Proudman Oceanographic Laboratory
NATURAL ENVIRONMENT RESEARCH COUNCIL

Climate Change: Understanding Recent Changes in Sea Level and the Ocean

Sea Level Rise

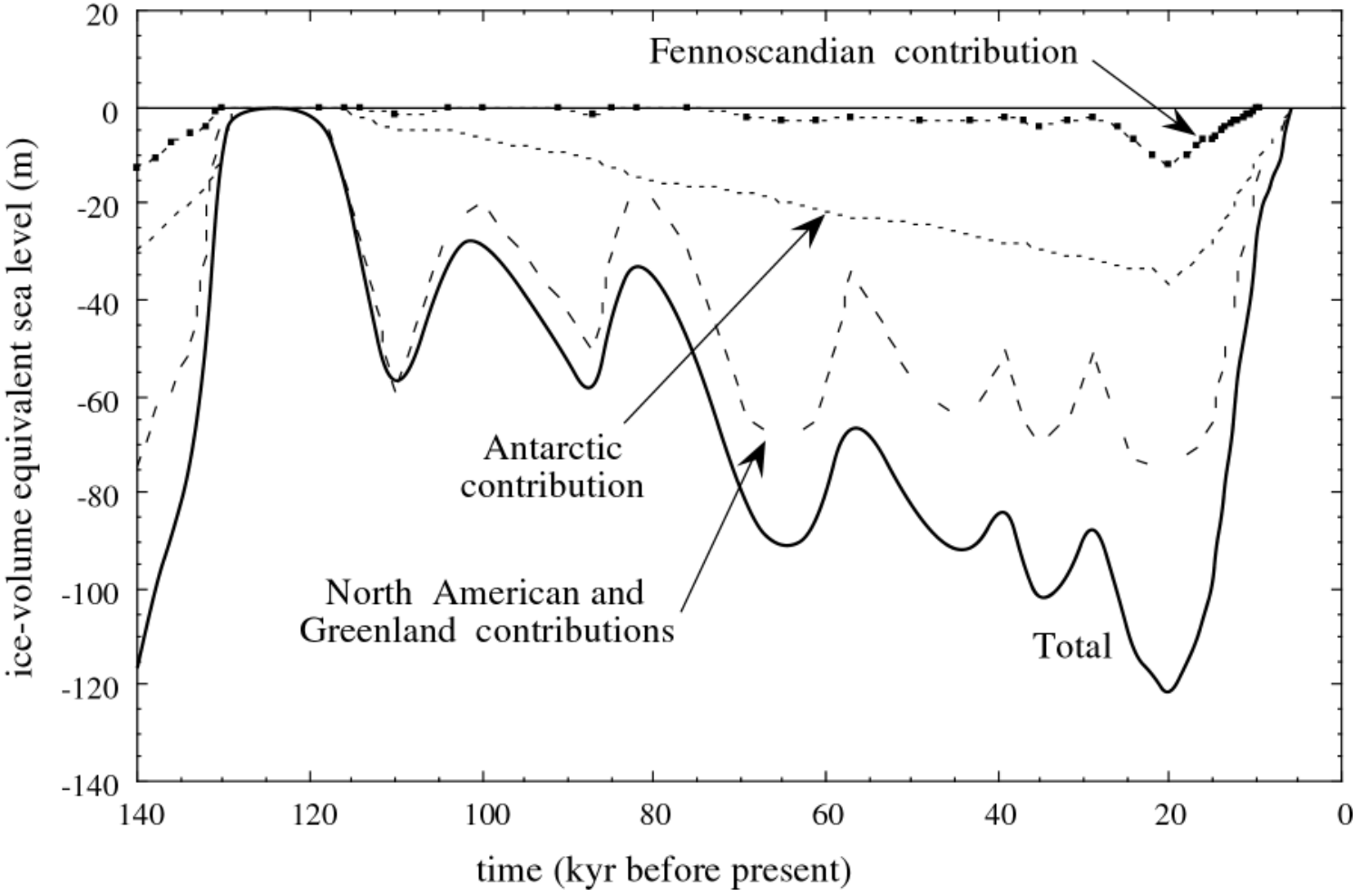
Philip L. Woodworth
Proudman Oceanographic Laboratory, Liverpool

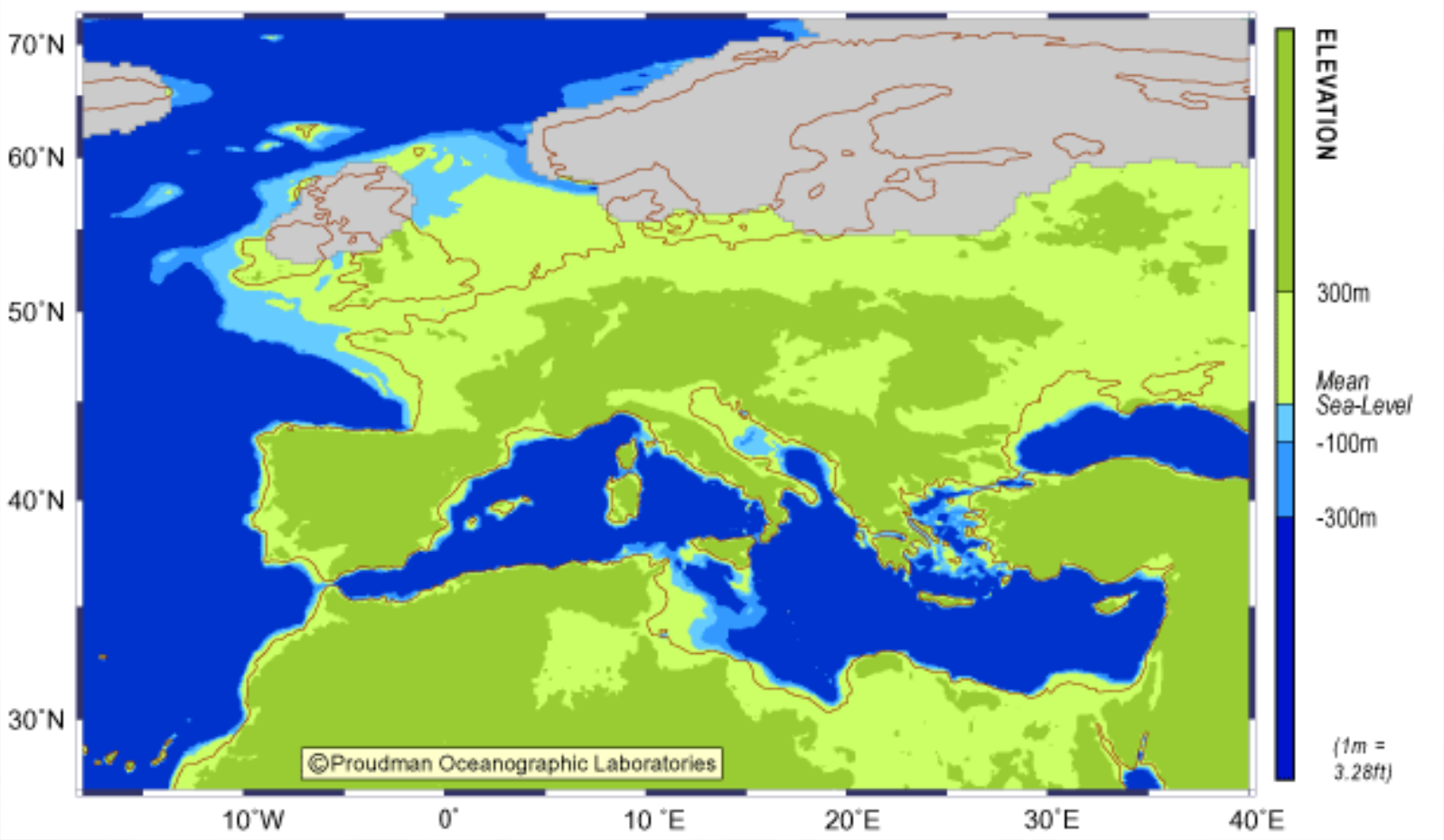
ASE/BA/City of Culture Evening 18 October 2007

Long Term Sea Level Changes

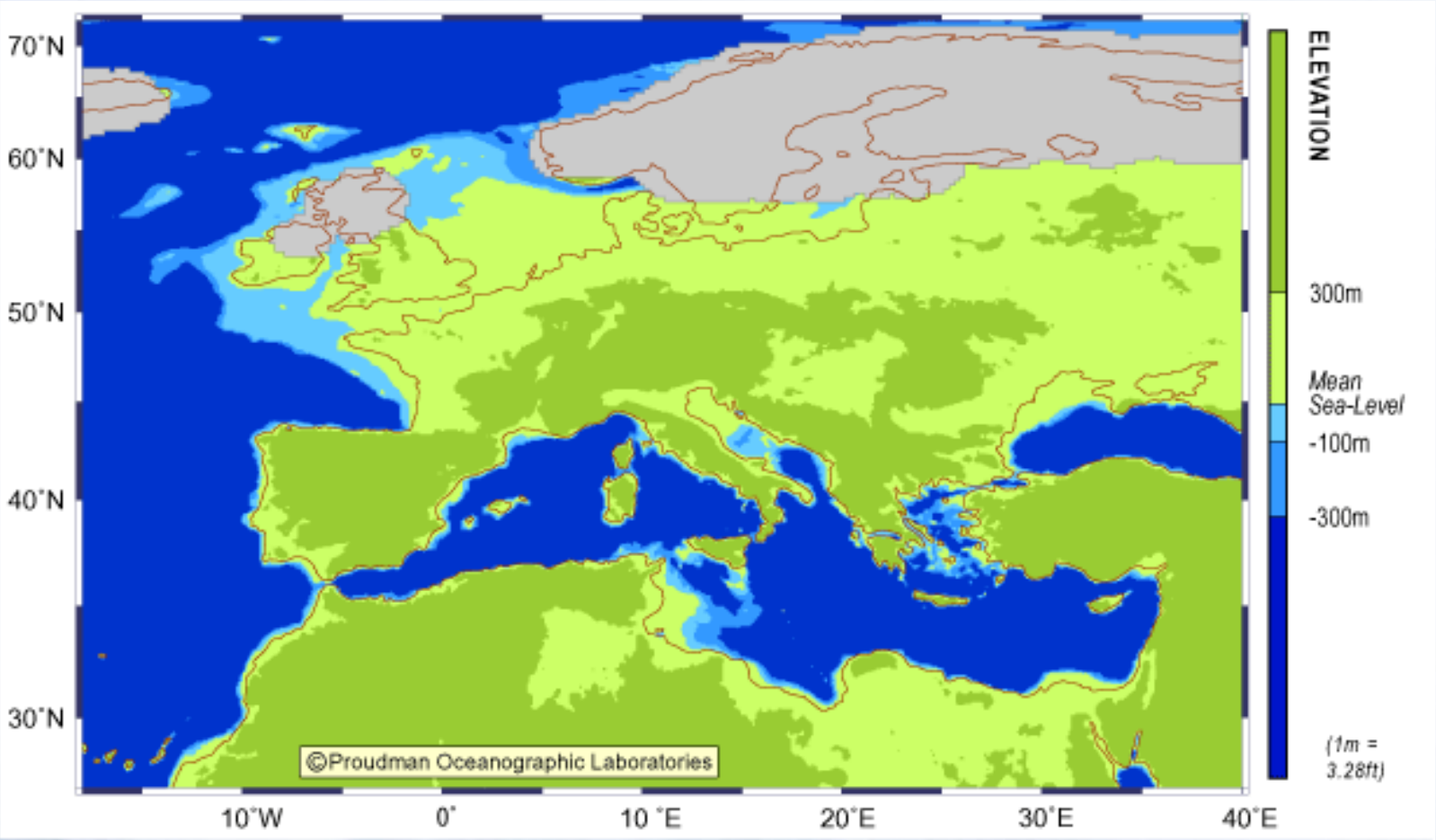
- We know from geologists that sea level has changed over many1000s of years largely as a result of the exchanges of water between the ocean and ice caps

