

The background of the slide is a photograph of a vast, flat-topped glacier or ice shelf meeting the sea. The ice is a pale blue-white color, and the water in the foreground is a deep blue with gentle ripples. The sky is a light, hazy blue.

Lecture course on
Sea level variations and global geodynamics

4. Secular sea level variations
(November 10, start 15:40)

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November 7–11, 2011

last revised november 7 2011

Il livello marino sta cambiando?

Giorgio Spada e Gaia Galassi

DiSBeF - Urbino University

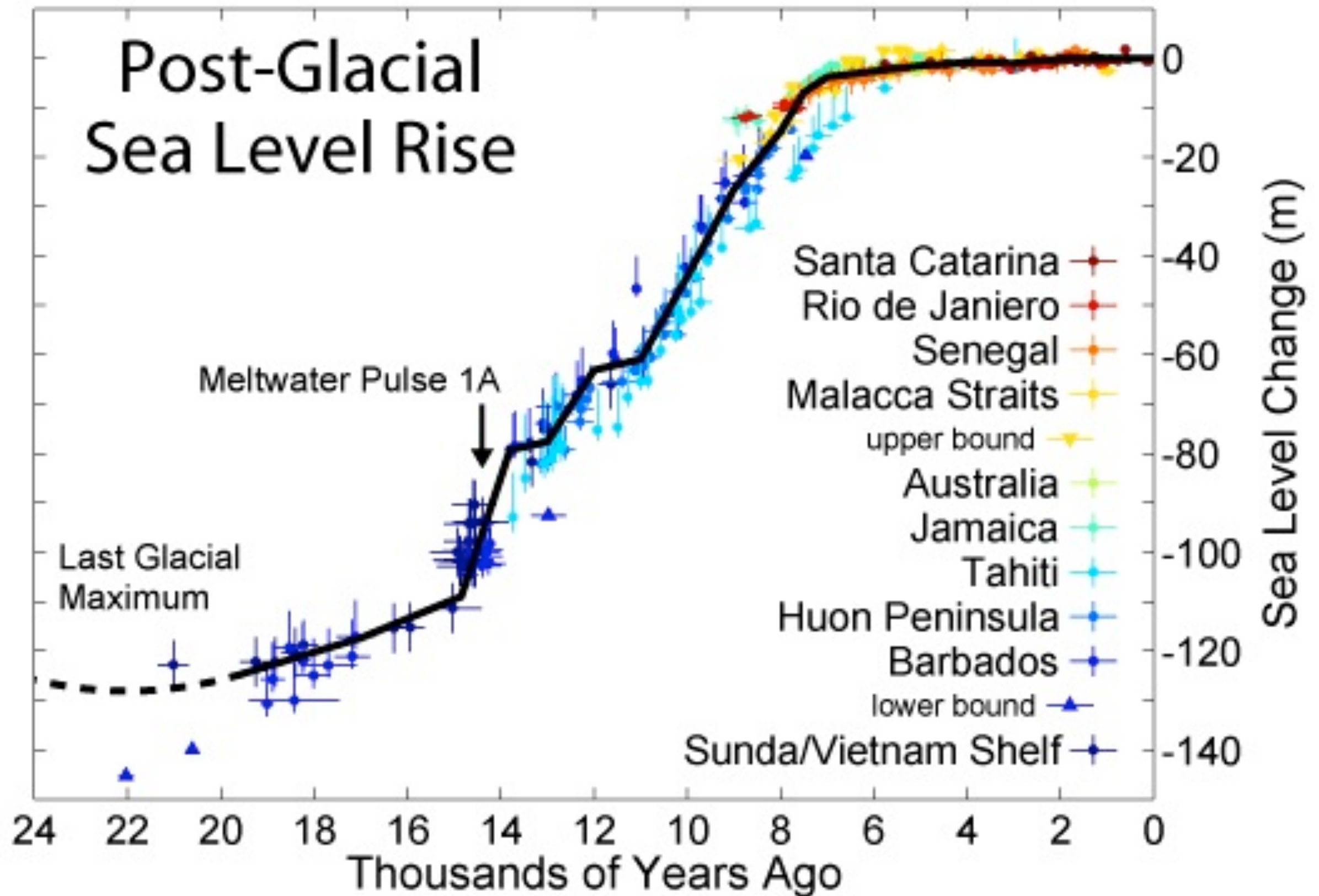
Seminari INGV BO - 19 Oct 2011 +
seminari Charles University PRAGA Nov. 2011

Contents:

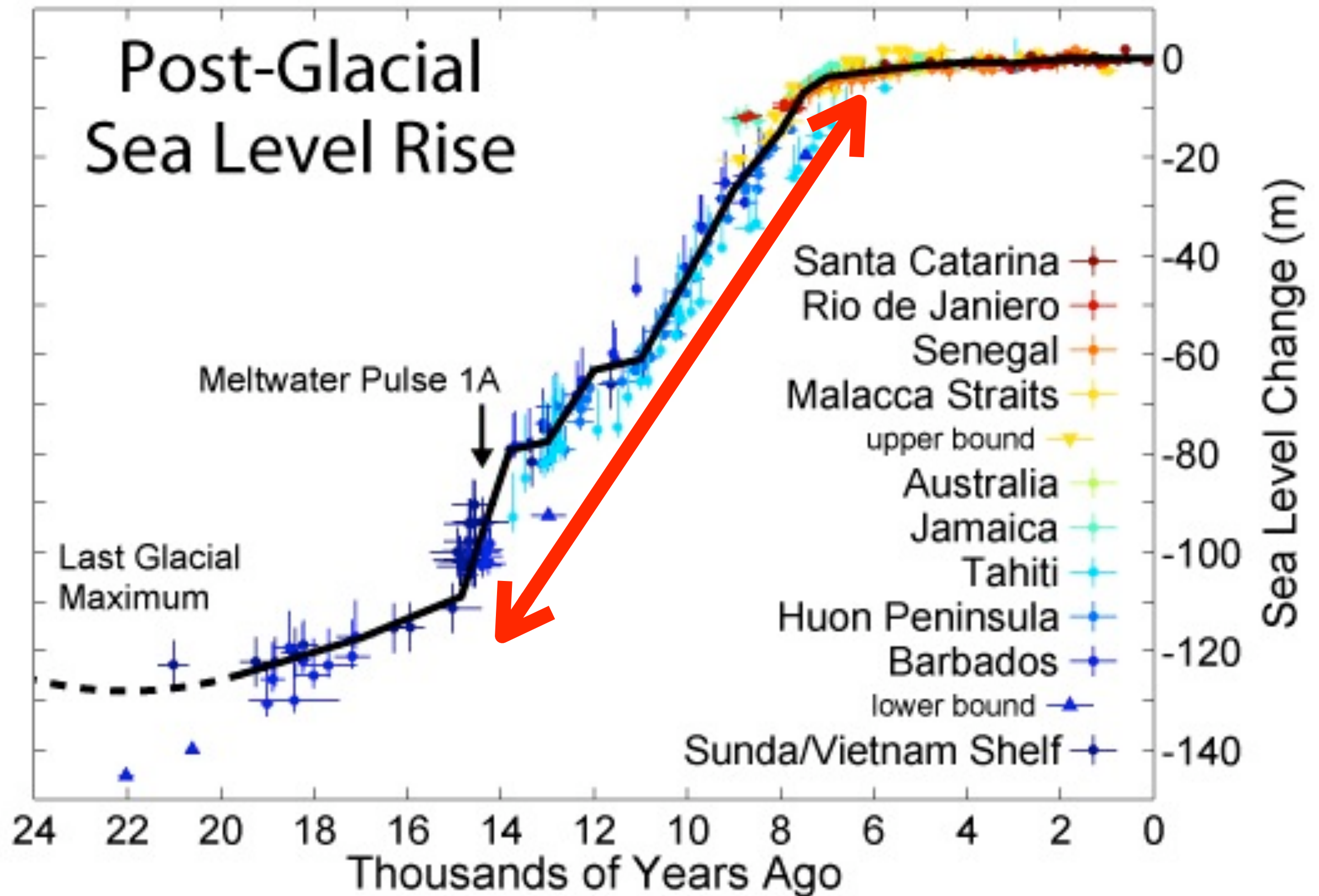
- 1). Motivations, previous work, relevance
- 2). Data: RLR tide gauge (TG) observations since 1880
- 3). Obtaining sea level trends from TG time series
- 4). Corrections in general and GIA corrections
- 5). Some new estimates of the secular sea level rise
- 6). Outlook

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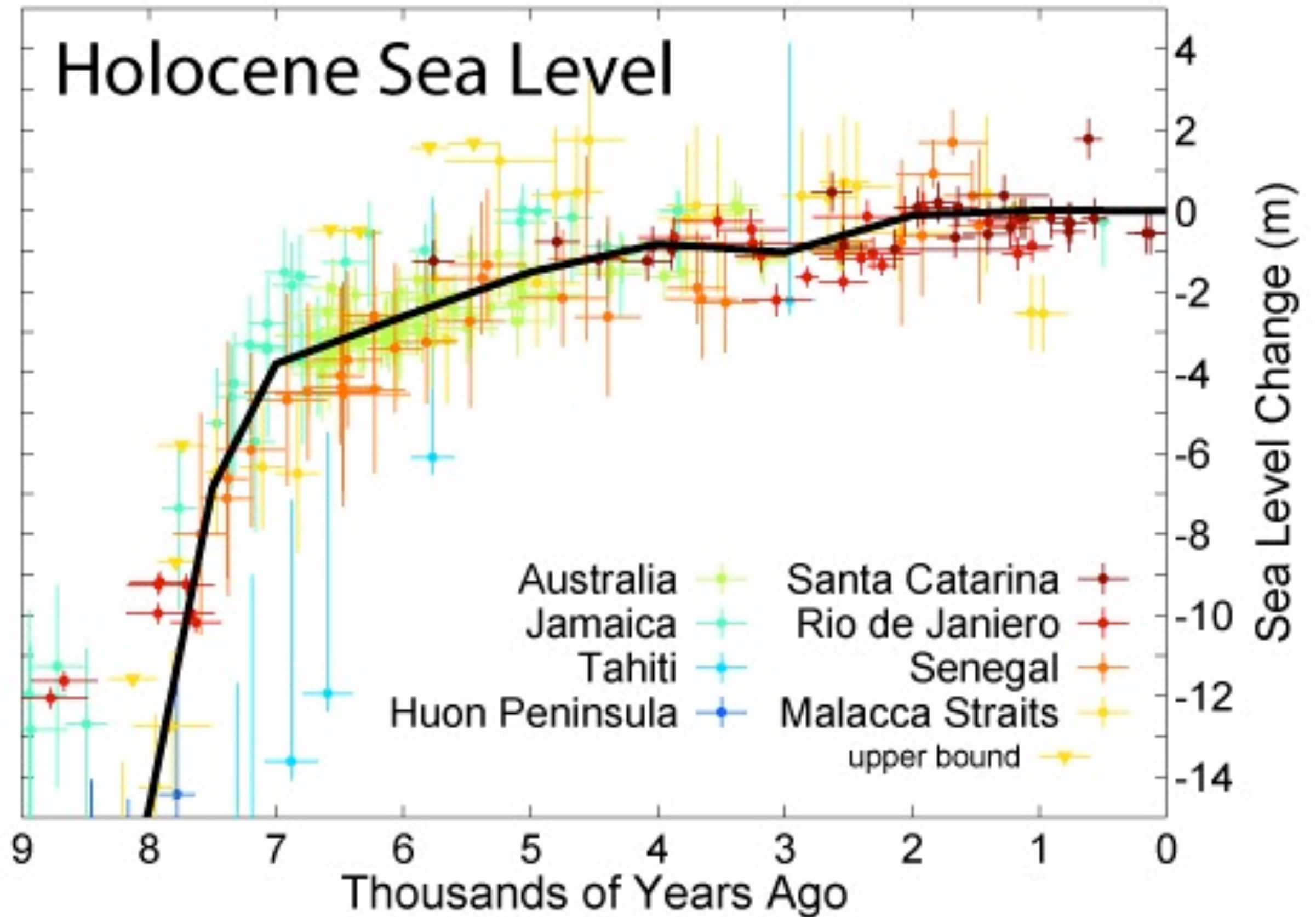


