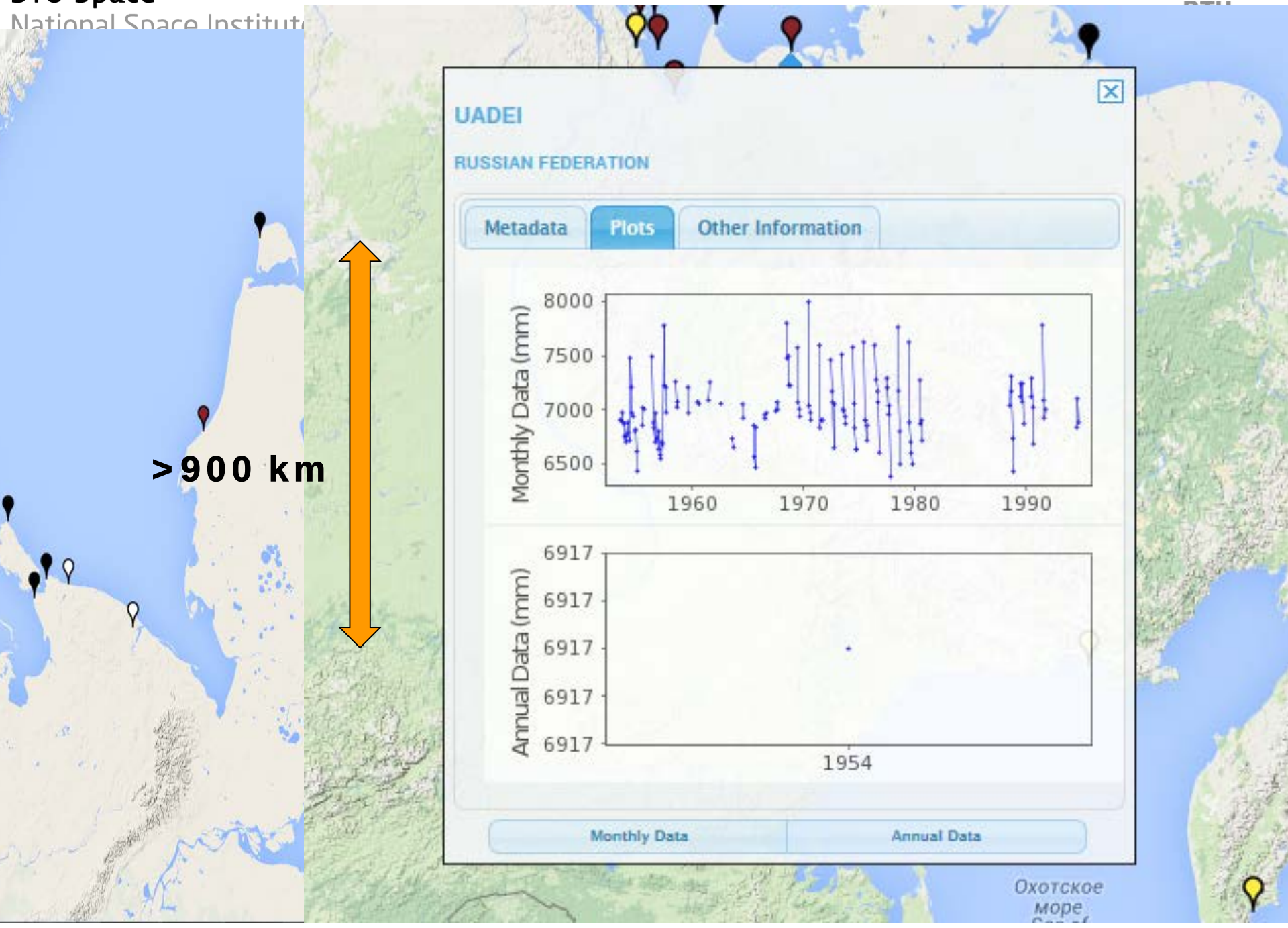


Currently

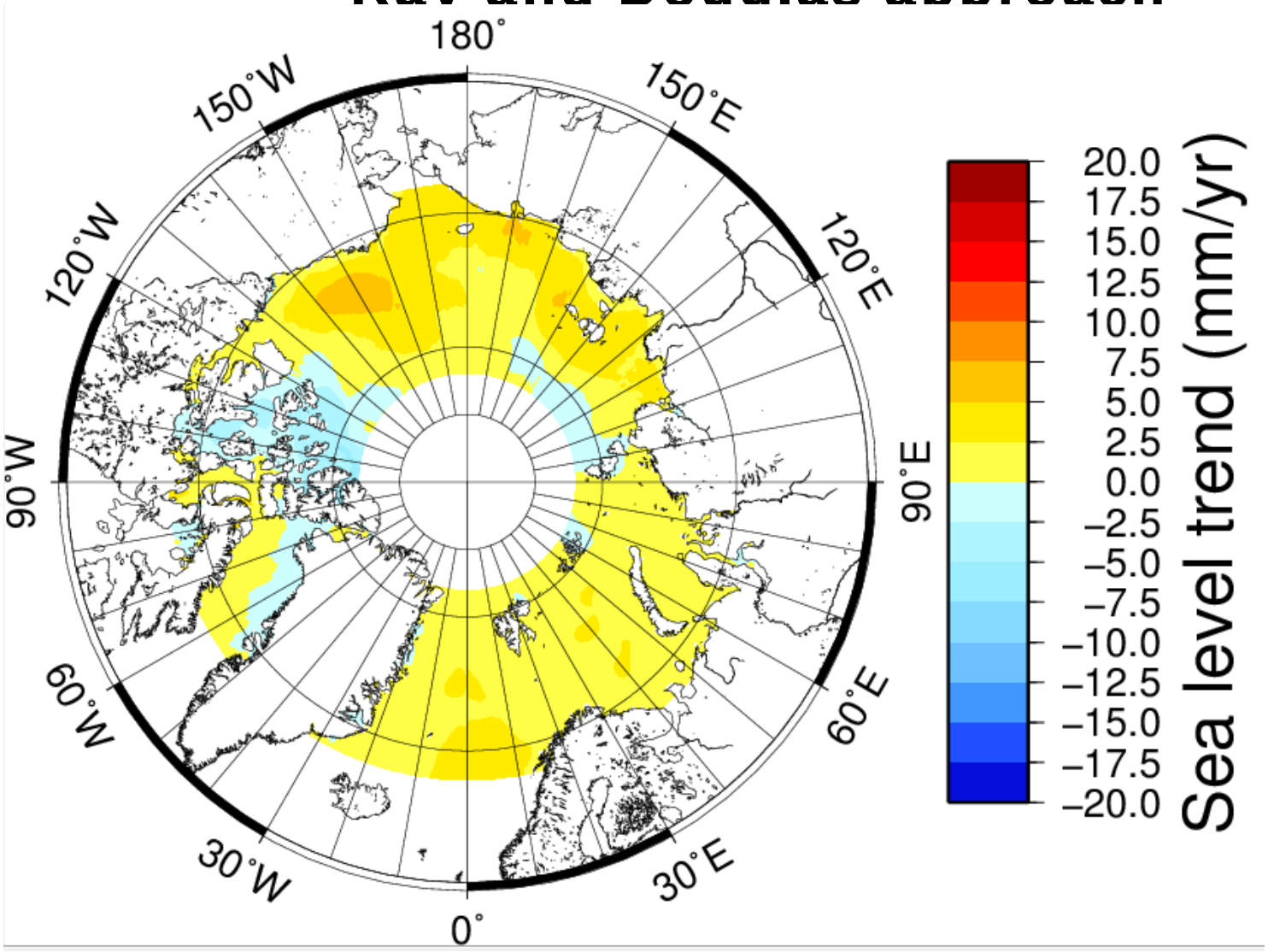
40 % Norwegian / Swedish Coast

50 % Russian Coast

10 % Canada / Greenland etc


>900 km
UADEI
RUSSIAN FEDERATION
Metadata
Plots
Other Information
Monthly Data (mm)
8000
7500
7000
6500
1960
1970
1980
1990
Annual Data (mm)
6917
6917
6917
6917
6917
1954
Monthly Data
Annual Data
Охотское
море