- So we should not be too surprised if sea level is still changing

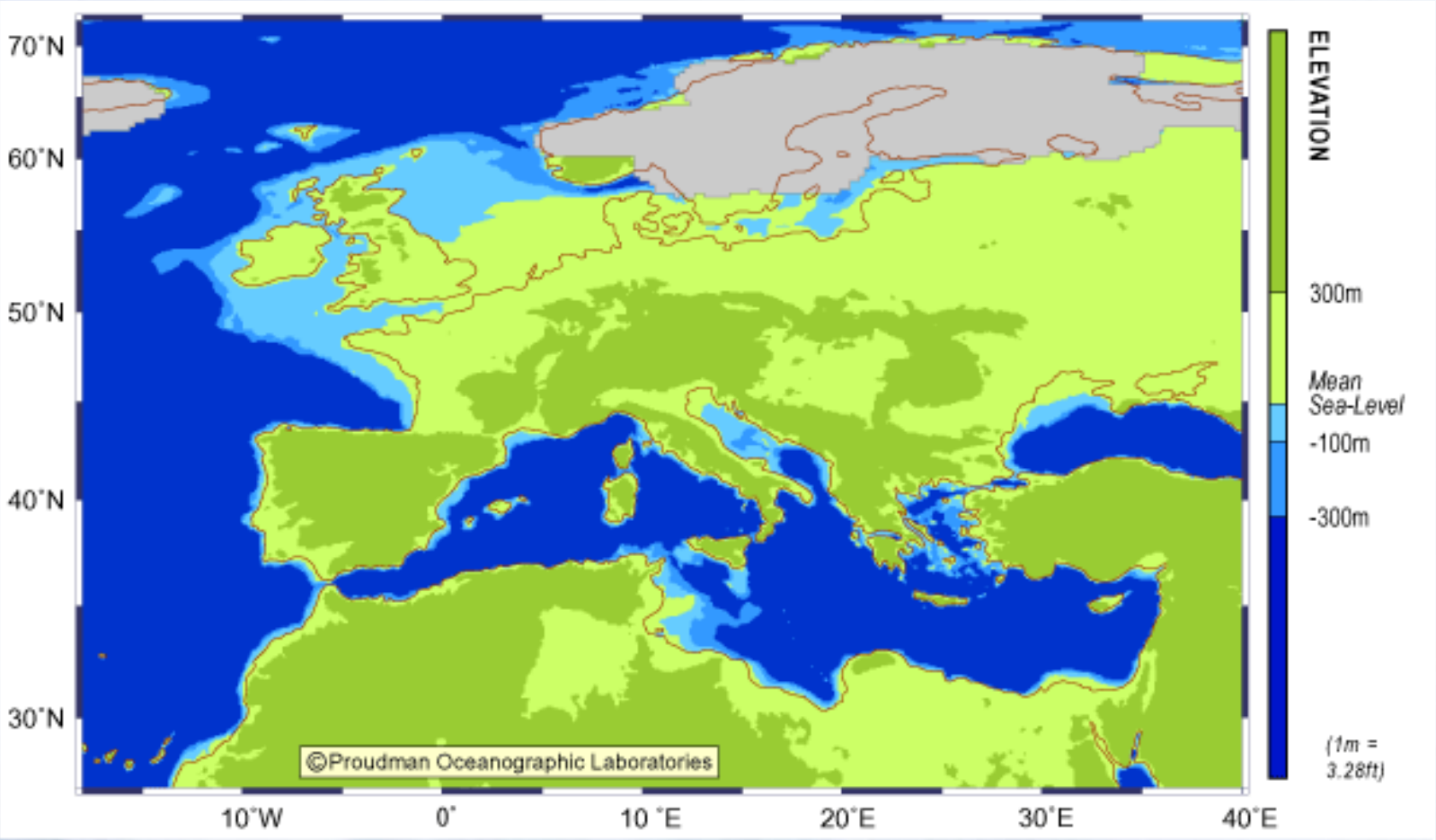

Fennoscandian contribution
Antarctic contribution
North American and Greenland contributions
Total
ice-volume equivalent sea level (m)
time (kyr before present)
20
0
-20
-40
-60
-80
-100
-120
-140
140
120
100
80
60
40
20
0


70°N
60°N
50°N
40°N
30°N
10°W
0°
10 °E
20°E
30°E
40°E
ELEVATION
300m
Mean Sea-Level
-100m
-300m
(1m = 3.28ft)
©Proudman Oceanographic Laboratories
Behrman Cylindrical Equal-Area projection
Scale 1: 30 000 000
Grounded Ice

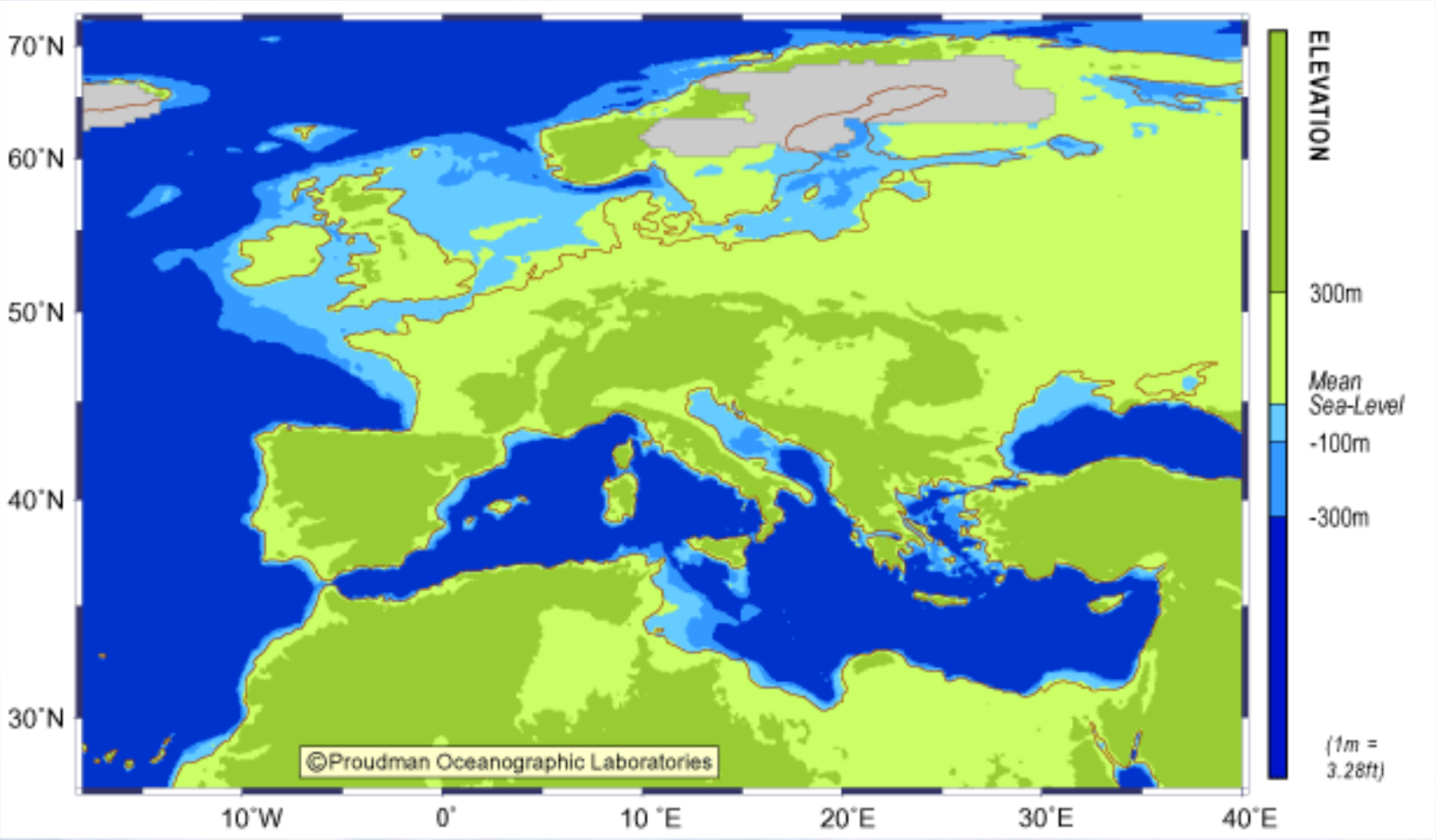
20K BP


70°N
60°N
50°N
40°N
30°N
10°W
0°
10 °E
20°E
30°E
40°E
ELEVATION
300m
Mean Sea-Level
-100m
-300m
(1m = 3.28ft)
©Proudman Oceanographic Laboratories
Behrman Cylindrical Equal-Area projection
Scale 1: 30 000 000
Grounded Ice