Observations from submerged coral reefs

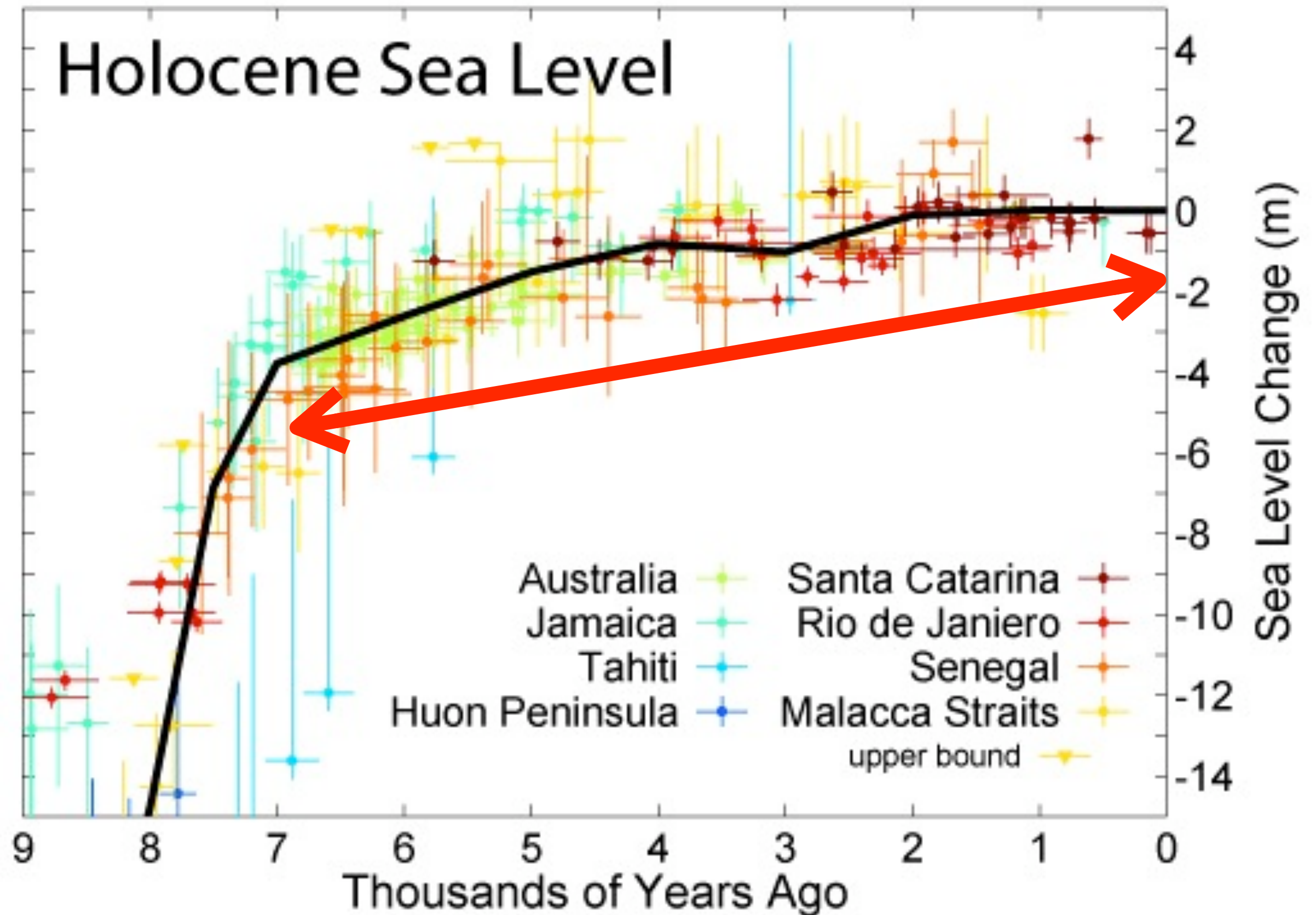


Average rate $\sim 100 \text{ m} / 10,000 \text{ yr} \sim 1 \text{ cm/yr}$

Observations from submerged coral reefs

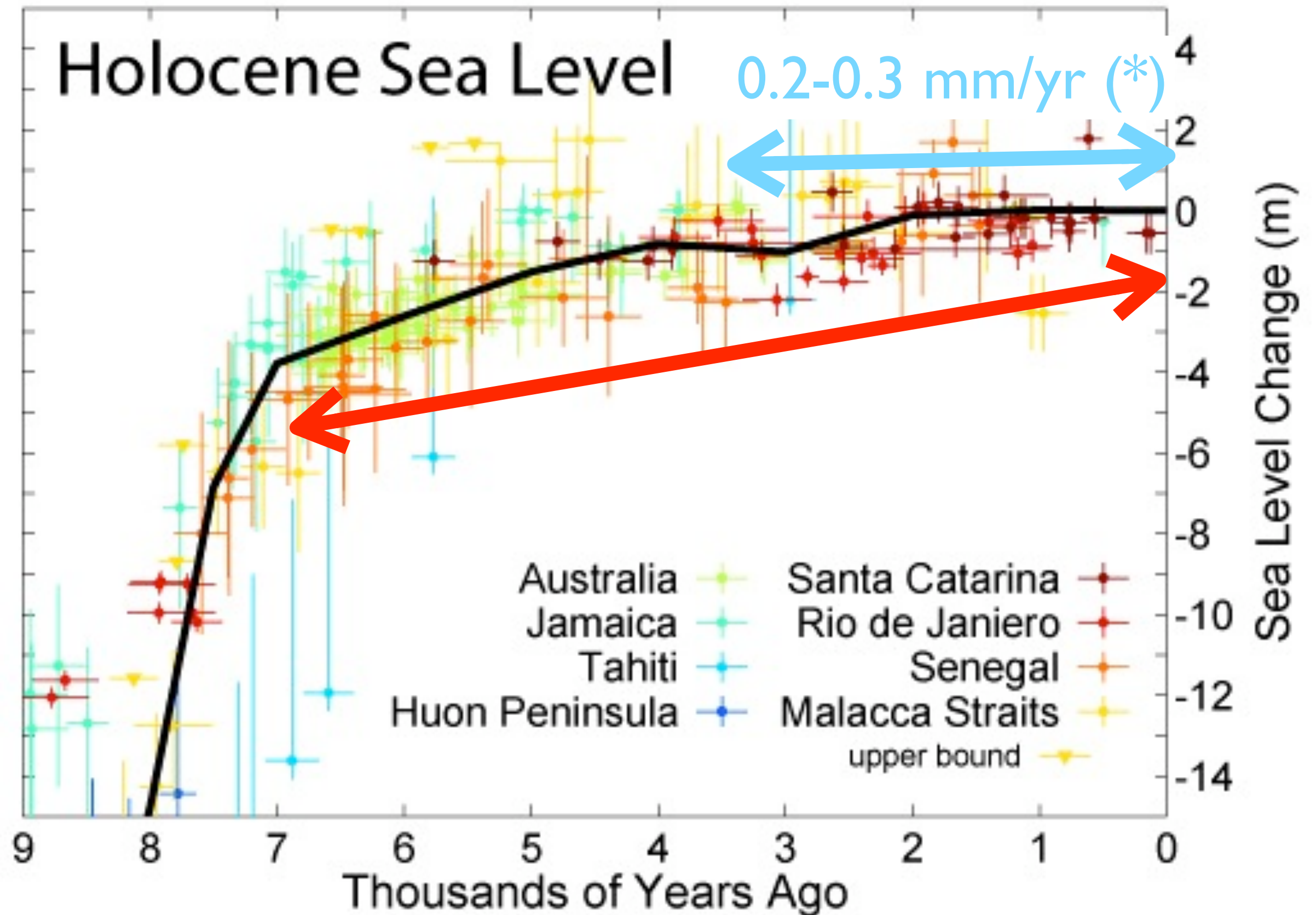


(*) From geomorphology, geology, archaeology...



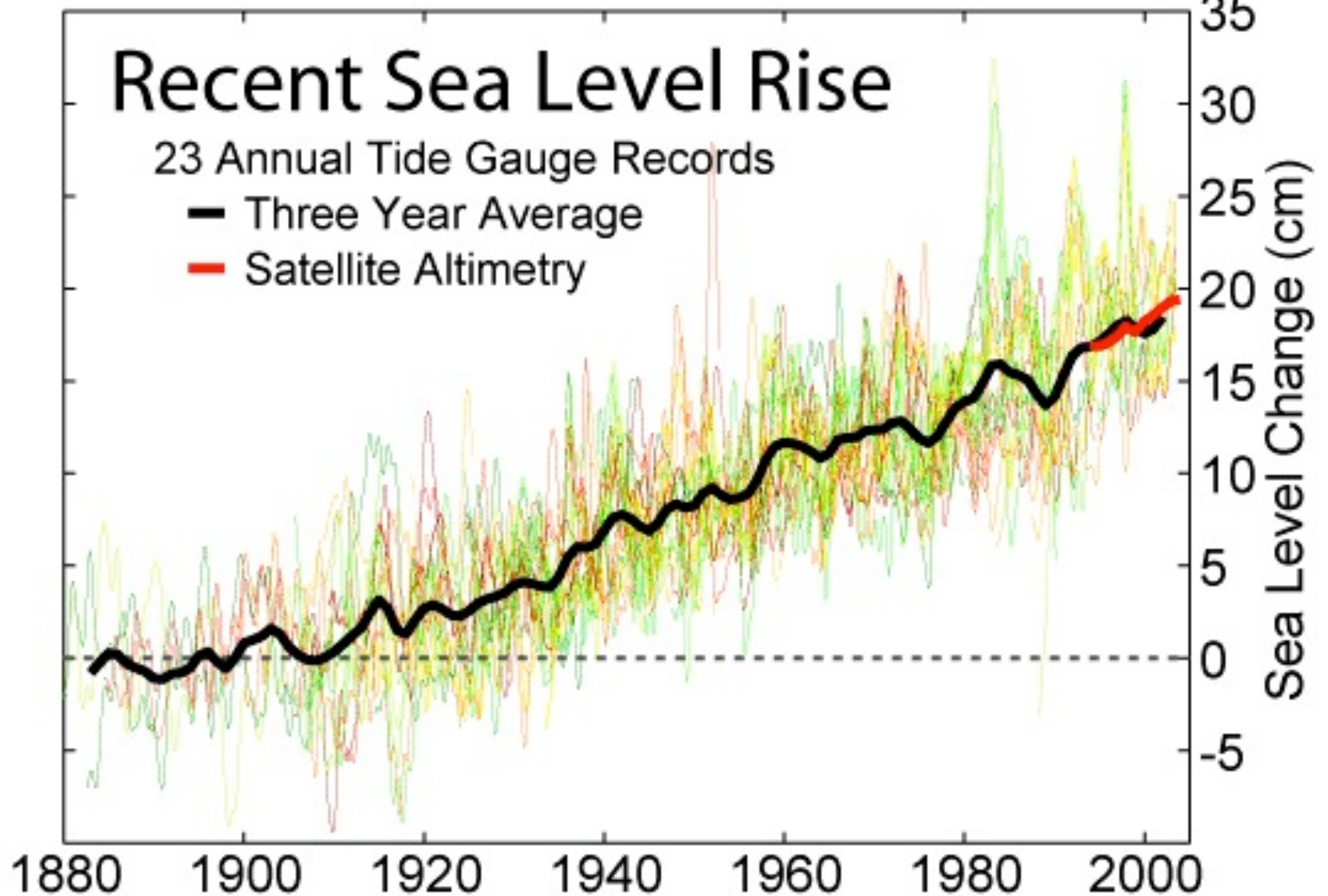
Average rate $\sim 4 \text{ m} / 7000\text{yr} \sim 0.5 \text{ mm/yr}$

(*) From geomorphology, geology, archaeology...