Altimetry+TG recon (1950-2010) Ray and Douglas approach



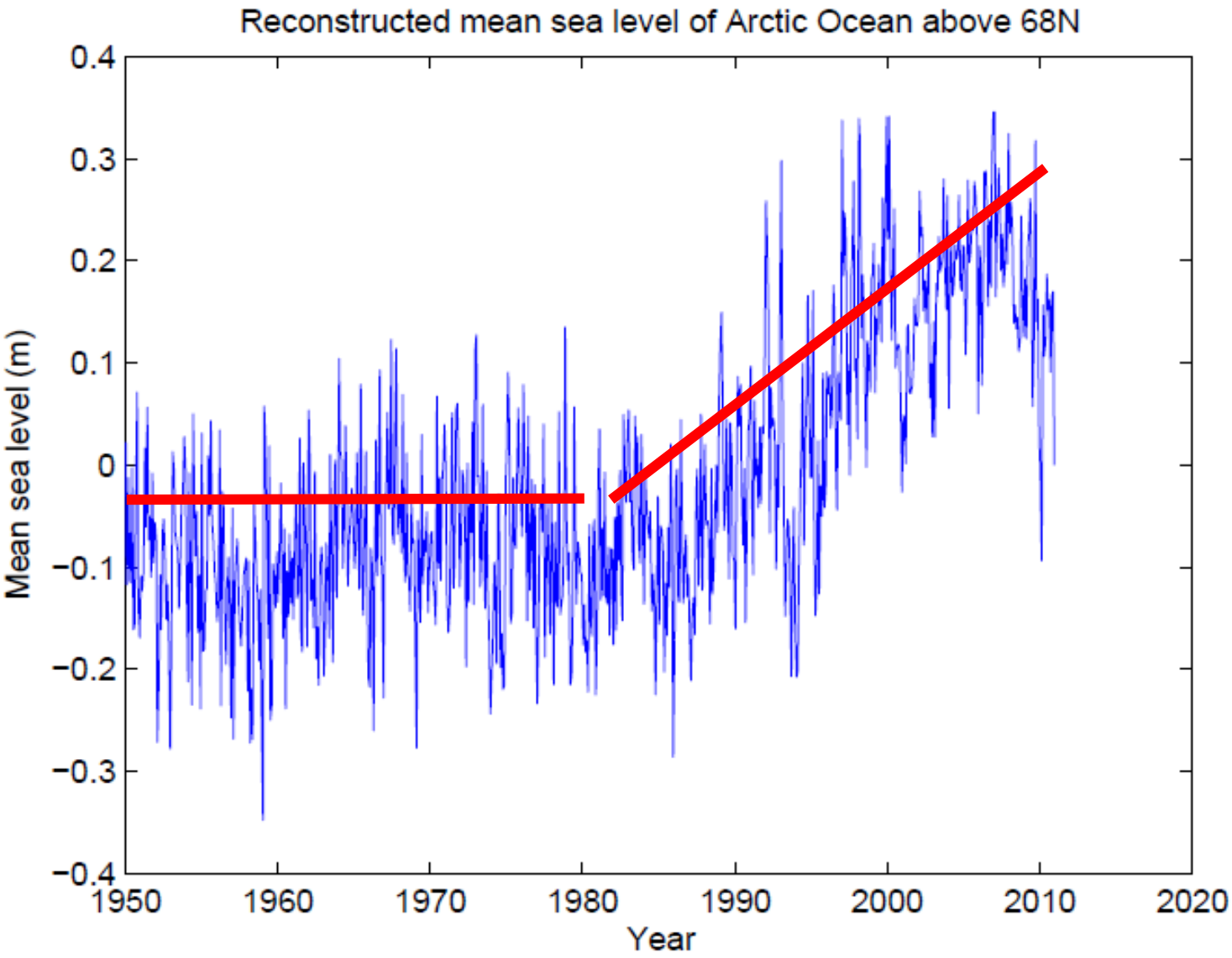
Arctic SL reconstructed trend 1950 – 2010 (65-82N)