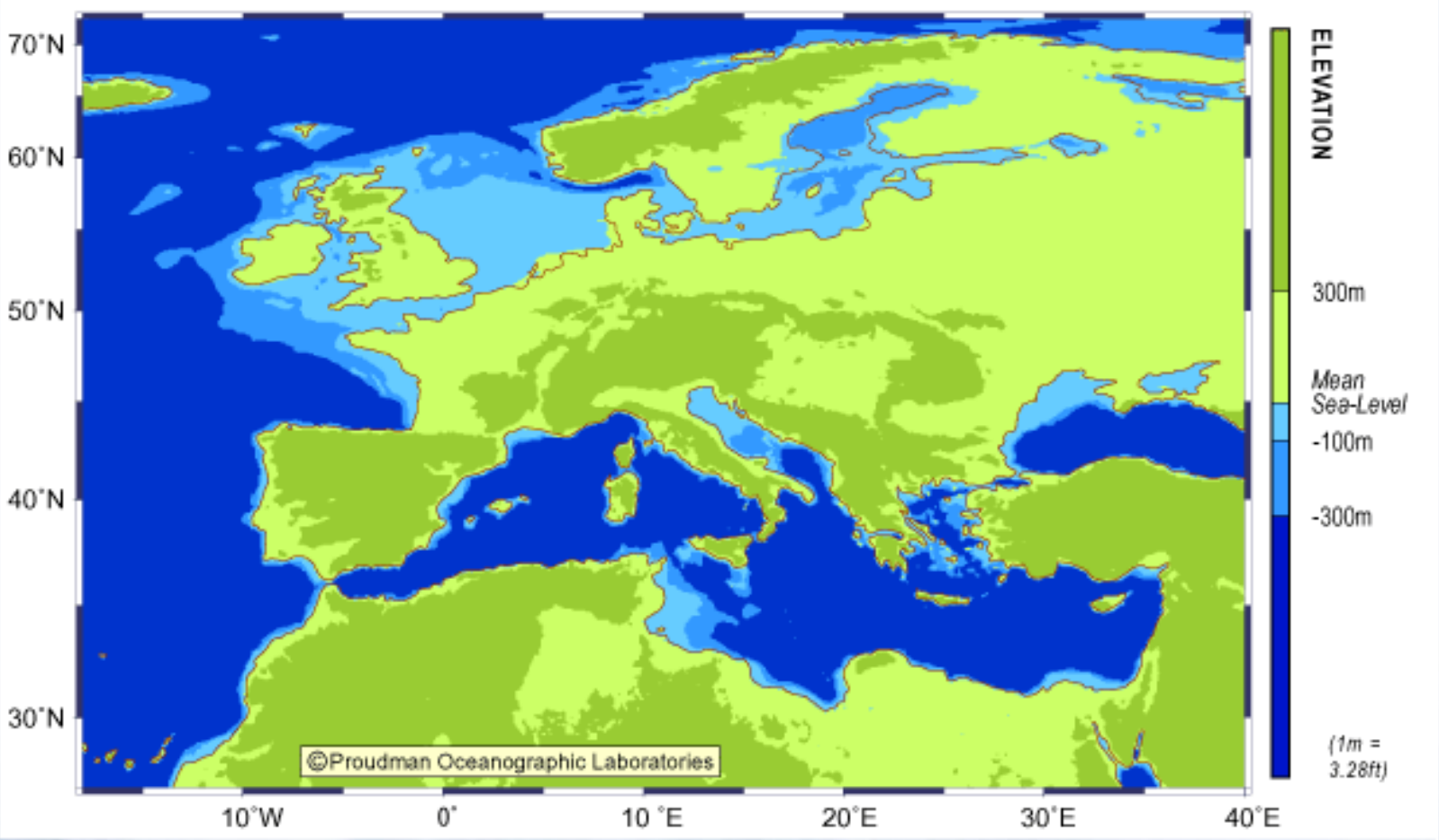
15K BP


70°N
60°N
50°N
40°N
30°N
10°W
0°
10 °E
20°E
30°E
40°E
ELEVATION
300m
Mean Sea-Level
-100m
-300m
(1m = 3.28ft)
©Proudman Oceanographic Laboratories
Behrman Cylindrical Equal-Area projection
Scale 1: 30 000 000
Grounded Ice

12K BP


70°N
60°N
50°N
40°N
30°N
10°W
0°
10 °E
20°E
30°E
40°E
ELEVATION
300m
Mean Sea-Level
-100m
-300m
(1m = 3.28ft)
©Proudman Oceanographic Laboratories
Behrman Cylindrical Equal-Area projection
Scale 1: 30 000 000
Grounded Ice

9K BP

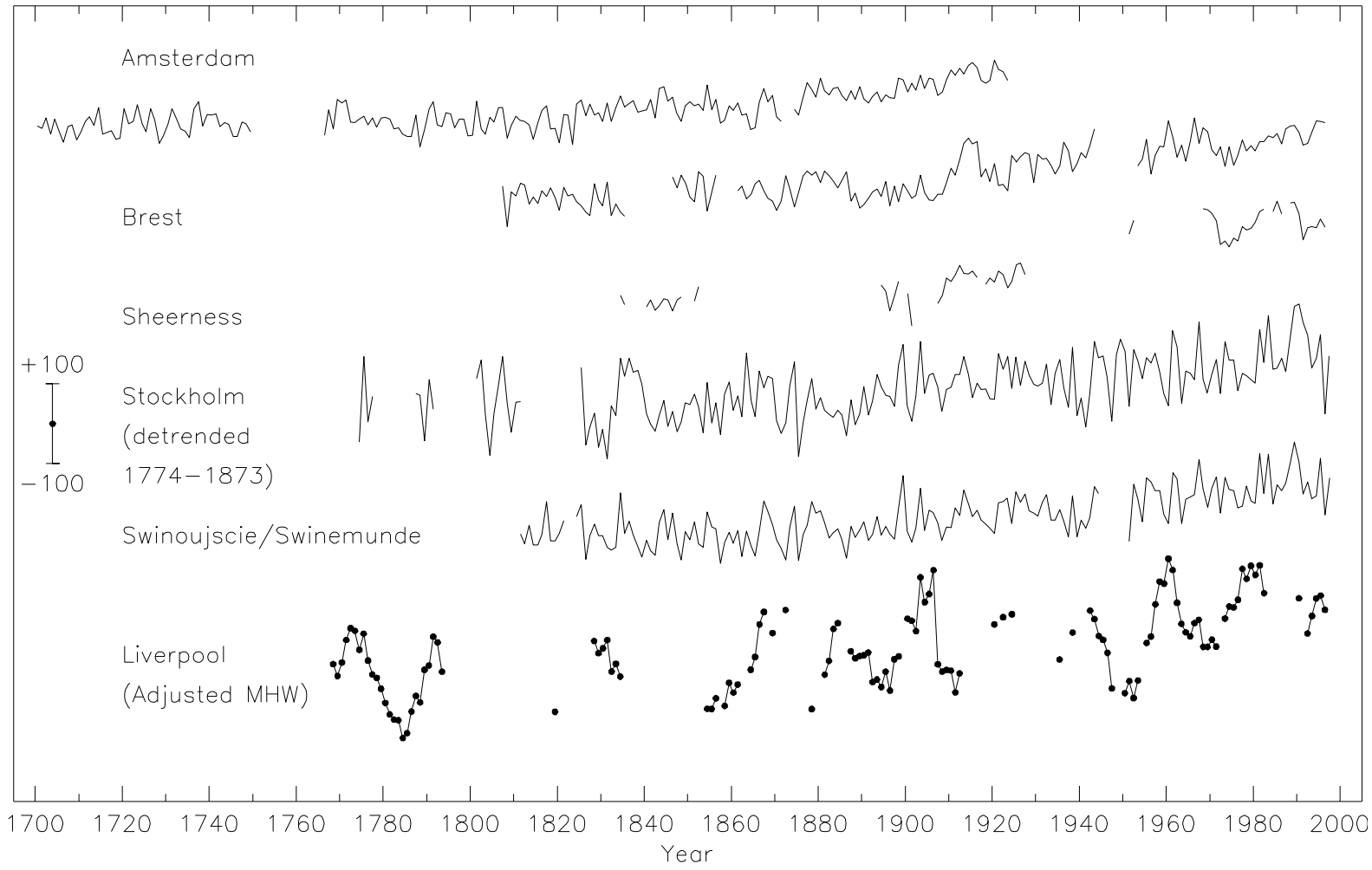


Behrman Cylindrical Equal-Area projection
Scale 1: 30 000 000

7K BP

Long Term Sea Level Changes

- For this talk ‘long term’ is the last 200 years (since the invention of the ‘tide gauge’ or ‘sea level recorder’) and the next 100 years



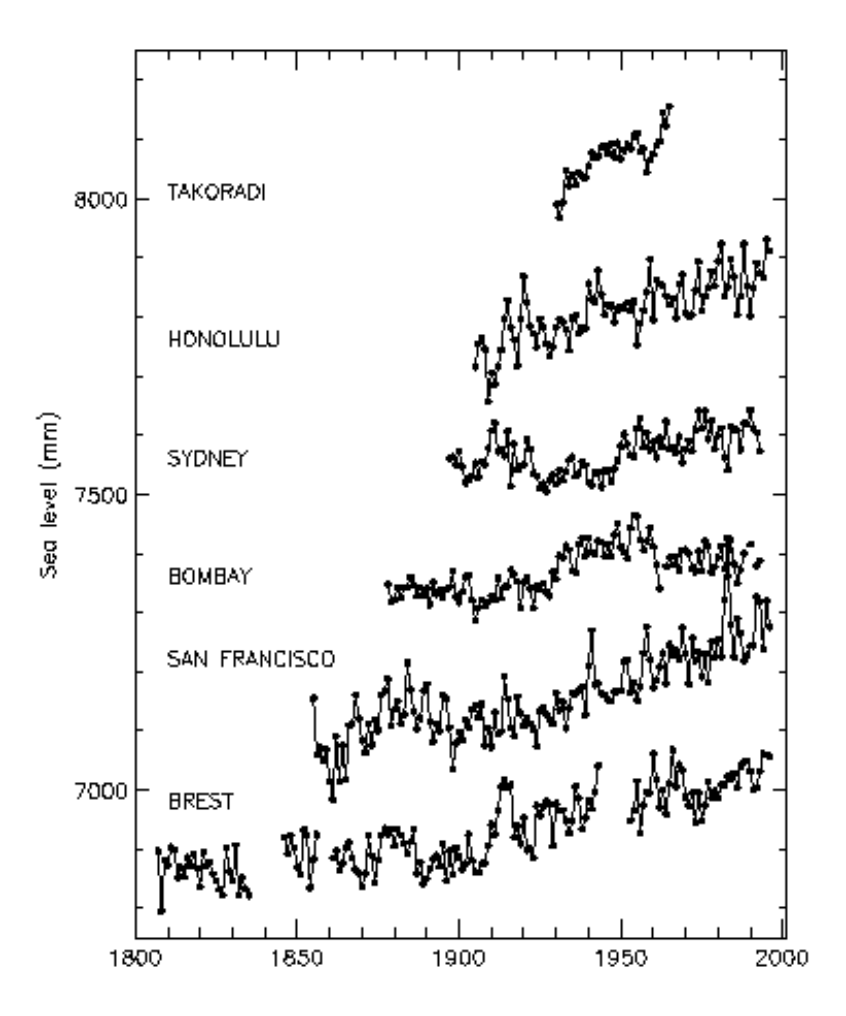
Sea level change contains an acceleration of sea level rise from the 19th to the 20th centuries probably due to climate change

Local Hero

William Hutchinson measured the heights and times of high waters at the Old Dock gates Liverpool 1764-1793

These were the first systematic tidal measurements in the UK

Sea Level Changes in Last 100 Years



Past 100 years

- Most records show evidence for rising sea levels during the past century
- IPCC Reports have concluded that there has been a global rise of approximately 10-20 cm during the past 100 years

9
8
7
6
5
4
3
2
1
7
9
8
7
6
5
4
3
2

Classical Float Gauge (from about 1832)