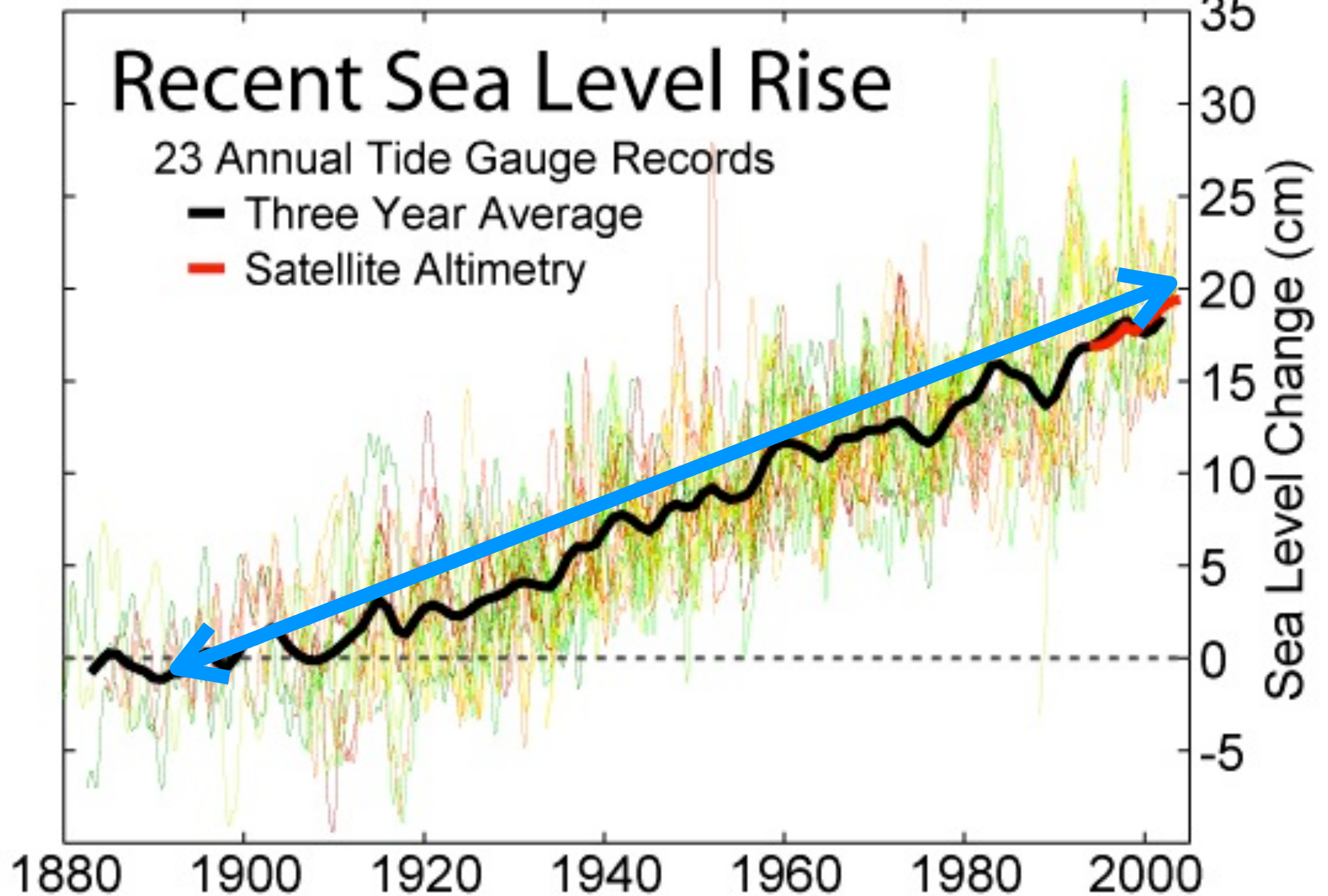


Average rate $\sim 4 \text{ m} / 7000 \text{ yr} \sim 0.5 \text{ mm/yr}$

(*) From geomorphology, geology, archaeology...



From direct observations: TIDE GAUGES



Average rate ~ 20 m/100 yr ~ 2 mm/yr

From direct observations: TIDE GAUGES

Sea level *will be* rising (IPCC scenarios)

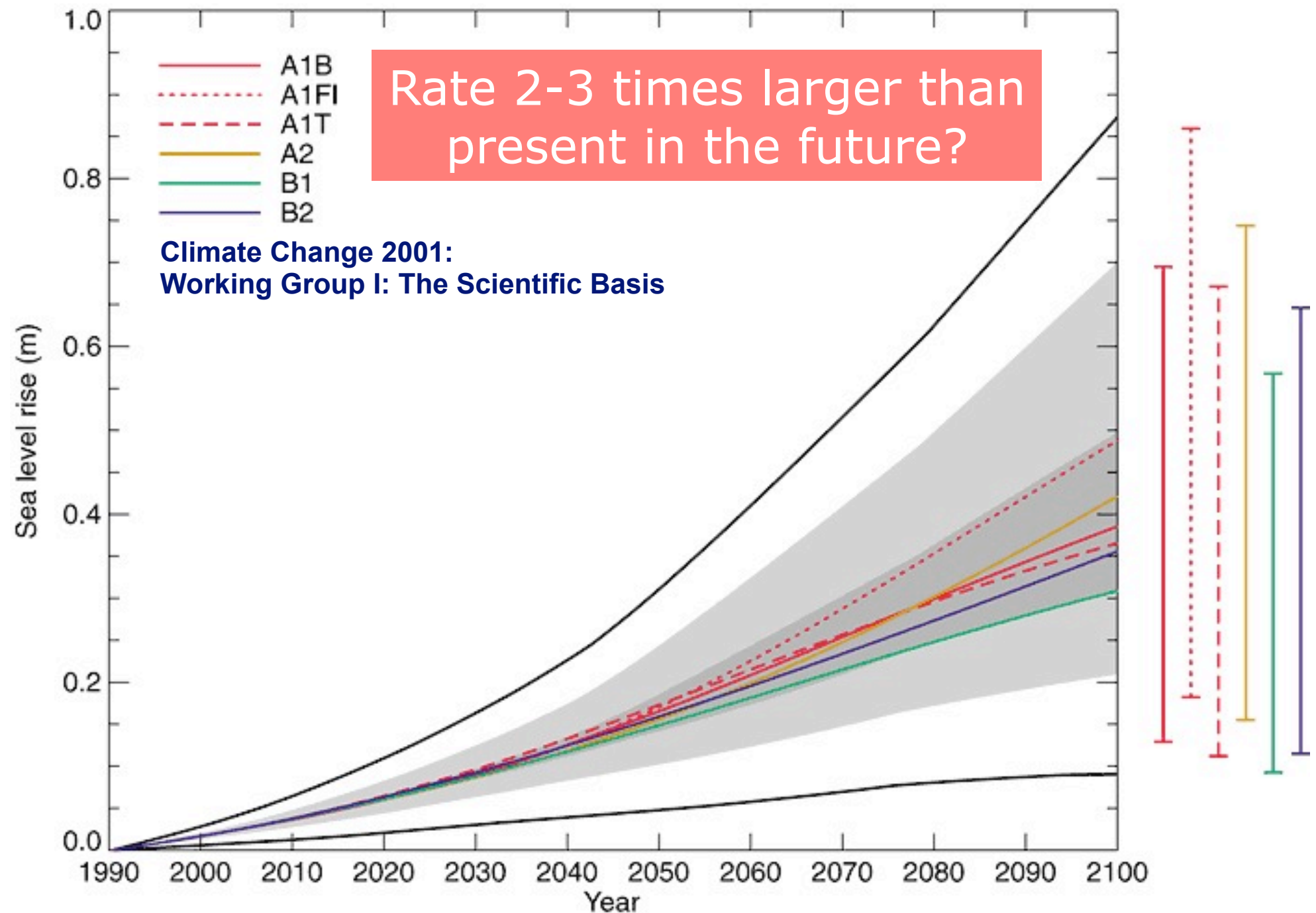


Figure 11.12: Global average sea level rise 1990 to 2100 for the SRES scenarios. Thermal expansion and land ice changes were calculated using a simple climate model calibrated separately for each of seven AOGCMs, and contributions from changes in permafrost, the effect of sediment deposition and the long-term sea level rise. **From projections, glaciology, AOGCMs predictions,** the range of the six scenarios including uncertainty in land-ice changes, permafrost changes and sediment deposition. Note that this range does not allow for uncertainty relating to ice-dynamical changes in the West Antarctic ice sheet. See [11.5.4.3](#) for a full discussion. The bars show the range in 2100 of all AOGCMs for the six illustrative scenarios

Sea level *will be* rising (IPCC scenarios)

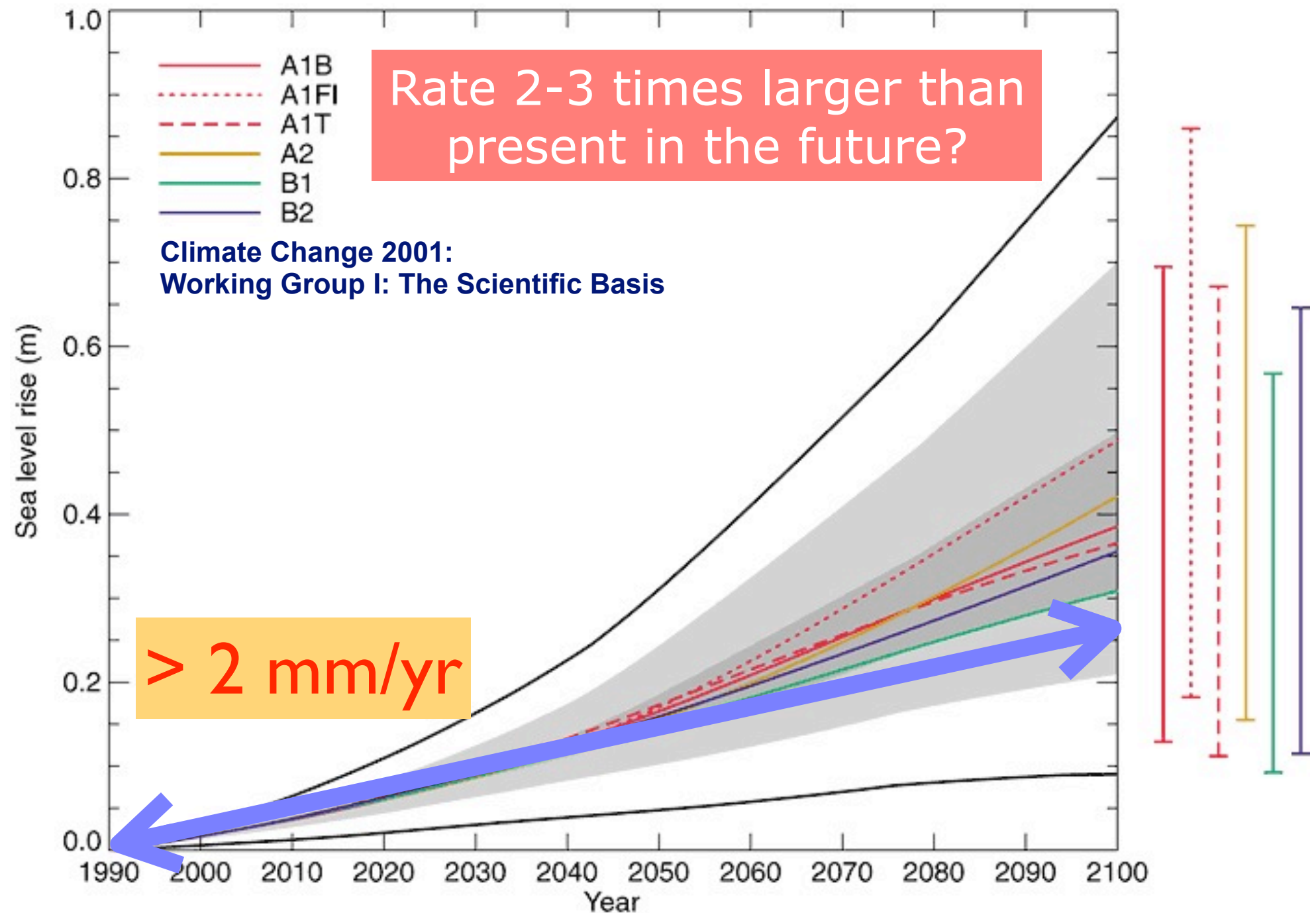
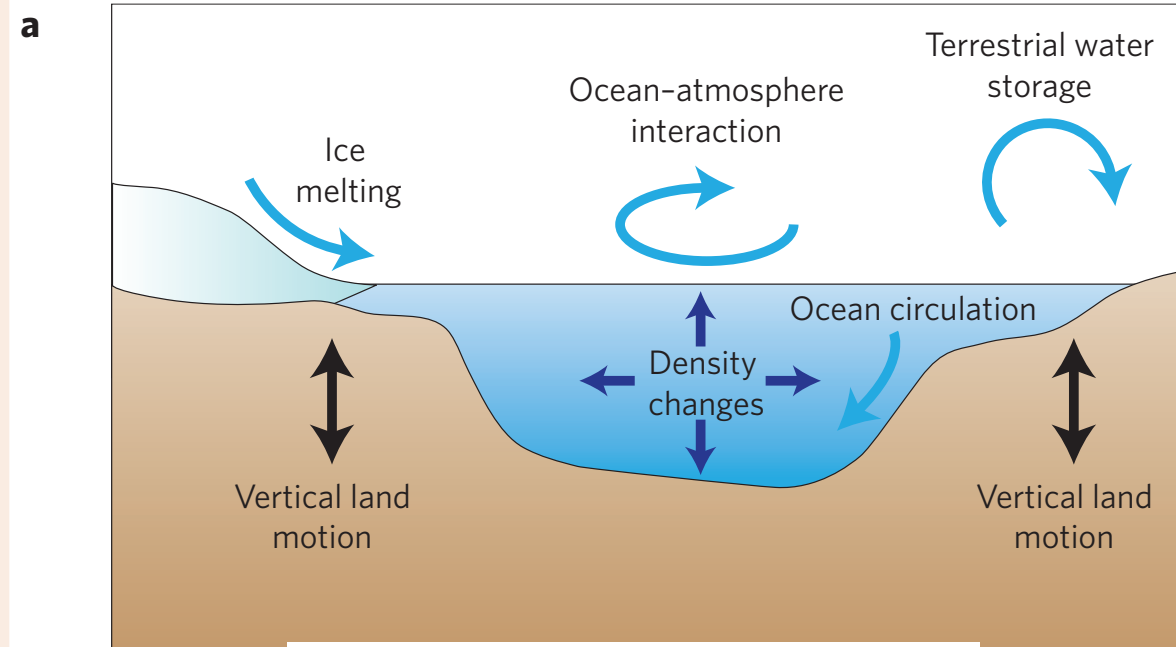