Church/Whit

Church/Whit

Ray /Douglas

Ray/Dougla



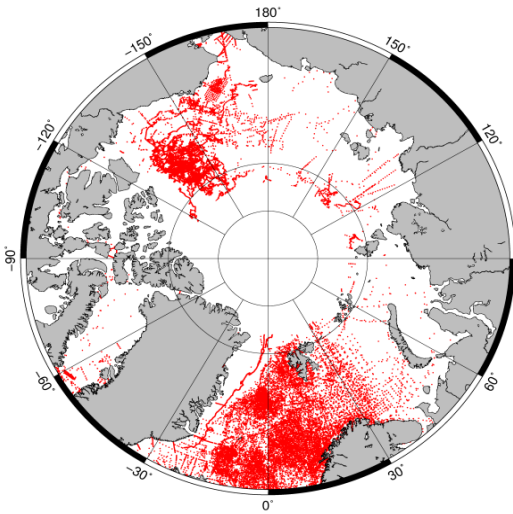
Regional Arctic sealevel budget.

The sea level budget may be expressed as height changes using the main components of sea level change:

$$\Delta SSH = \Delta SH + \Delta OM$$

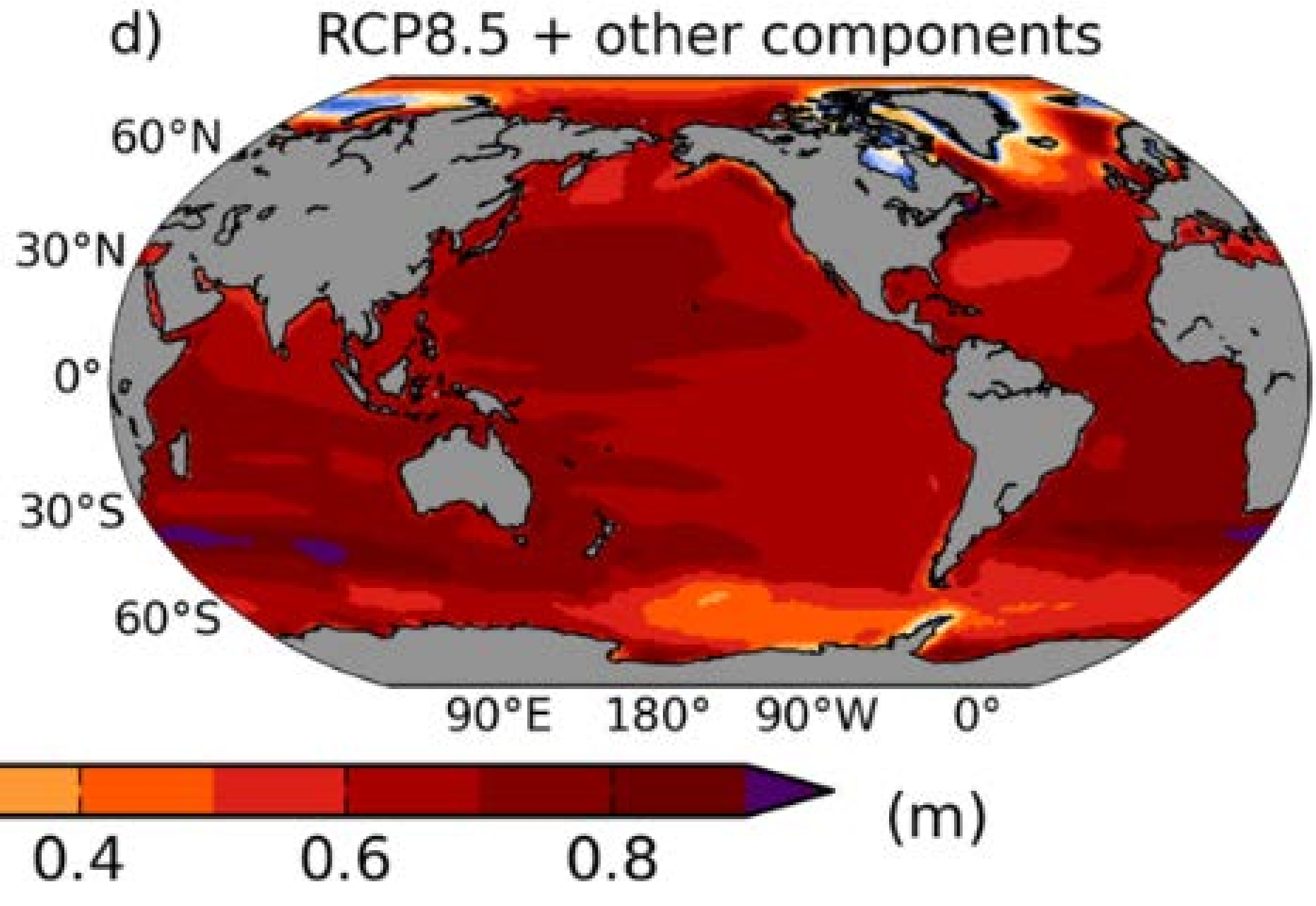
SSH = sea surface height, SH = steric height,
OM = ocean mass from GRACE (JPL-MASCONS)