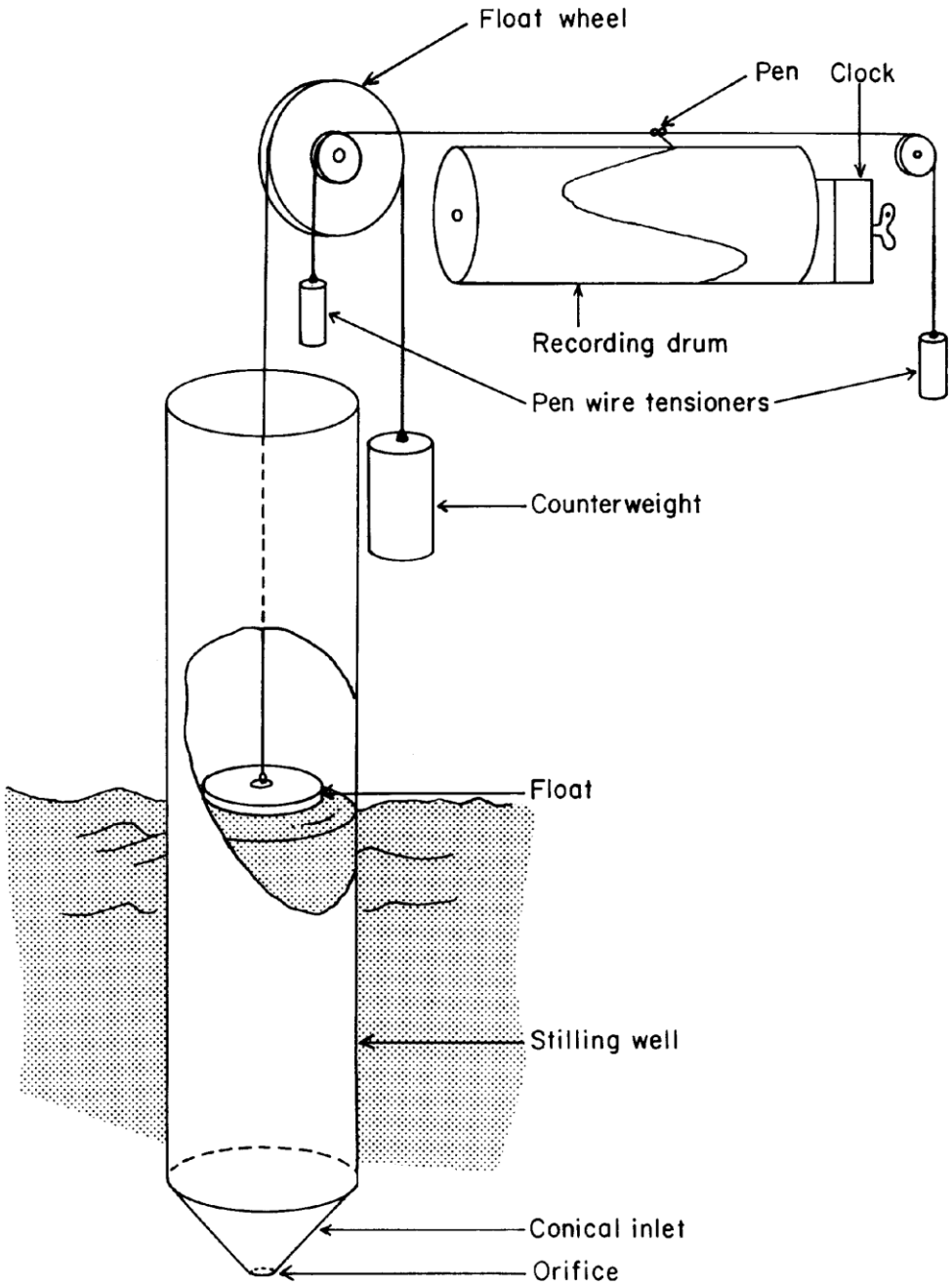


Figure 3.1

UK Float Gauge at Holyhead

Float gauges are still important devices.

They can be made into digital gauges with the use of shaft encoders

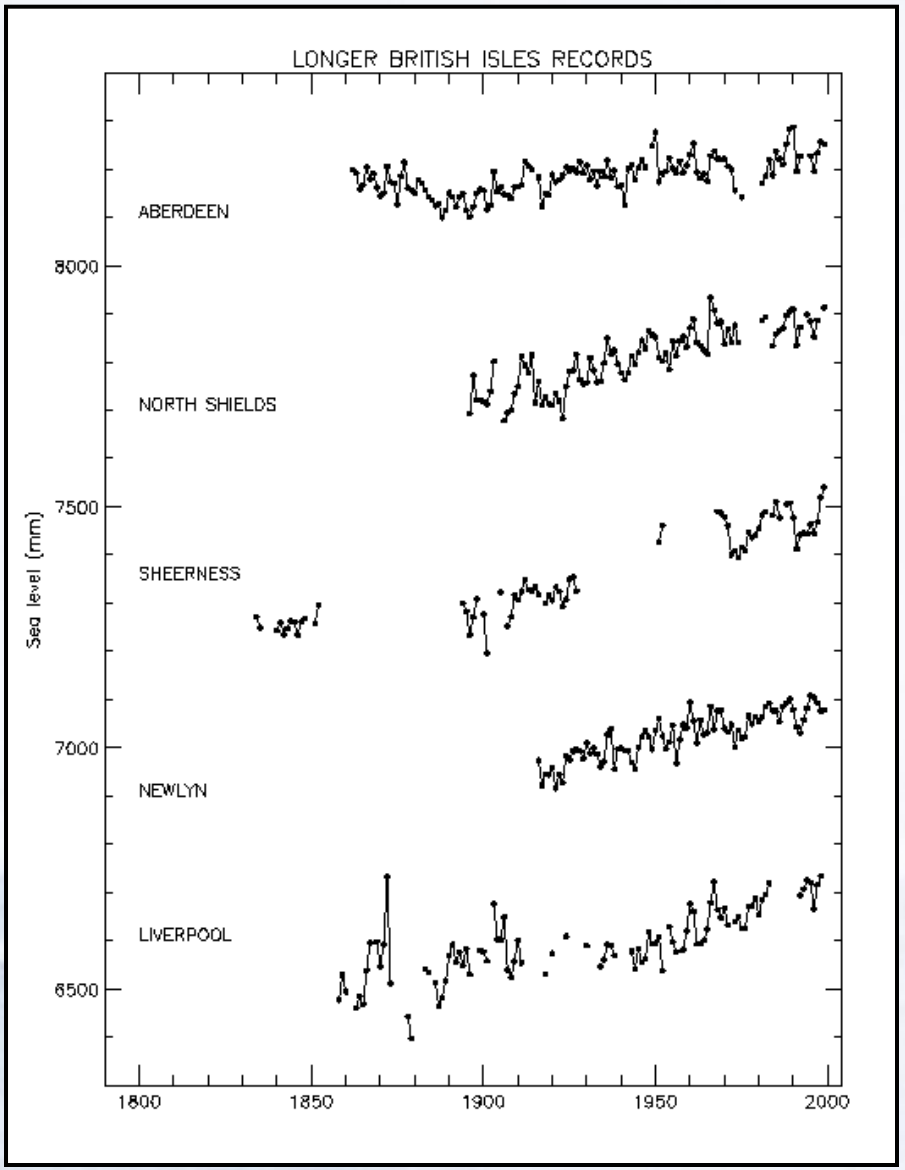
Radar gauge at Liverpool

UK National Level Network

- UK Tide Gauge Network for both national and international scientific and practical purposes

UK Sea Level Change

- UK mean sea level (MSL) is rising
- Plot shows MSL "relative" (to the land) as measured by tide gauges
- Corrected for local land movements, the "absolute" MSL trend is about +1mm/y = 10cm/century