Figure 11.12: Global average sea level rise 1990 to 2100 for the SRES scenarios. Thermal expansion and land ice changes were calculated using a simple climate model calibrated separately for each of seven AOGCMs, and contributions from changes in permafrost, the effect of sediment deposition and the long-term sea level rise. From projections, glaciology, AOGCMs predictions, the range of the six scenarios including uncertainty in land-ice changes, permafrost changes and sediment deposition. Note that this range does not allow for uncertainty relating to ice-dynamical changes in the West Antarctic ice sheet. See [11.5.4.3](#) for a full discussion. The bars show the range in 2100 of all AOGCMs for the six illustrative scenarios

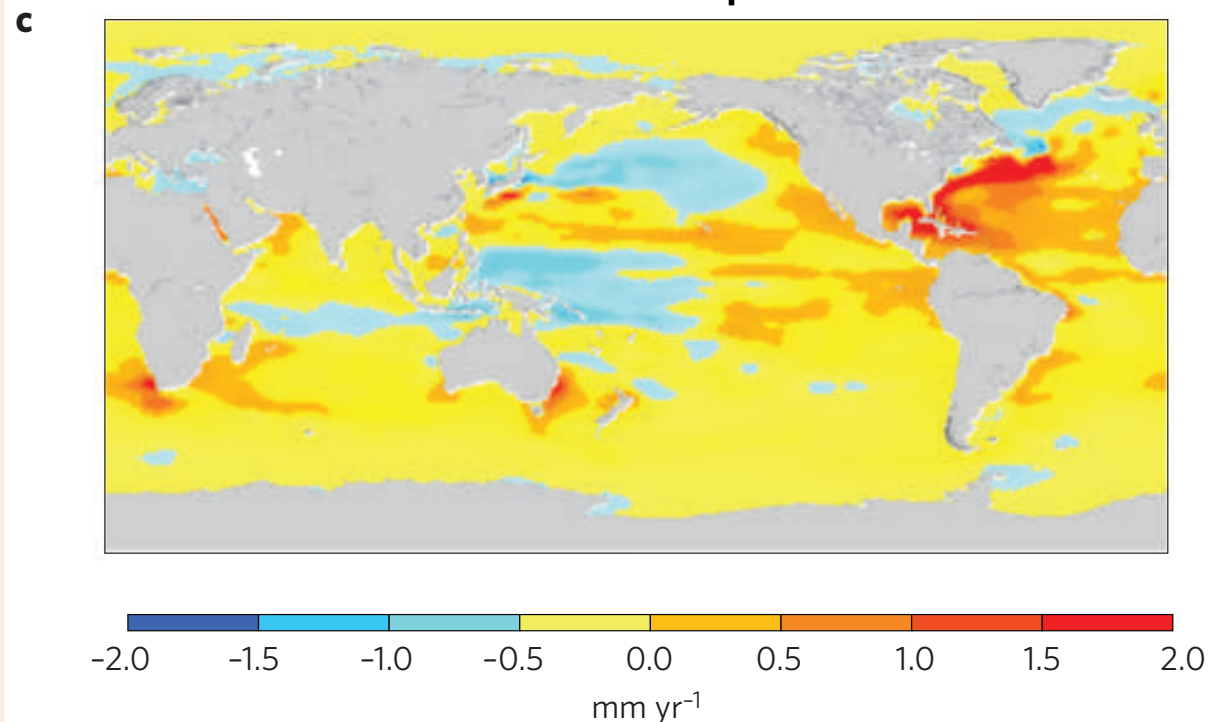
Identifying the causes of sea-level change

Glenn A. Milne, W. Roland Gehrels, Chris W. Hughes and Mark E. Tamisiea, NATURE GEOSCI 2009

Possible causes

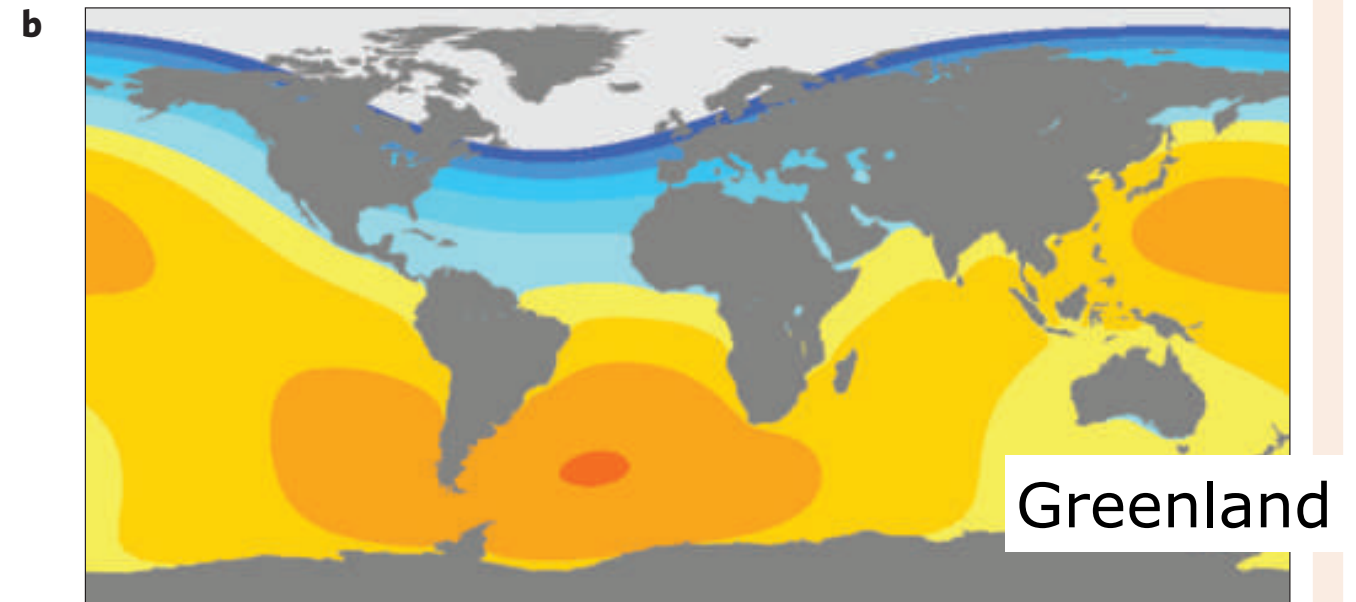
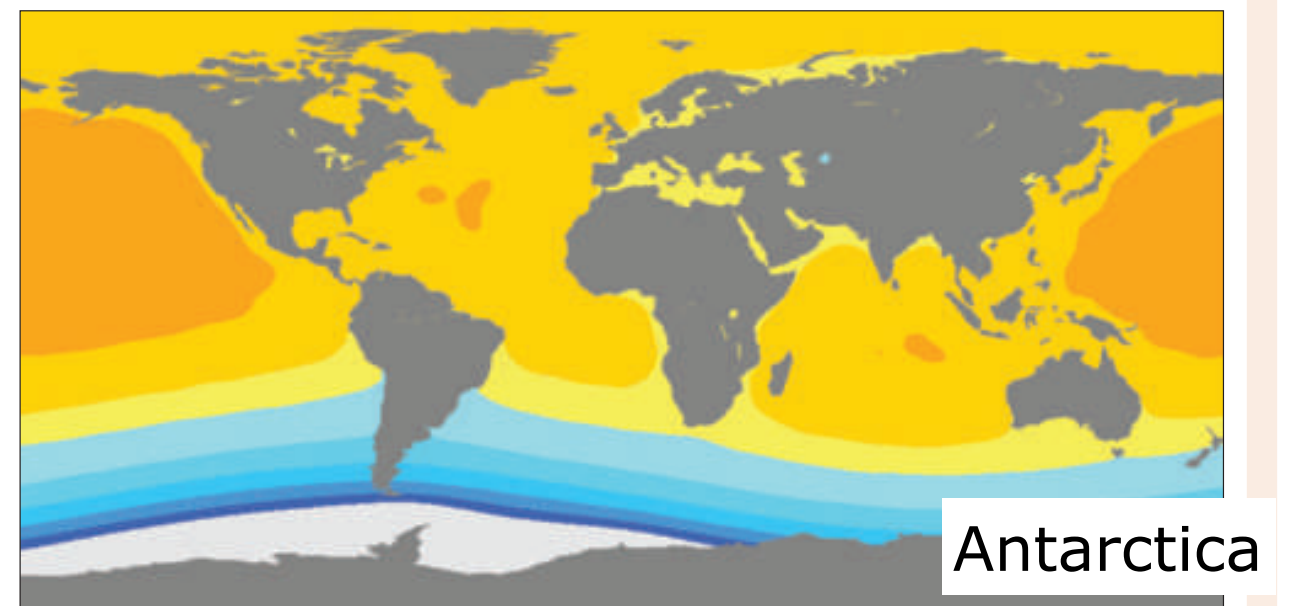
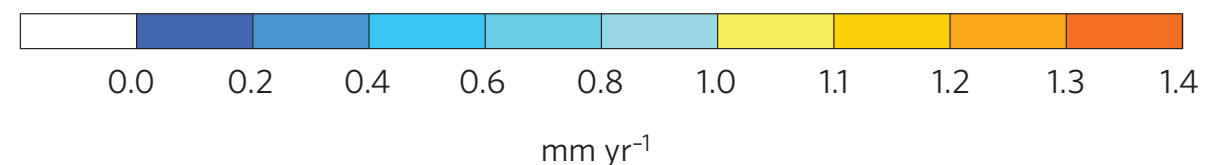