Halosteric component is the main contributor
No ARGO data are available
Steric signal from NOAA model
-> 2005-2015 period.



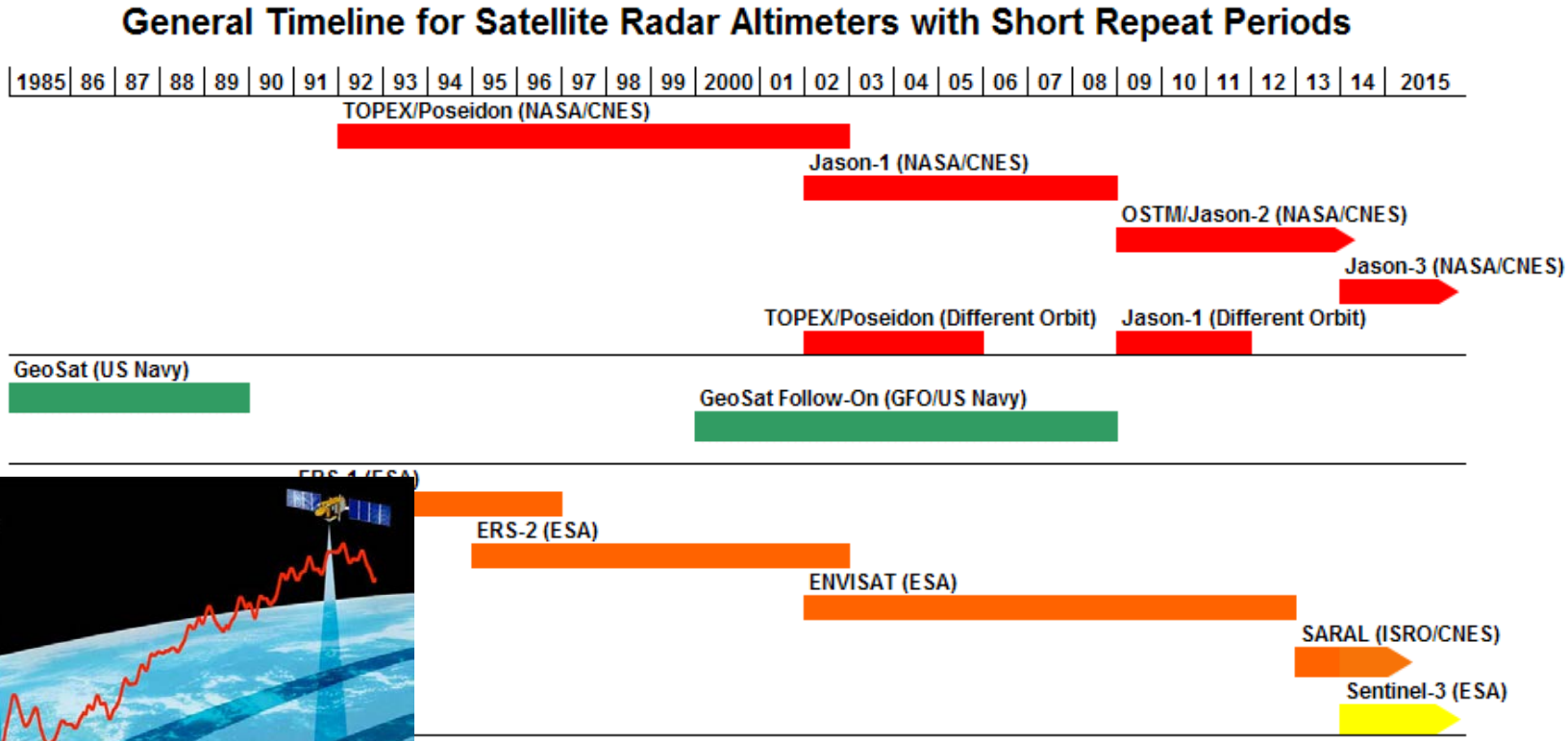
Closing the Arctic Sea Level budget (2005-2015 -> early attempt)