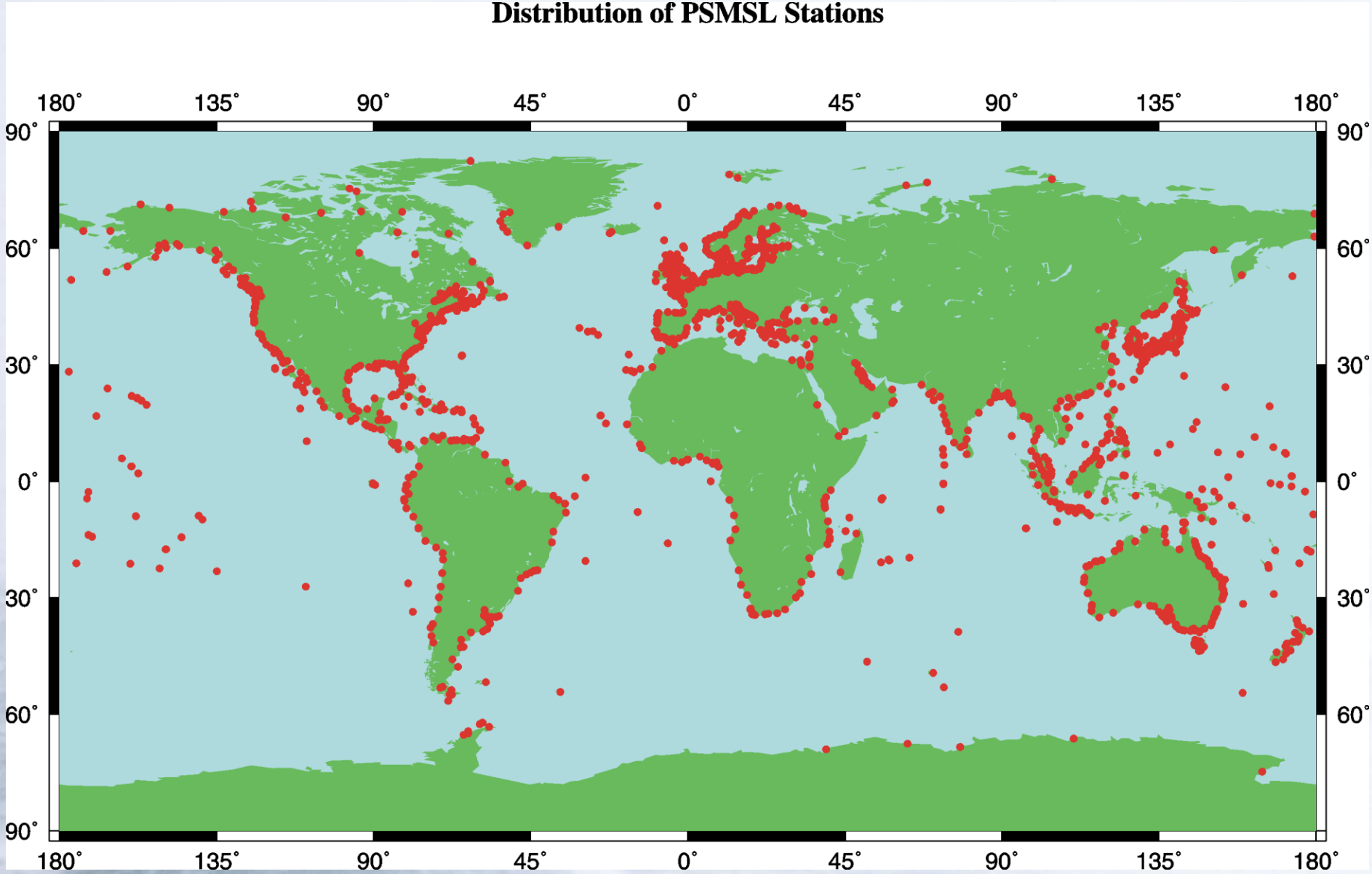


Countries Share Data through International Data Banks such as

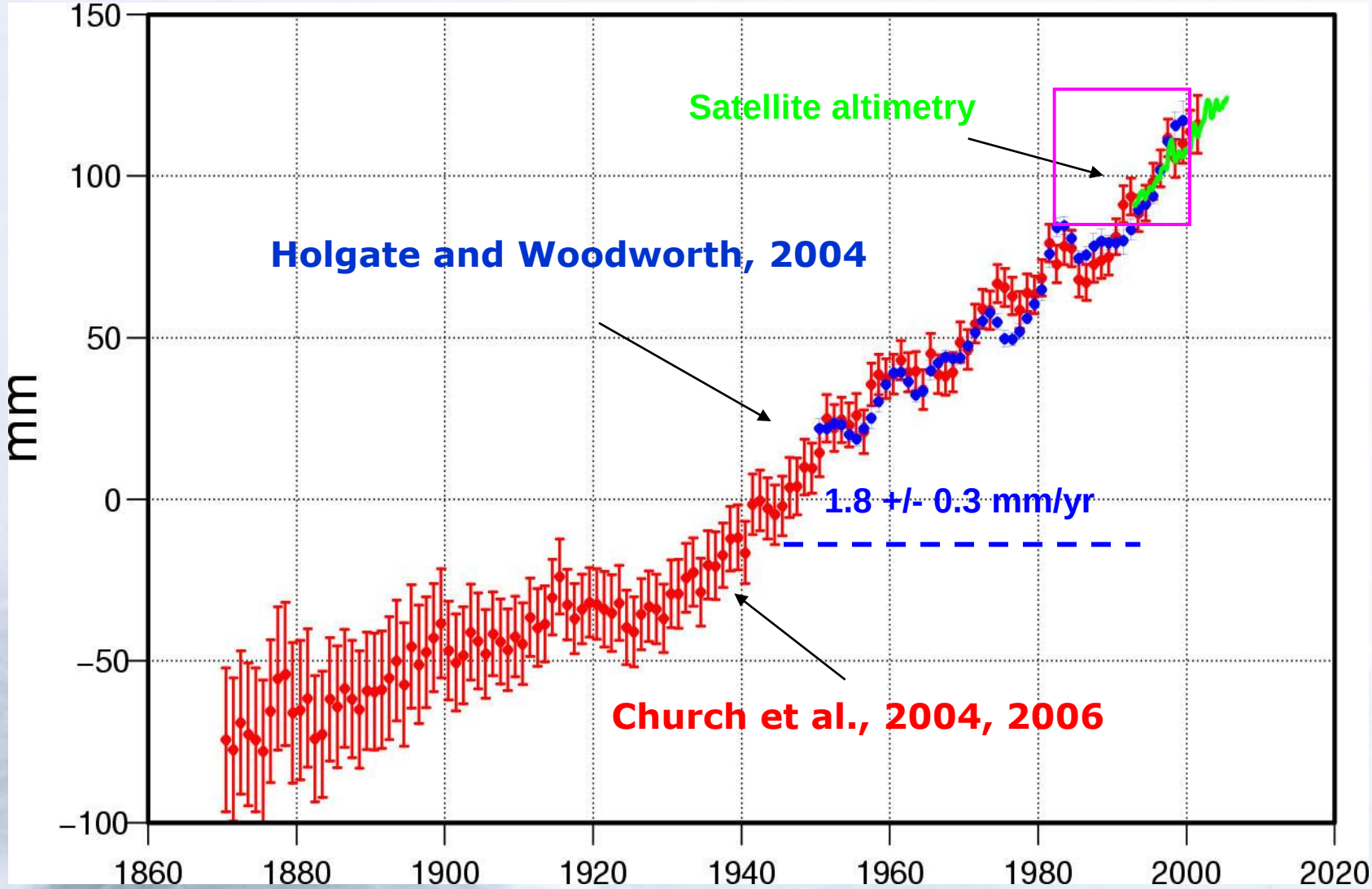
The Permanent Service for Mean Sea Level

on behalf of the International Council for Science

which is based at Proudman Oceanographic Laboratory in Liverpool


Distribution of PSMSL Stations
180˚
135˚
90˚
45˚
0˚
45˚
90˚
135˚
180˚
90˚
60˚
30˚
0˚
30˚
60˚
90˚

20th century sea level rise

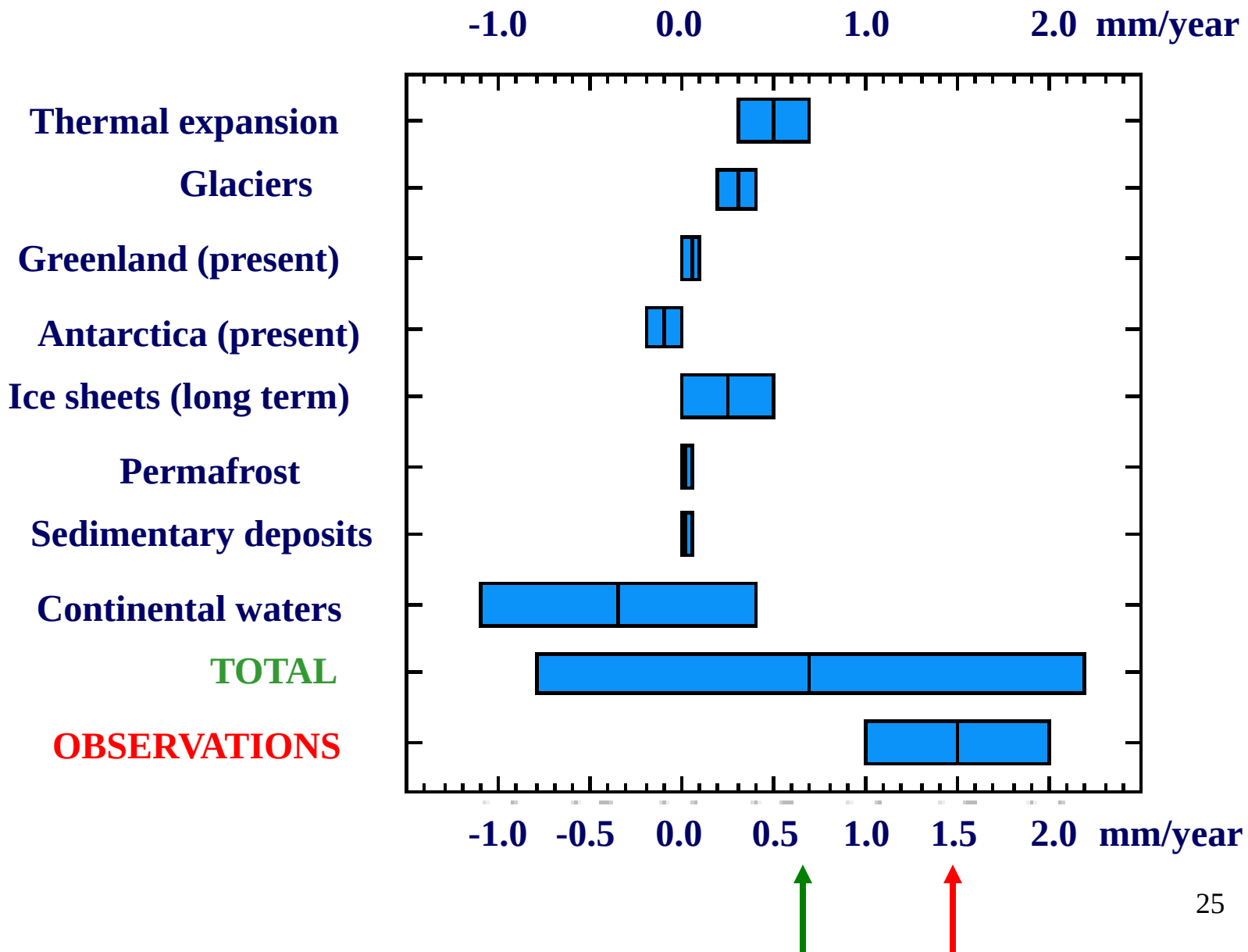


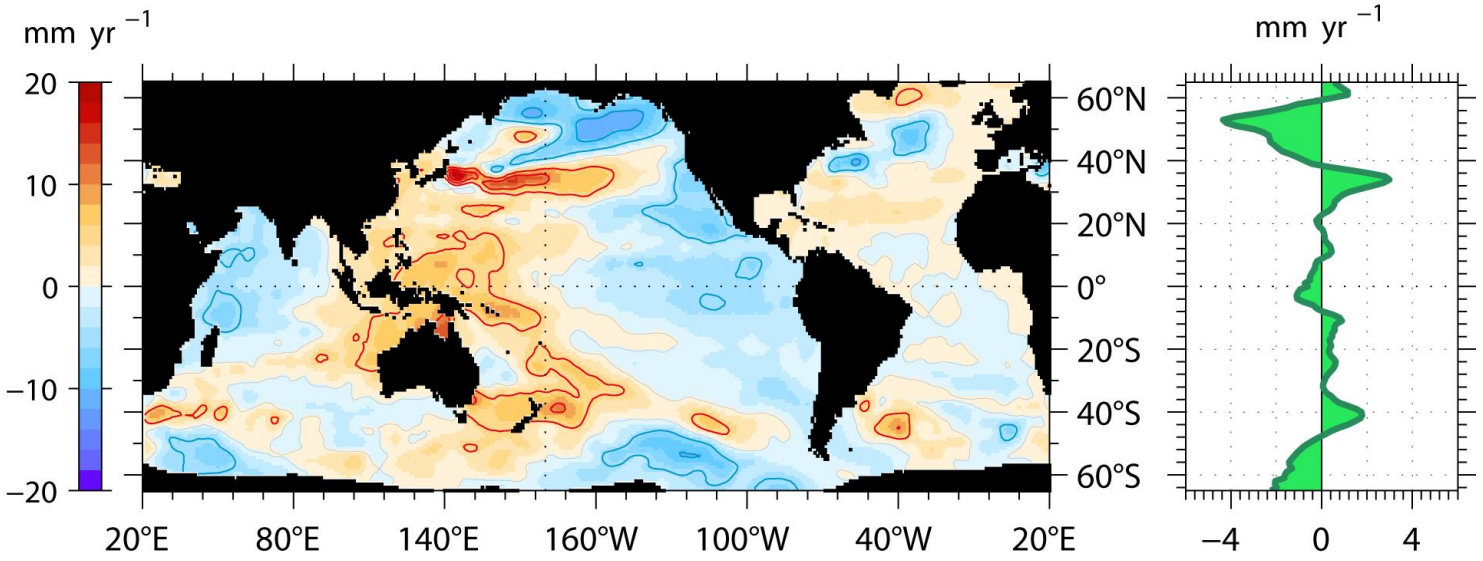
Monitor sea levels and surface waters from space by satellite altimetry