1. Thermal expansion

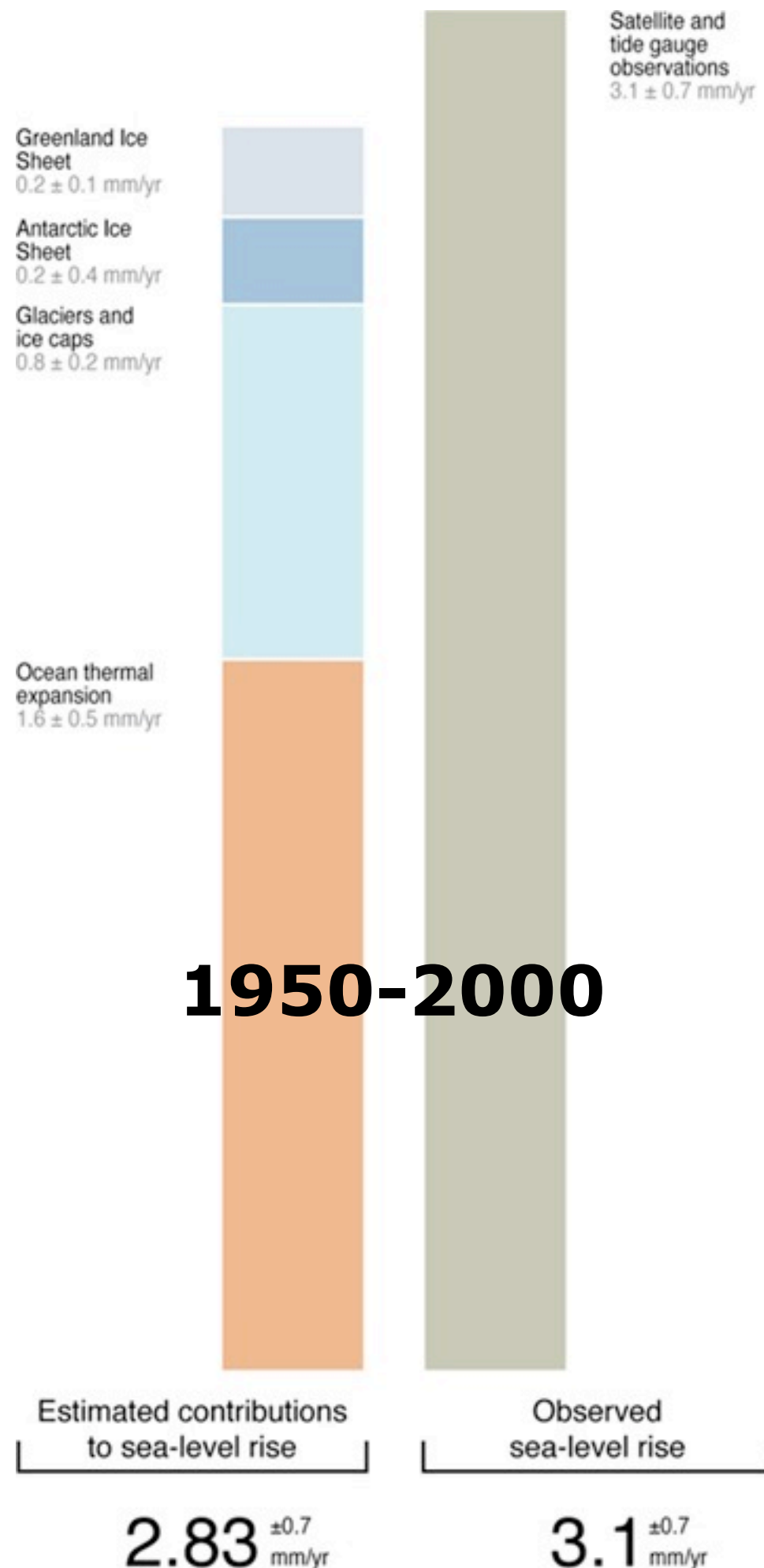


“steric contribution”

2. Current ice melting



“mass contribution”



Causes of “secular” sea level rise

1. Thermal expansion of the oceans in response to global warming

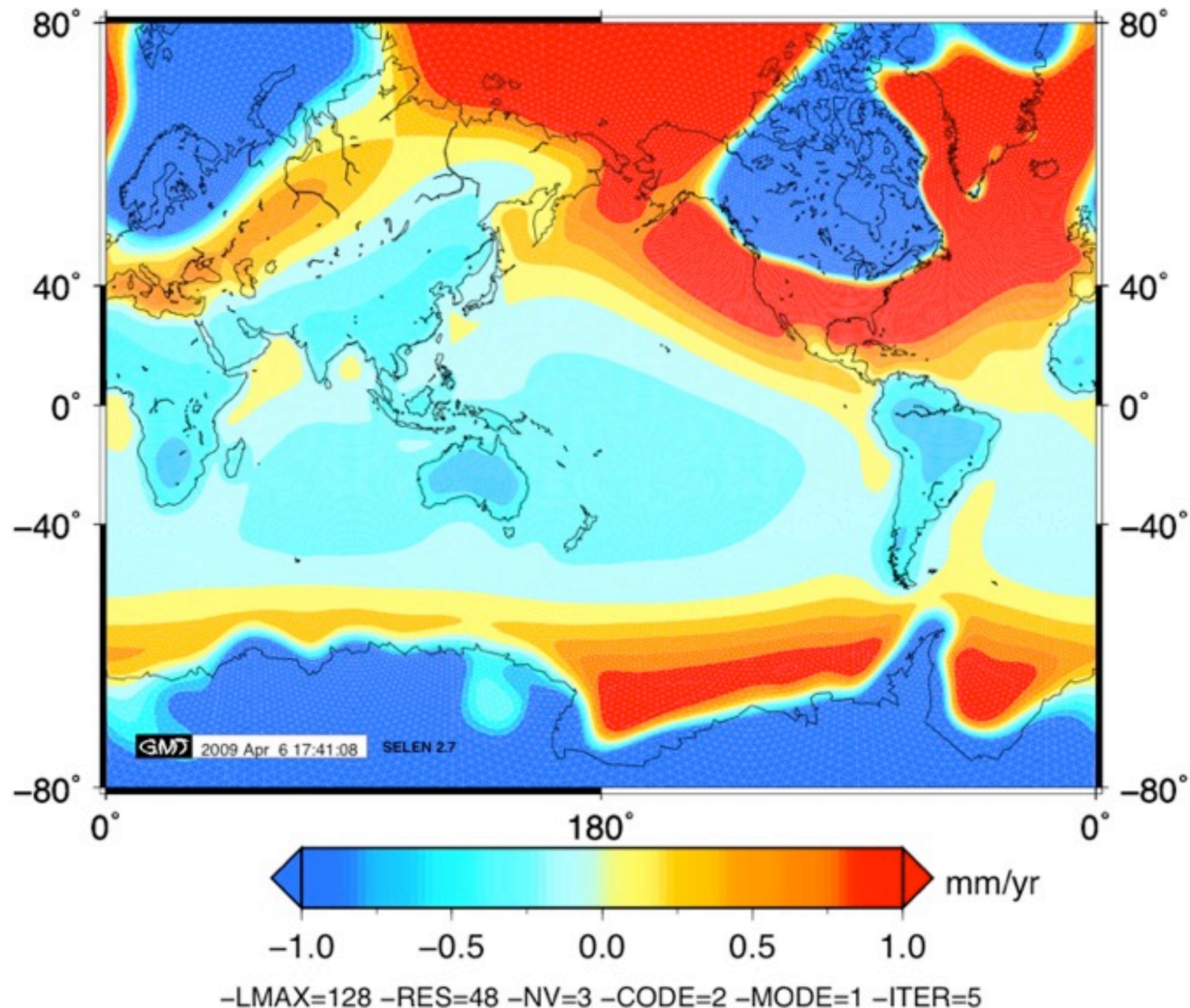
2. Melting of mountain glaciers and ice caps

3. Melting of large ice sheets (Greenland and Antarctica)

GIA: signals from the past - **NOT related to current climate change**

Rate of sea level change today

–Ice model: ICE5G –Viscosity profile: /10. 0.4 0.4/





How and what do we observe?

a few words about tide gauges



Courtesy of Philip L. Woodworth - PSMSL
OTT Kalesto Radar Gauge



High-frequency sampling of the ocean surface (relative to the solid Earth)



High-frequency sampling of the ocean surface (relative to the solid Earth)

A photograph of a tide gauge in Liverpool. The image shows a stone wall with a tide pole (a vertical scale) attached to it. The water level is visible in the foreground. In the background, there is a building with a clock tower and a bridge. The text "SEA LEVEL RELATIVE TO LAND" is overlaid on the image.