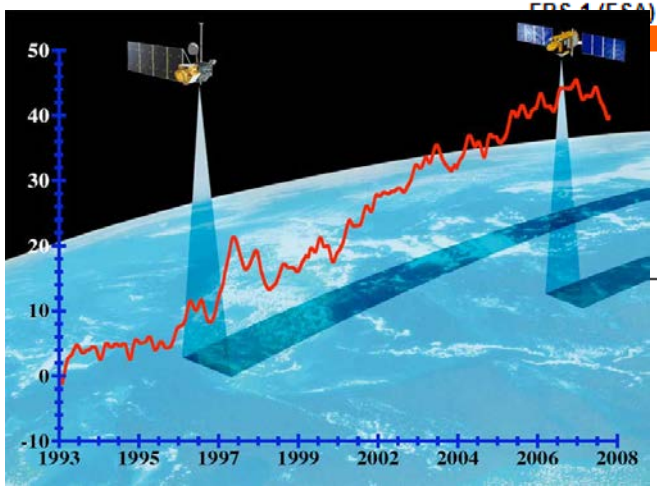
Components	Linear trend (2005 – 2015) [mm/y]
Sea level (Altimetry)	4.34 ± 2.44
Mass (GRACE)	3.85 ± 0.87
Total steric (NOAA)	0.09 ± 0.36
Thermosteric	0.33 ± 0.32
Halosteric	-0.24 ± 0.14
GRACE + steric	3.94 ± 0.94


d)
RCP8.5 + other components
60°N
30°N
0°
30°S
60°S
90°E
180°
90°W
0°
0.4
0.6
0.8
(m)

Summary – Future

Essential: GGOS, Longer time series, >lowers uncertainty > improves prediction.