Global coverage of altimeter satellites

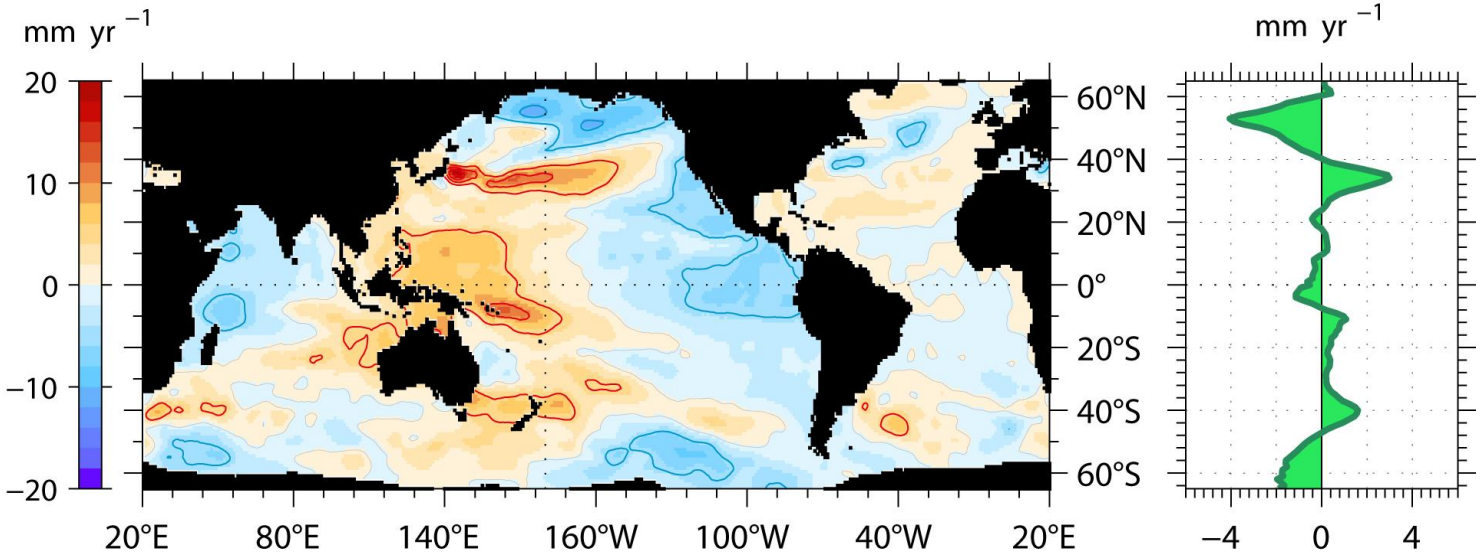
Why is Sea Level Rising?

Budget of 20th Century Sea Level Rise (IPCC 2001)





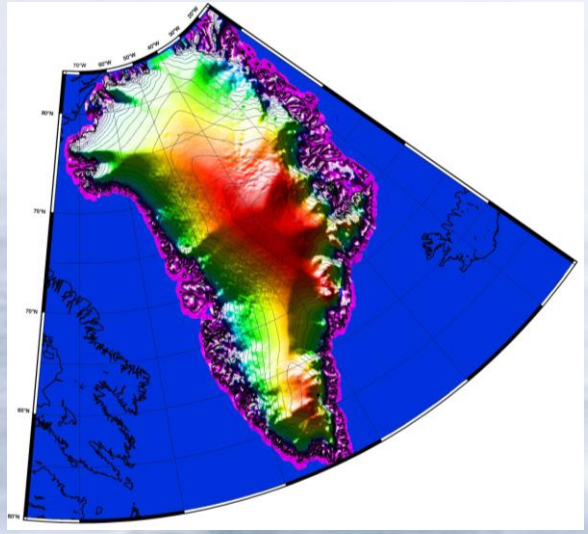
Sea Level



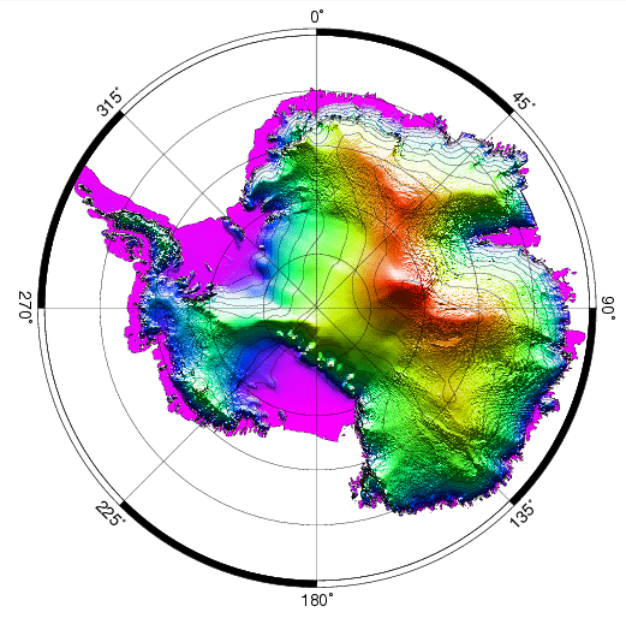
Thermal Expansion

Land Ice Contribution (past few years)

Dyugerov and Meier, 2005
Cogley, 2005
…….



Rignot & Thomas, 2002
Thomas et al., 2004
Krabill et al., 2004
Zwally et al., 2005
Johanessen et al., 2005
Davis et al., 2005
Rignot & Kanagaratnam, 2006
Rignot et al., 2006
Velicogna & Wahr (2005, 2006)
Ramillien et al. (2006)
…….



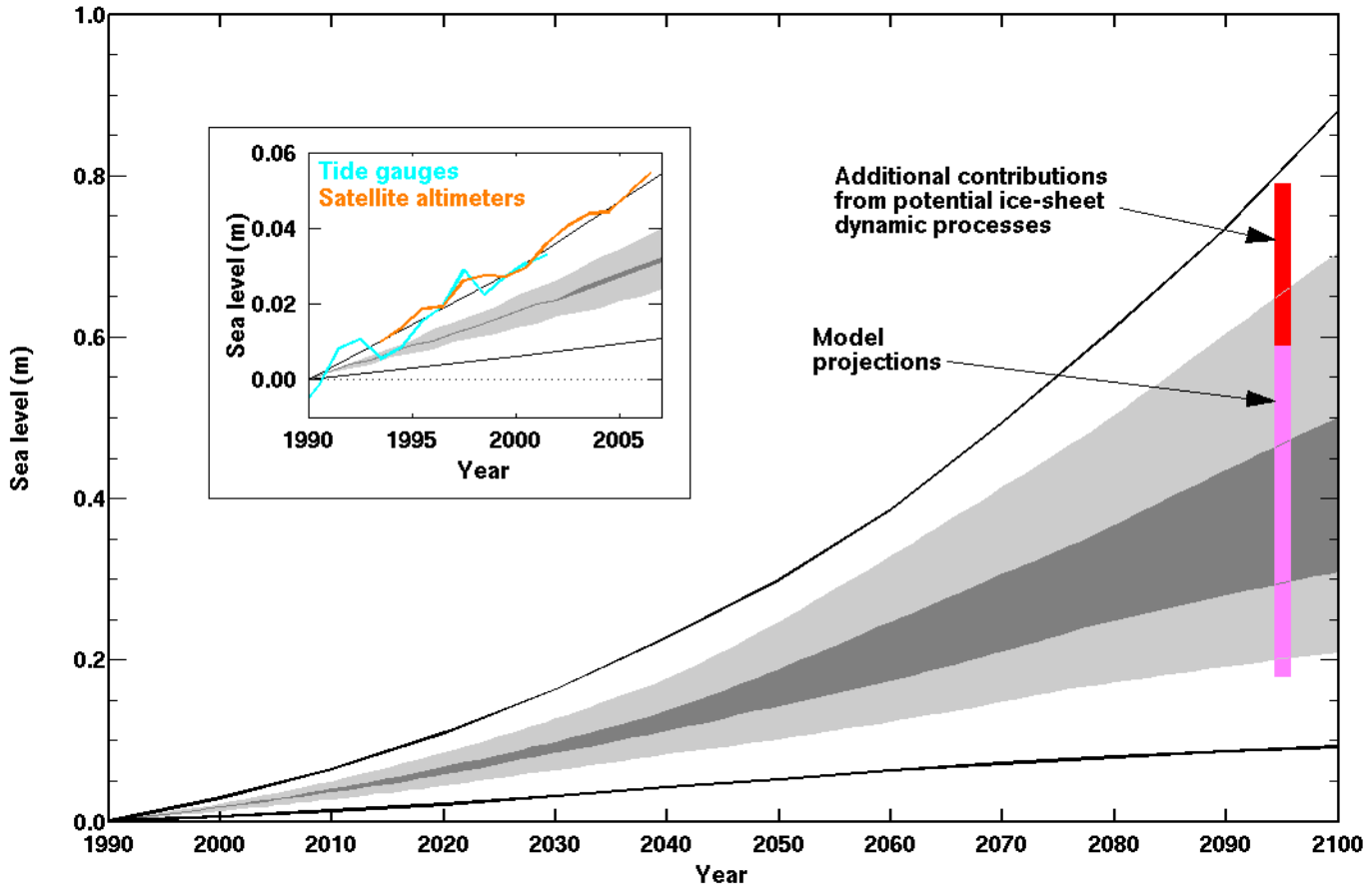
Increasing concern about ice-sheet stability and a substantially larger rise in sea level

- Surface melting

  For sustained warmings above 4.5±0.9 K in Greenland (3.1±0.8 K in global average), it is likely that the ice sheet would eventually be eliminated. [Gregory and Huybrechts, accepted]

- Dynamic instability

How Much will it Rise in the Near Future ?


Sea level (m)
1.0
0.8
0.6
0.4
0.2
0.0
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Year
Additional contributions
from potential ice-sheet
dynamic processes
Model
projections
Tide gauges
Satellite altimeters
Sea level (m)
0.06
0.04
0.02
0.00
1990
1995
2000
2005
Year

Sea Level Rise is Not the Same Everywhere

- Ocean circulation readjusts in response to changing climate ➔ changes in the ‘ocean topography’
- There are vertical land movements as well as sea level changes e.g. submergence due to mining, uplift due to post glacial rebound

It is important to keep in mind that these rising Sea Levels sooner or later lead to changes in Extreme Levels and often to local flooding.