SEA LEVEL RELATIVE TO LAND

Liverpool, february 3, 2009

Tide gauge types

Tide pole / Tide staff

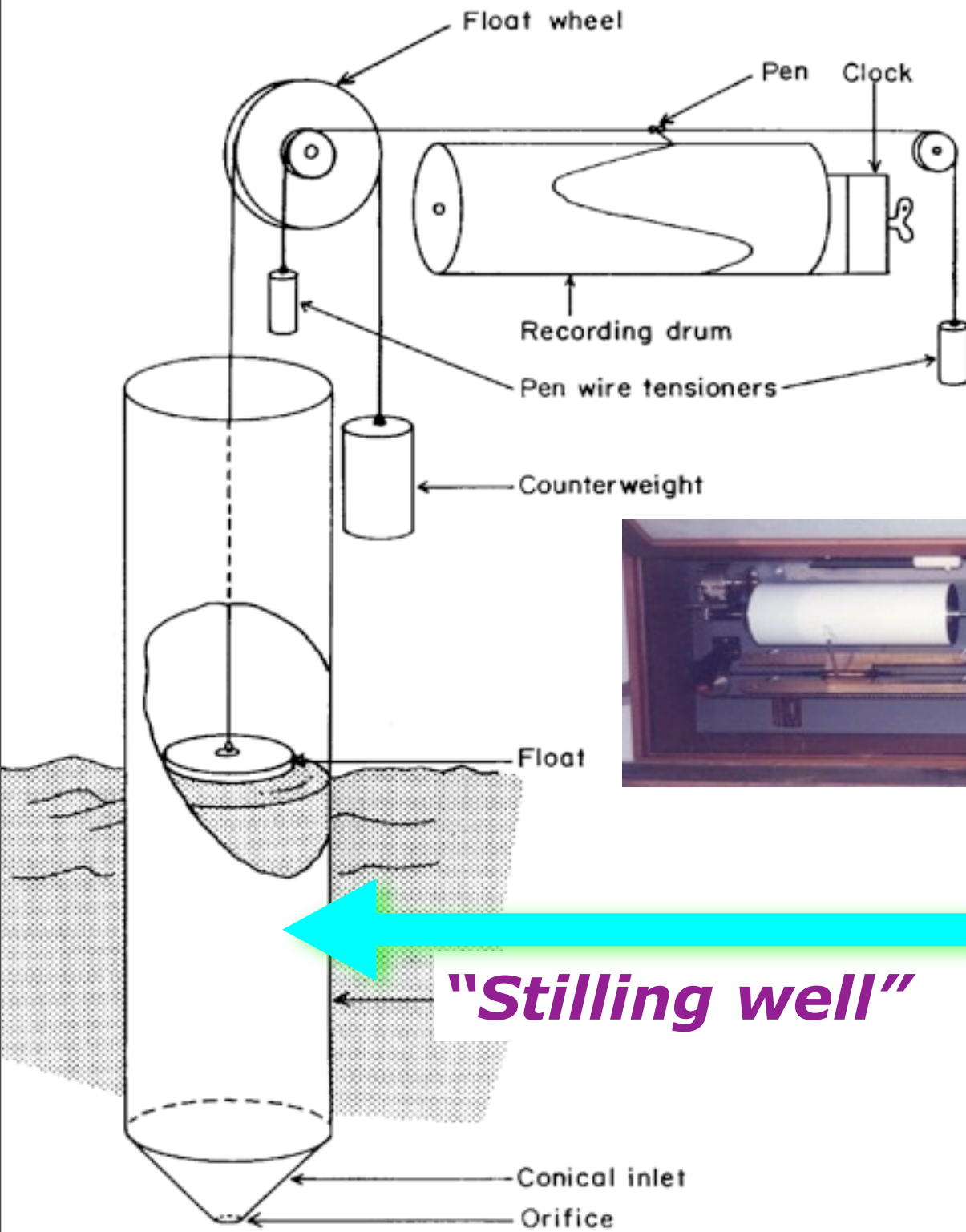
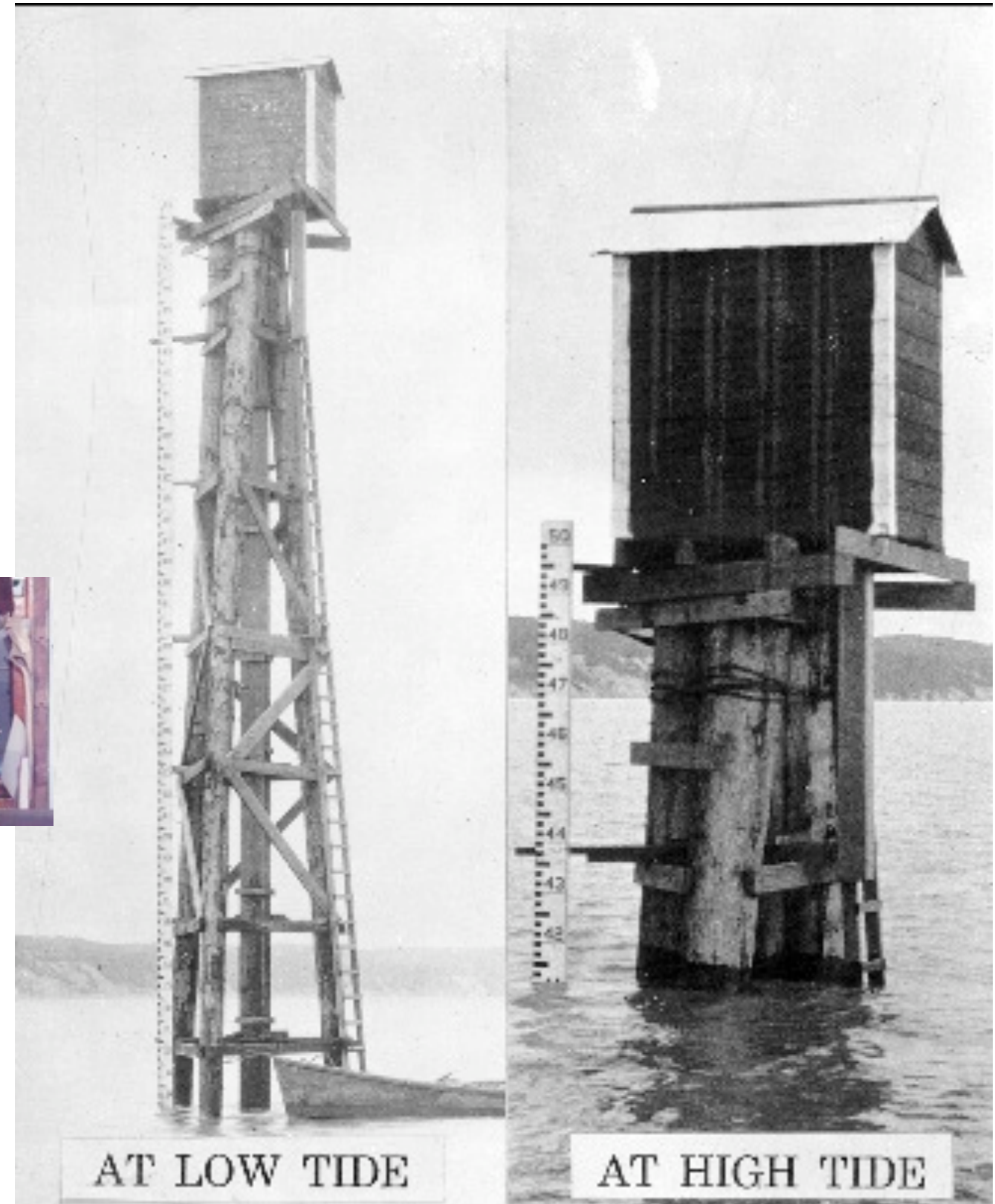


Figure 3.1

13



Classical stilling well float gauge from the US east coast high tidal range area

Tide gauge types

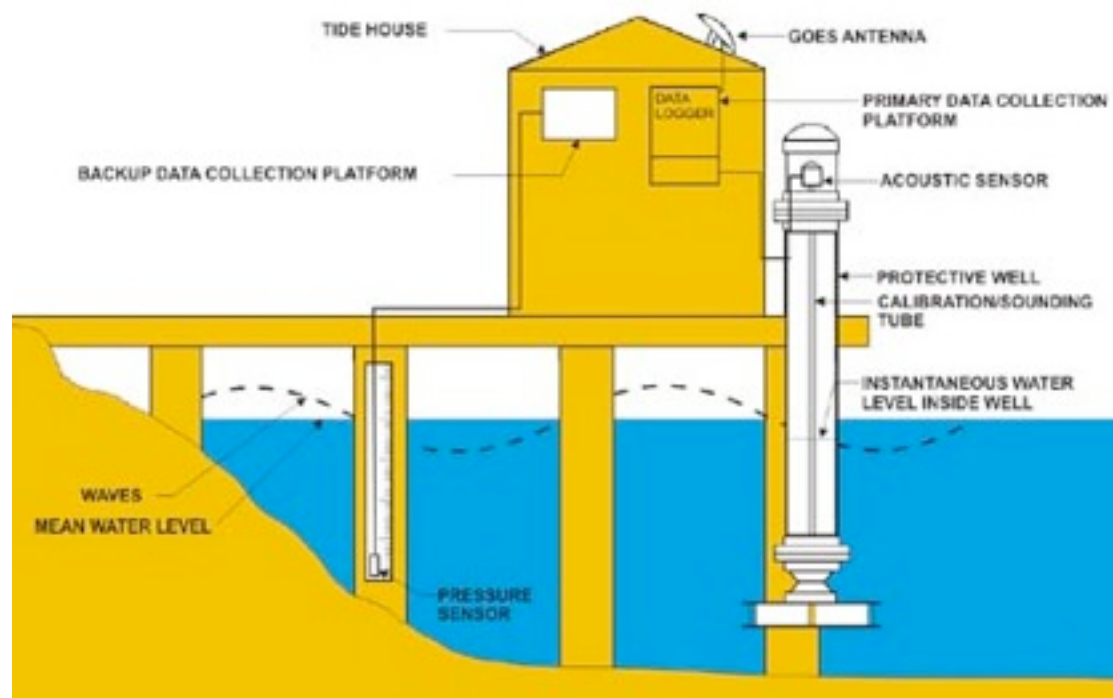
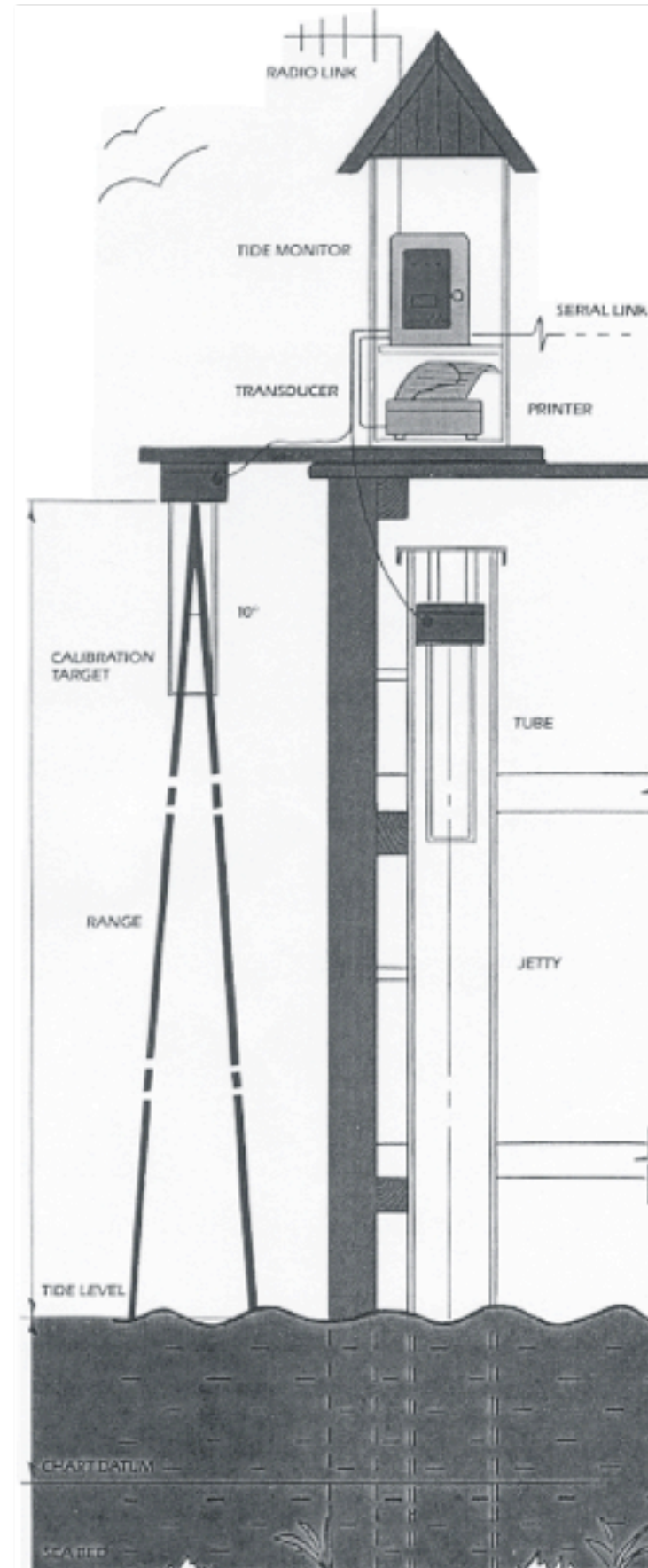
Acoustic gauge

The SRD Digital Tide Monitor is an acoustic above-water, temperature-corrected tide monitoring system, which is a 53 kHz 'in air' echo-sounder measuring the distance from the transducer to the water surface.

Any temperature-dependent variation of the speed of sound is taken into account by the use of a reference target, providing auto-calibration.

The system-displayed resolution is 10 mm. System accuracy is 1 per cent.

Tidal variation of up to 10 m can be monitored.



SRD TIDE MONITOR

The SRD Tide Monitor has been developed with the active assistance and advice from port authorities and survey companies to meet the requirements for a lightweight, robust, highly accurate and versatile system to replace the float, pressure and bubbler systems now in use. It has been extensively tested and copies of the test results are available from the company on request.

The system is quick and easy to install and no maintenance other than chart checking is required. The reference datum gives the unit excellent accuracy with no recalibration requirements. The telemetry output allows the chart to be printed any distance from the tide gauge using an SRD Tide Monitor Receiver, or for the connection of the tide monitor to a central Tide Data Control.

The use of low cost dot matrix printers with the self printing graph record removes the requirement for pre-printed charts and ensures accurate time and height records.

For permanent installations or where the line of sight of the transducer is likely to be interrupted, it is strongly recommended that the system operate down a plastic tube. The tubes can be supplied to suit the particular application. No additional maintenance is required for the tube, and no flow filter is required as with float systems. The transducer is mounted inside the tube forming a completely protected system.