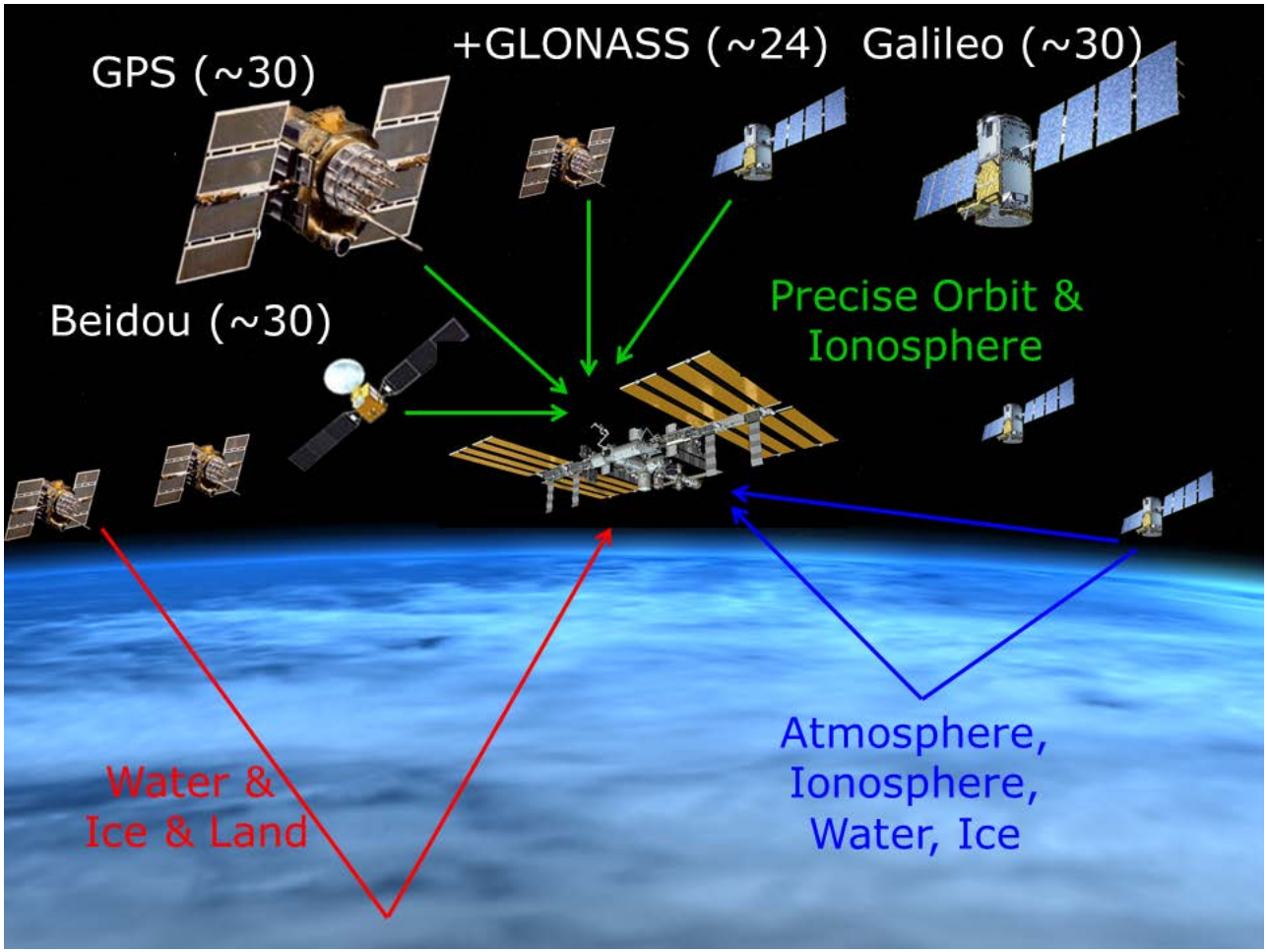




Gain new knowledge about Sea level (sub-mesoscale)

Improved spatio temporal mapping of sea level.