This is not only a ‘Scientific’ exercise.

$$X(t) = T(t) + S(t) + Z(t)$$

where

X = still water level
T = tide
S = surge (or residual)
Z = slowly varying level (MSL)

Z could be trend or decadal variability or ENSO signal

S depends primarily on changing meteorology (or eddy activity for example)

North Sea floods 1953

Extreme sea level (storm surge) Bangladesh 1970. Over 300,000 killed

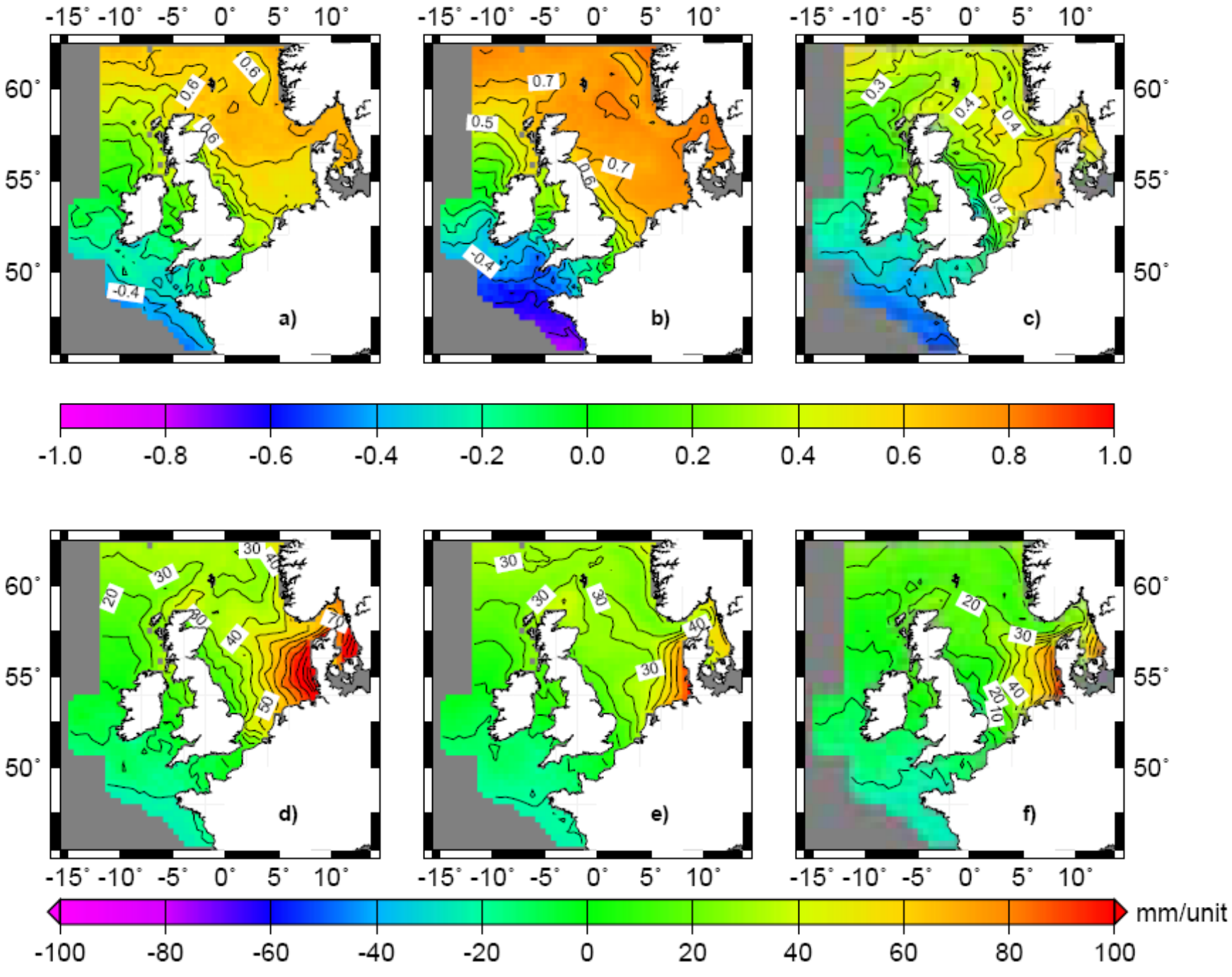
Bay of Bengal Major Surges

1737	300,000 killed
1864	100,000
1876	100,000
1897	175,000
1970	300,000 (tide plus 6m surge)

And at least 23 surge events with over 10,000 killed since 1737

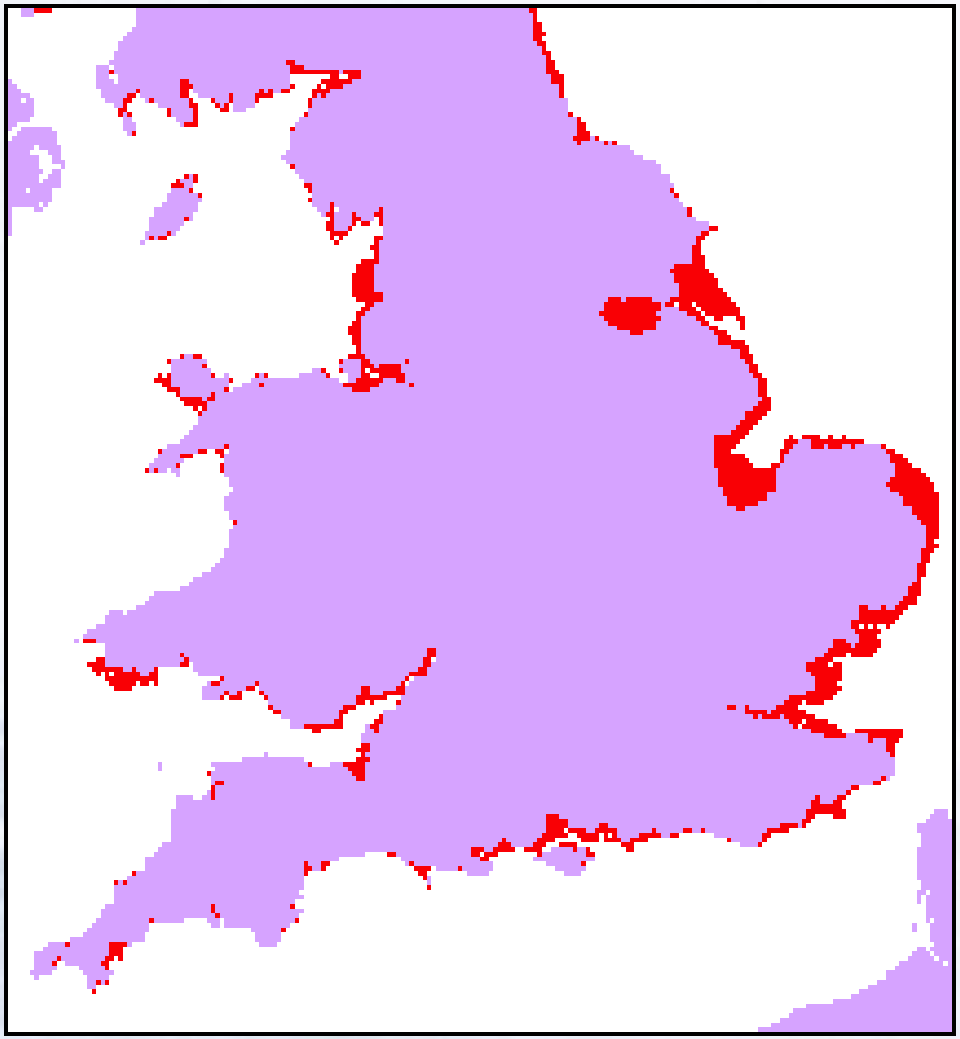
These considered lower limits (Murty, Flather and Henry, 1986 Progress In Oceanography; Murty and Flather, 1994 Journal of Coastal Research)

Will Floods Become More Frequent ?


-15° -10° -5° 0° 5° 10°
60°
55°
50°
a)
b)
c)
d)
e)
f)
-1.0 -0.8 -0.6 -0.4 -0.2 0.0 0.2 0.4 0.6 0.8 1.0
-100 -80 -60 -40 -20 0 20 40 60 80 100
mm/unit