Operation

The SRD Tide Monitor obtains the distance from the transducer to the sea surface by measuring the time elapsed between transmission and reception of an acoustic pulse. This time is converted to distance using a calibration velocity obtained from the fixed range target measurement. This distance is subtracted from the set datum to give the TIDE LEVEL which is then averaged over the selected period, displayed on the four digit display, printed on the graph and transmitted by whatever telemetry method is selected.

Installation

The fully waterproof transducer is installed at a convenient site, at a minimum height of 2M above the maximum tide height. The transducer has to be mounted within 2 degrees of horizontal to achieve optimum results. The view of the transducer should be unobstructed within a 10 degree conical angle to avoid interfering targets. The required datum, averaging interval, printing options, time and date are selected by a series of rotary switches.

Reference Target

The speed of sound in air is significantly temperature dependent. A temperature sensor in the transducer can go some way to compensate for temperature variations, but the most effective compensation is to use a fixed range target to measure the actual speed of sound. The target provided is fixed 75cm from the transducer and will correct the distances measured to within 0.05%. The correct operation of the reference target compensation is indicated on the tide graph by a target at a fixed range of 1.0M. This information can also be transmitted.

Another means of measuring water level variations is a **"bubbler" gauge (pneumatic tide gauge)**.

A flow of nitrogen or compressed air into a tube with one end in the water is adjusted continuously by a mechanism so that it releases bubbles at a constant rate.

When the water level rises, the pressure must be increased to maintain the flow of bubbles.

The pressure variations are thus a measure of water level. A small tank of gas can operate this system for many months.

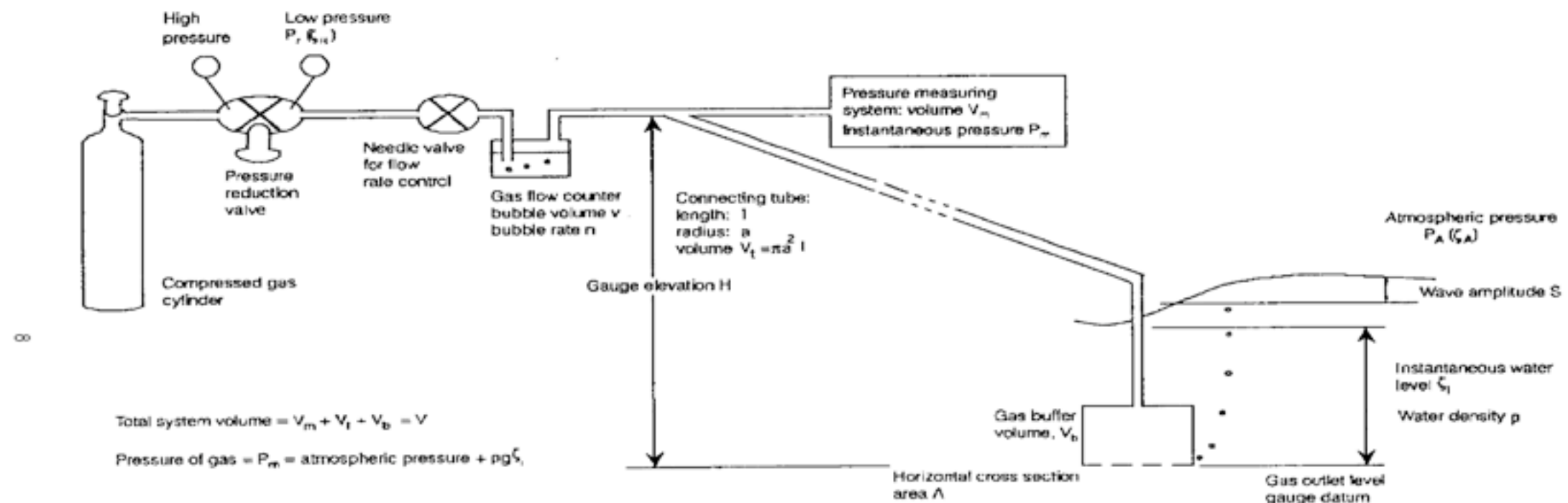
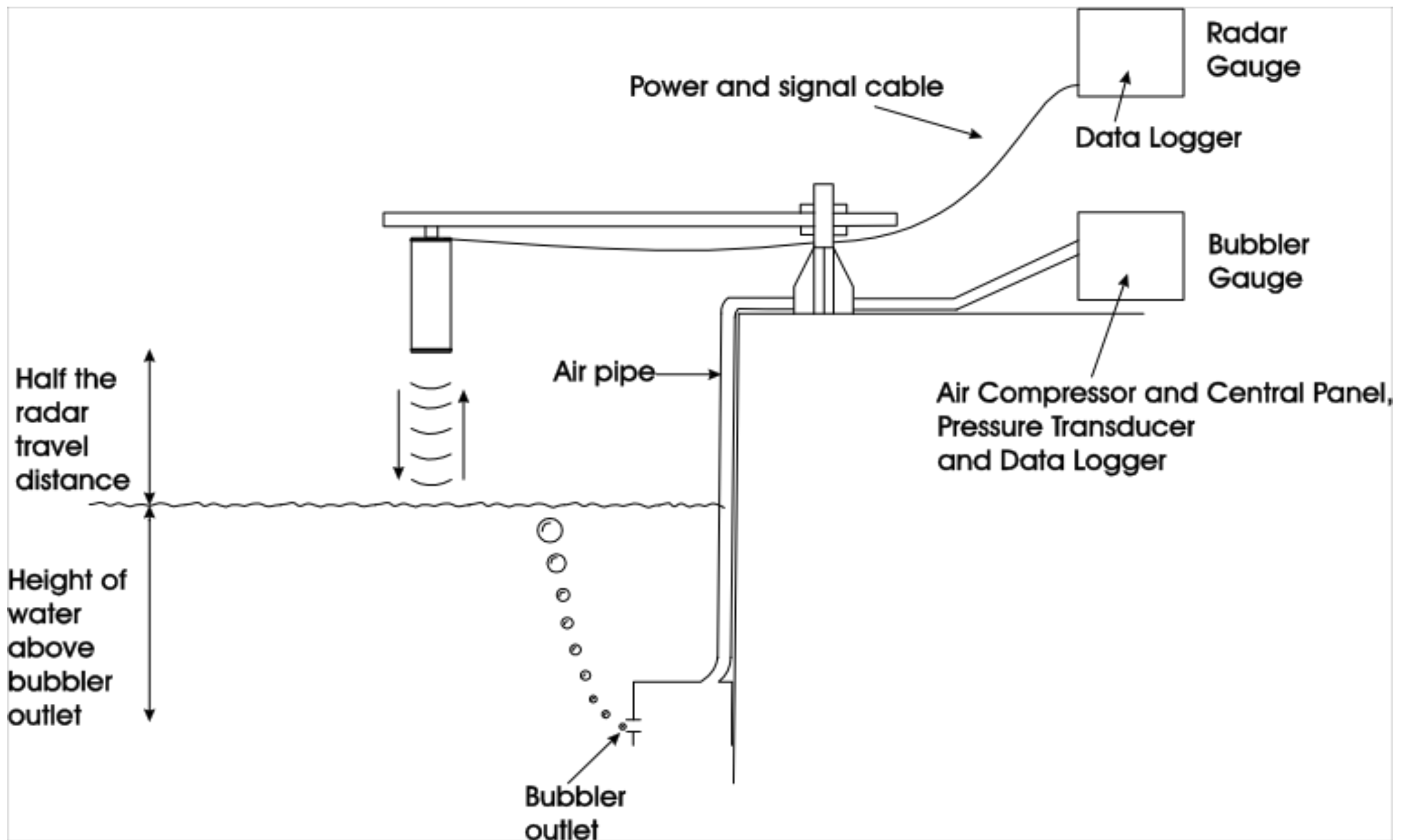


Figure 2.2

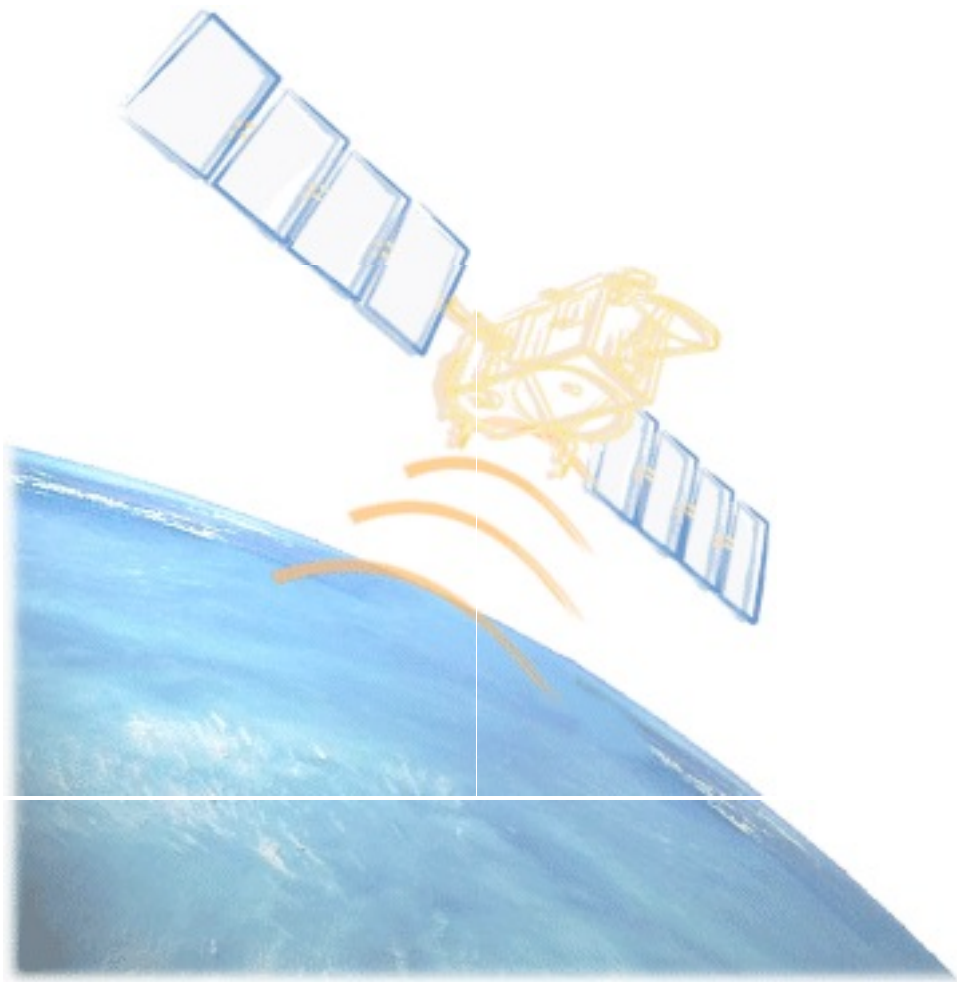
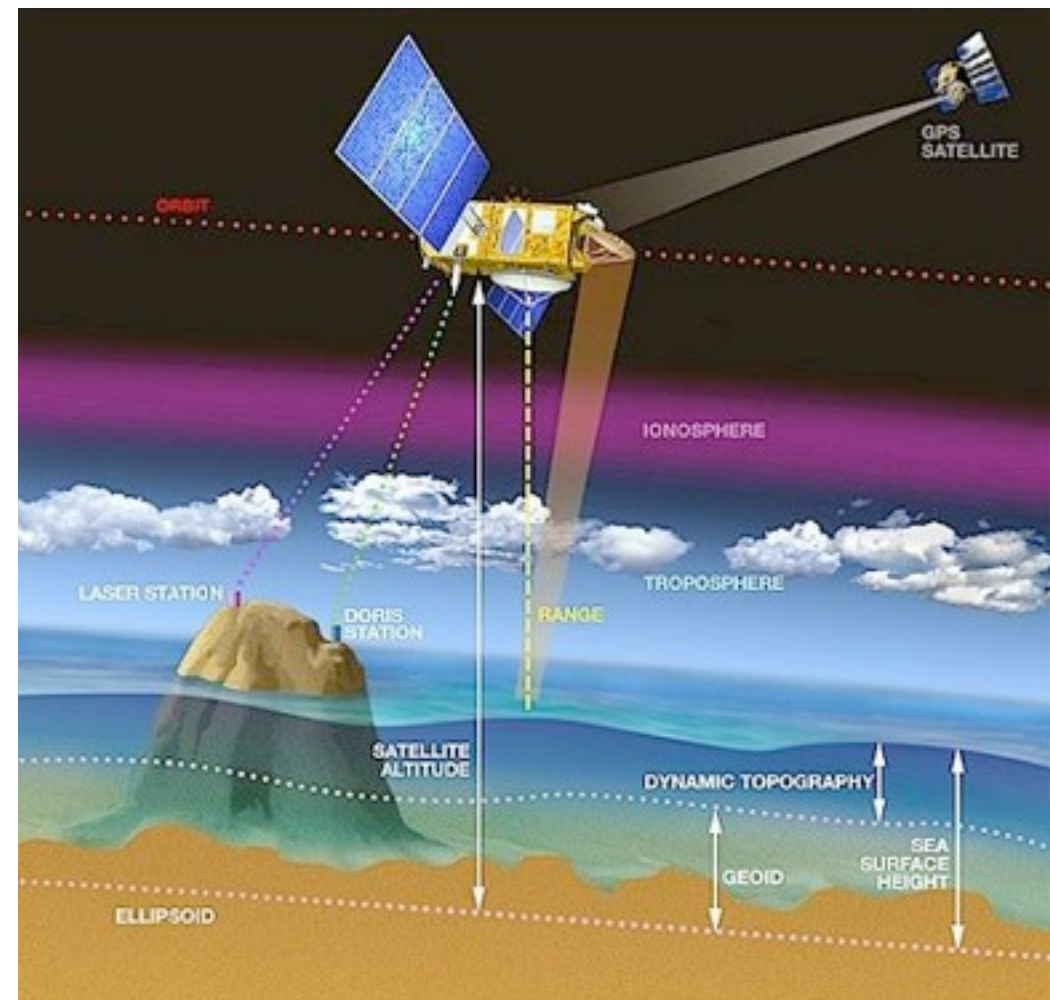
Schematic diagram of the pneumatic tide gauge and its principal system parameters