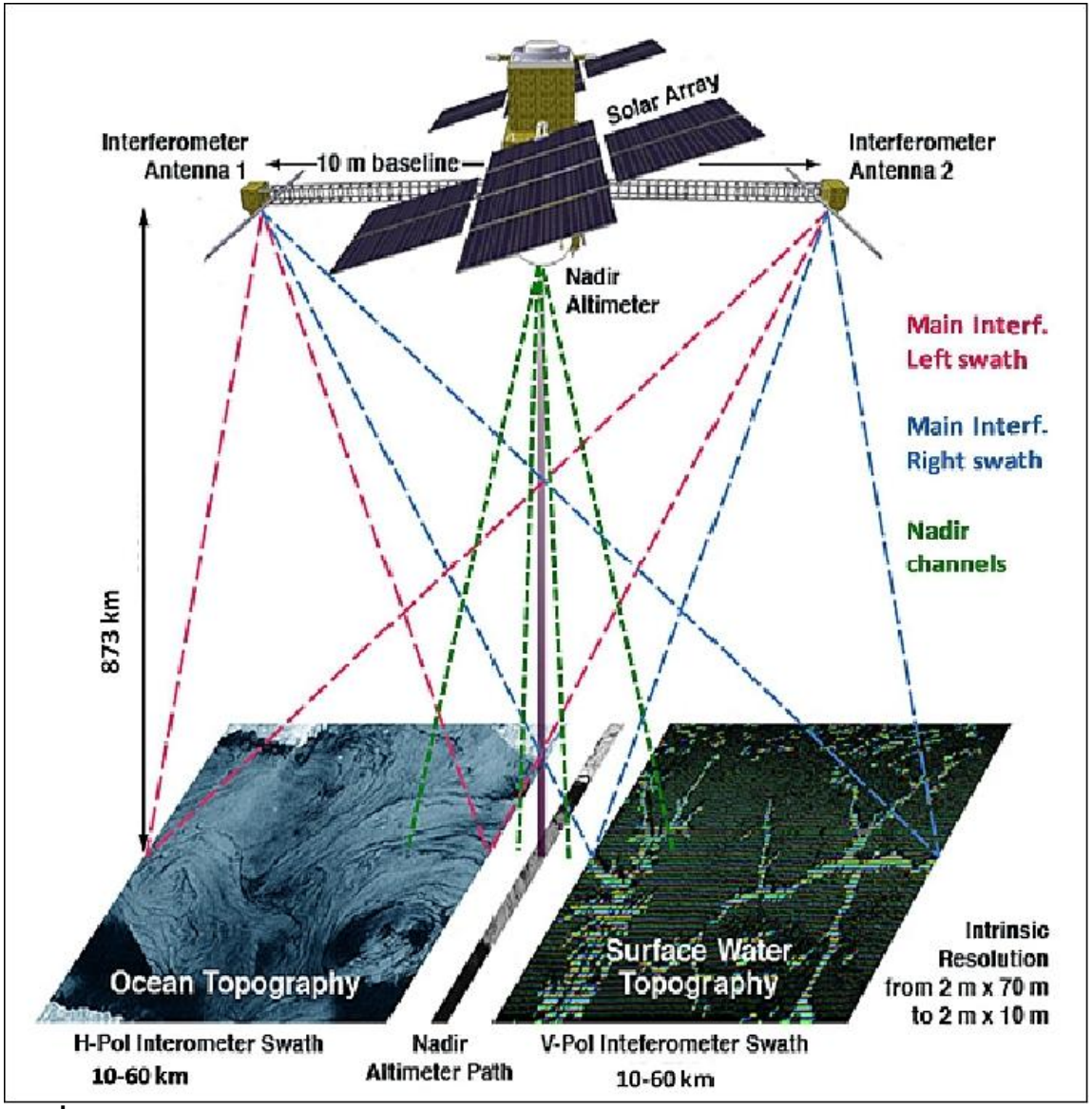
GEROS



Wickert, Andersen et al. 2016

SWOT 2020

- Full SAR interferometry
- altimetry



Thank you.

Questions ??????