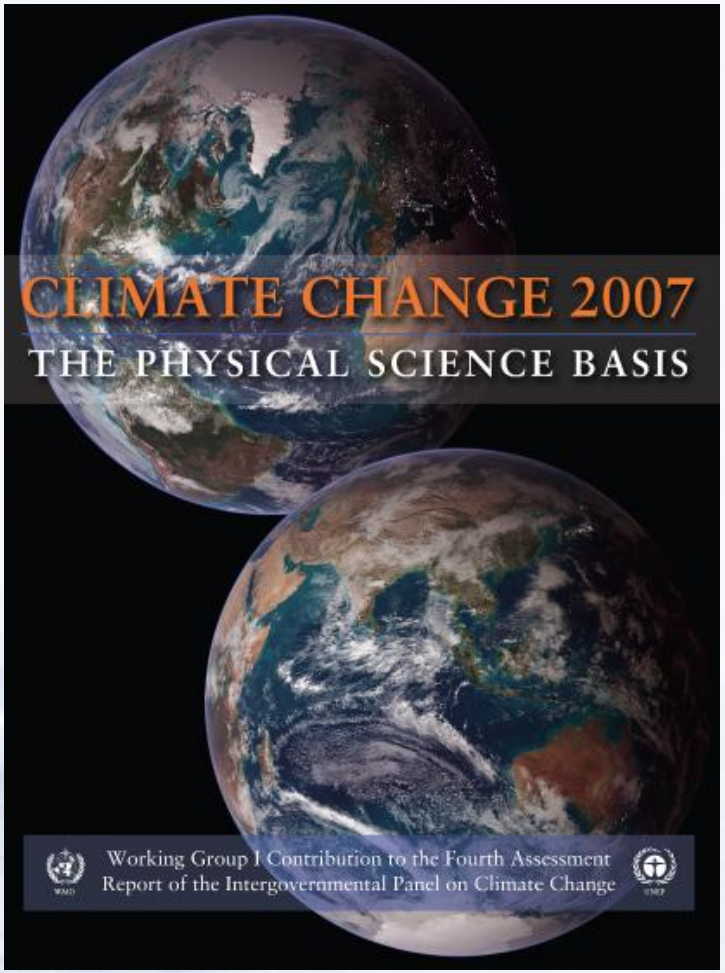
Coastal areas at risk

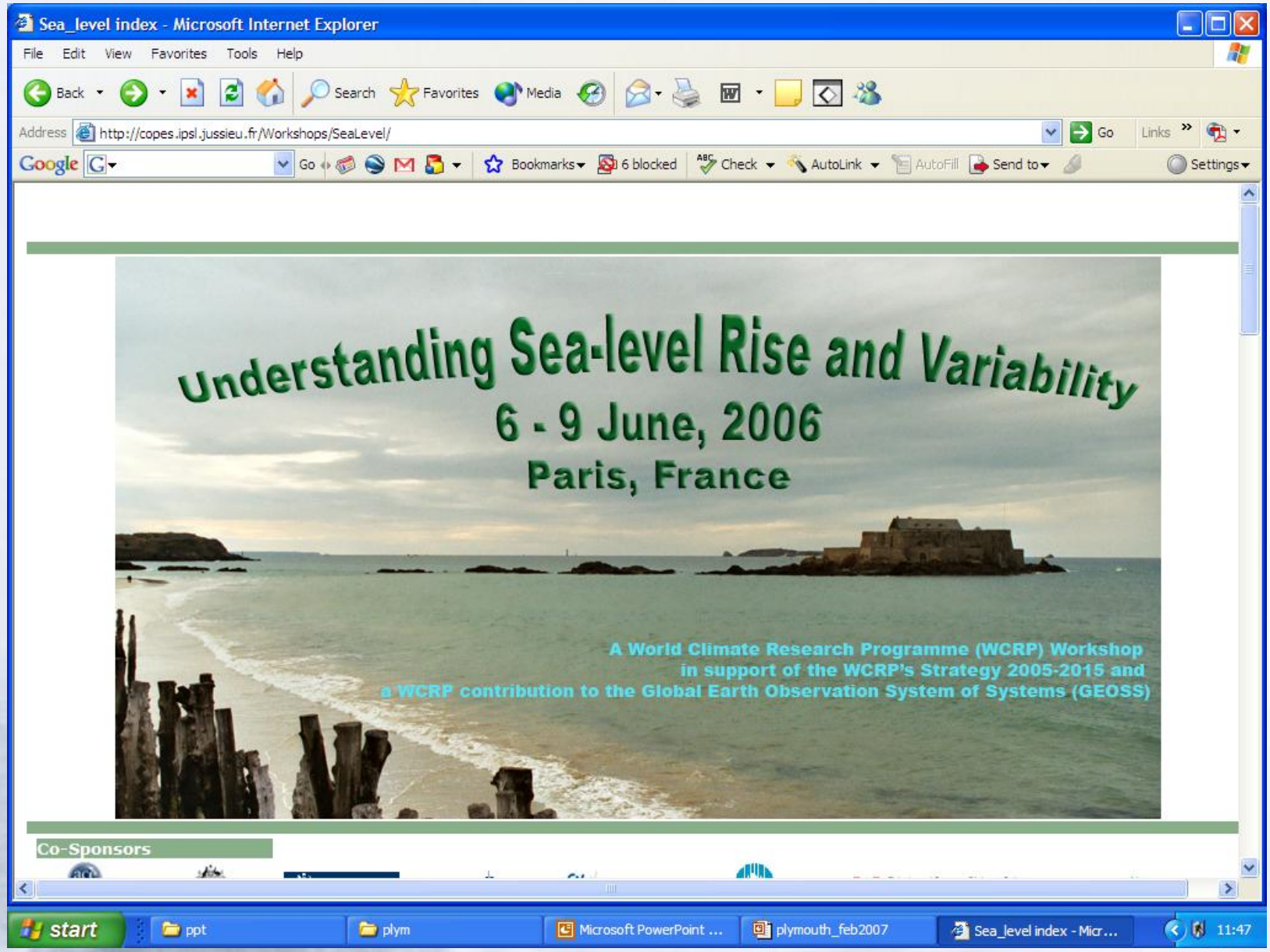
- Areas below 1000-year return period level
- By 2100: the **1 in 1000 year** flood level (shown here in red) may become a **1 in 100 year** level



IPCC Fourth Assessment Report – e.g. see Summary for Policymakers

- *Chapter 4 Observations: snow, ice and frozen ground.*
- *Chapter 5 Observations: Oceanic Climate Change and Sea Level.*
- *Chapter 10 Global climate predictions.*





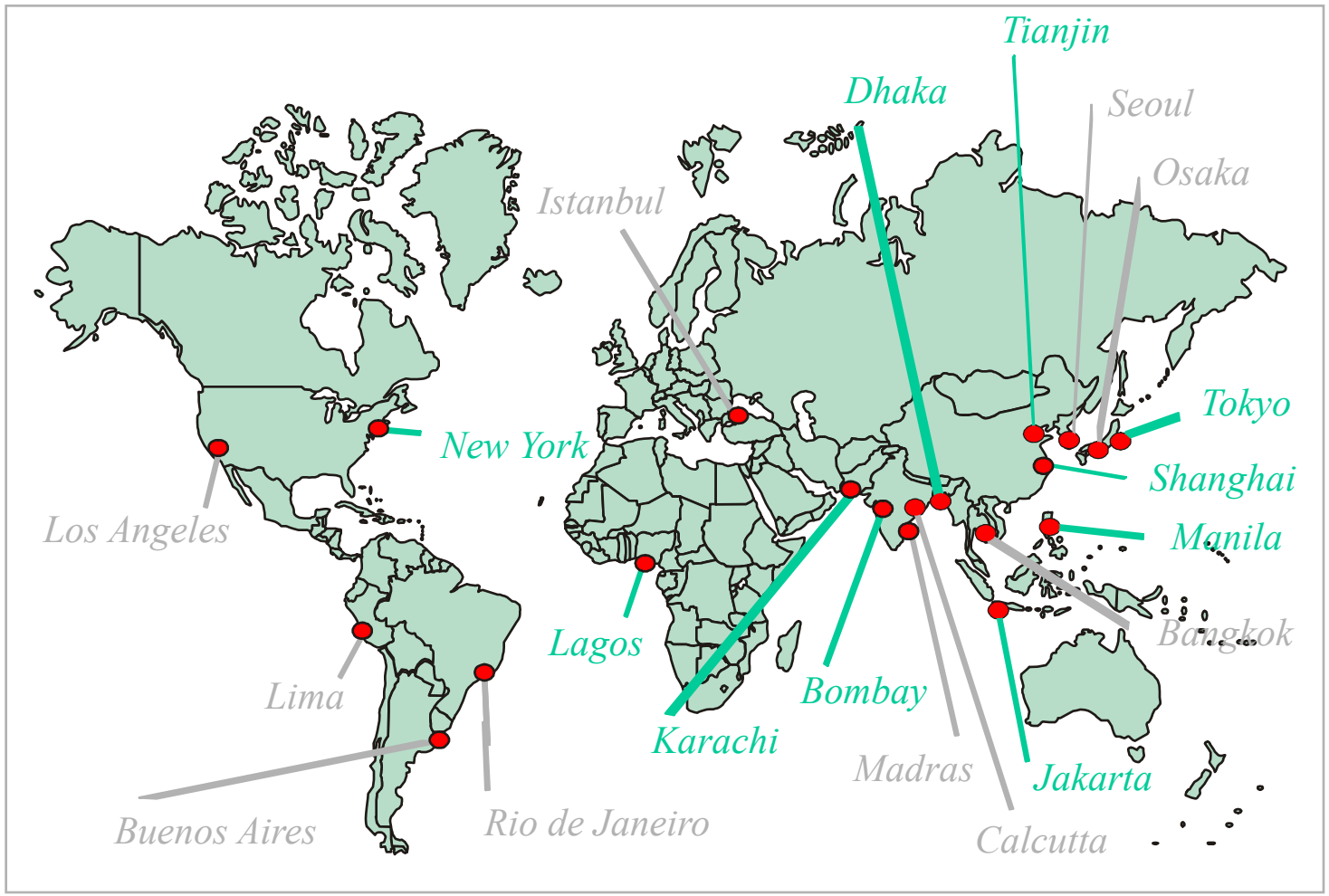
http://copes.ipsl.jussieu.fr/Workshops/SeaLevel/

How Much will it All Cost ?

- In 1990 23 percent of the world's population (1.2 billion people) were living within 100 km distance and 100 m elevation of the coast at densities three times the global average.
- Stern Review on the Economics of Climate Change

Projected Coastal Megacities: 2010

(≥8 million inhabitants)

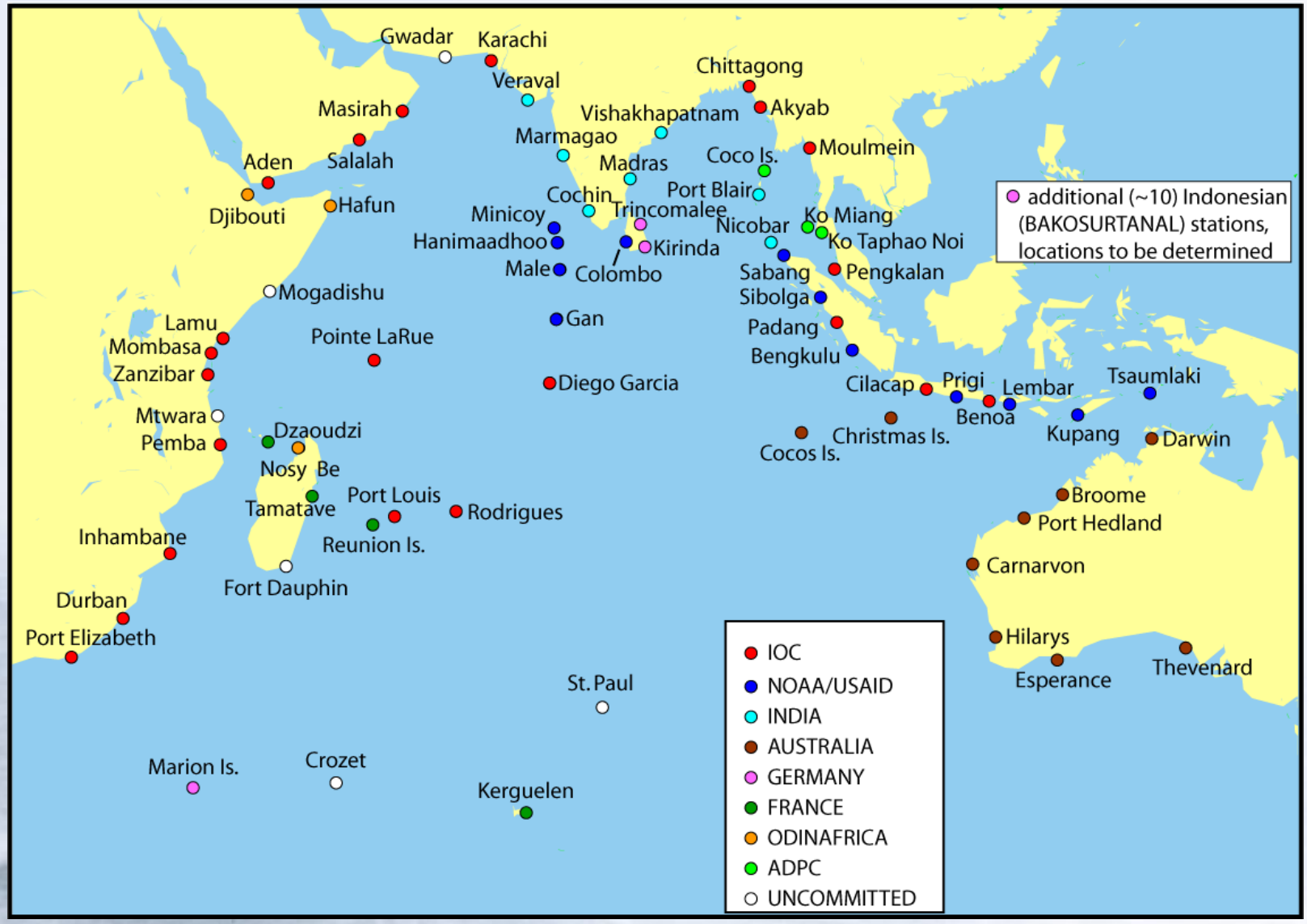


Liverpool – Home of Sea Level Science

- Sea Level Science is an exciting interdisciplinary topic
- Sea Level Science is a very practical and important topic

- Much of the history of Sea Level Science, and we hope much of the future (!), is connected with Liverpool

Recent and Upcoming Installations and Upgrades in the Indian Ocean



CD for Liverpool BA 2008