Courtesy of Philip L. Woodworth - PSMSL

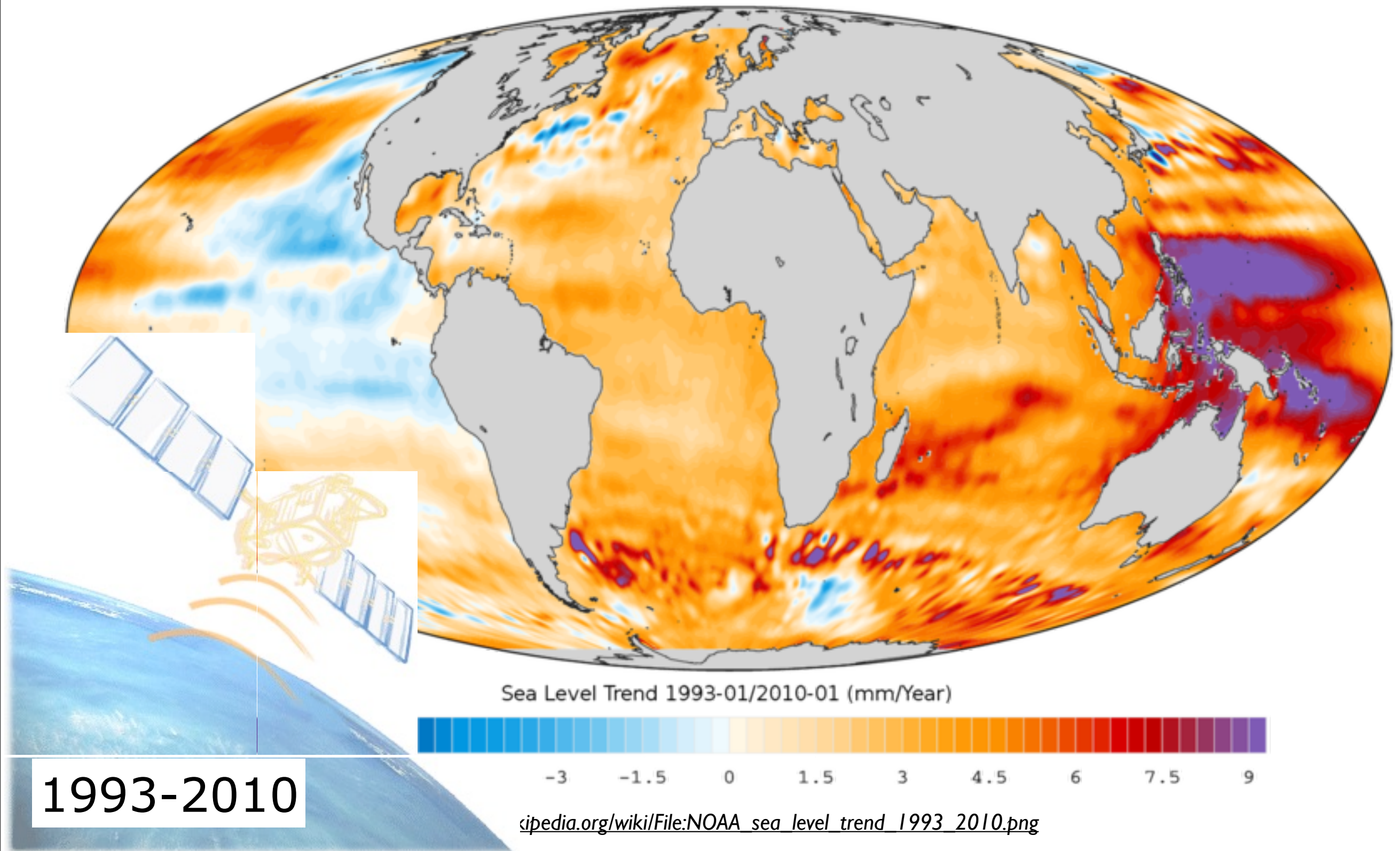
Satellite altimetry

Radar altimeters on board the satellite permanently transmit signals at high frequency (over 1700 pulses per second) to Earth, and receive the echo from the sea surface. This is analyzed to derive a precise measurement of the round-trip time between the satellite and the sea surface. The time measurement, scaled by the speed of light yields a range measurement. By averaging the estimates over a second, this produces a very accurate **measurement of the satellite-to-ocean range.**



http://www.jason.oceanobs.com/html/faq/alti_uk.html

Sea level **is rising** (by altimetry)
“viewpoint of space”

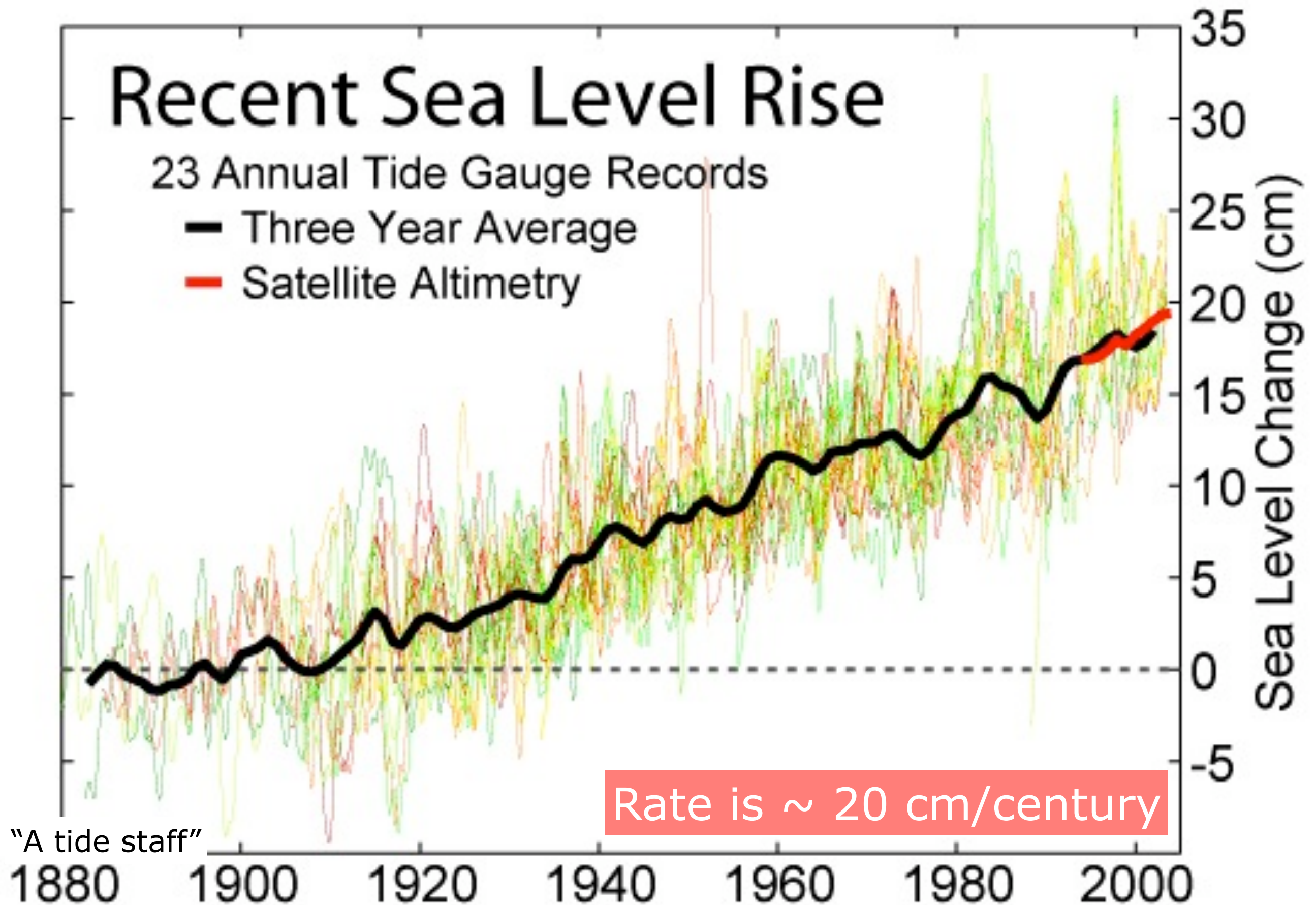


Recent Sea Level Rise

23 Annual Tide Gauge Records

— Three Year Average

— Satellite Altimetry



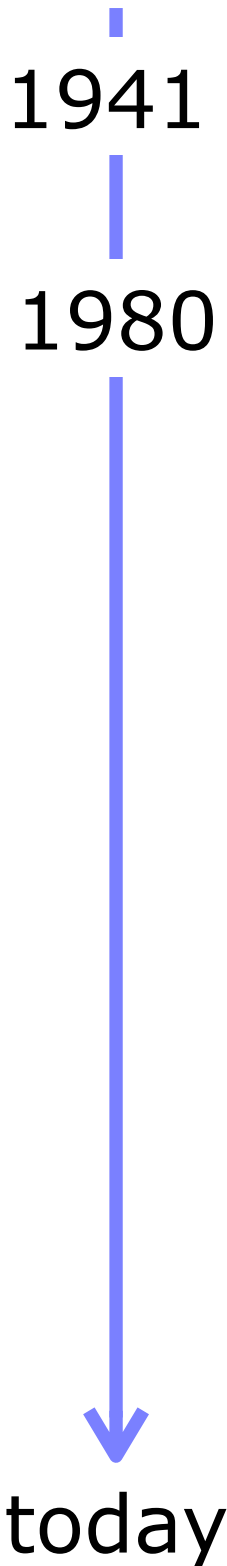
"A tide staff"

Rate is ~ 20 cm/century

Previous work on sea level rise
from tide gauges

Previous estimates of global sea level rise

Gornitz (1989).



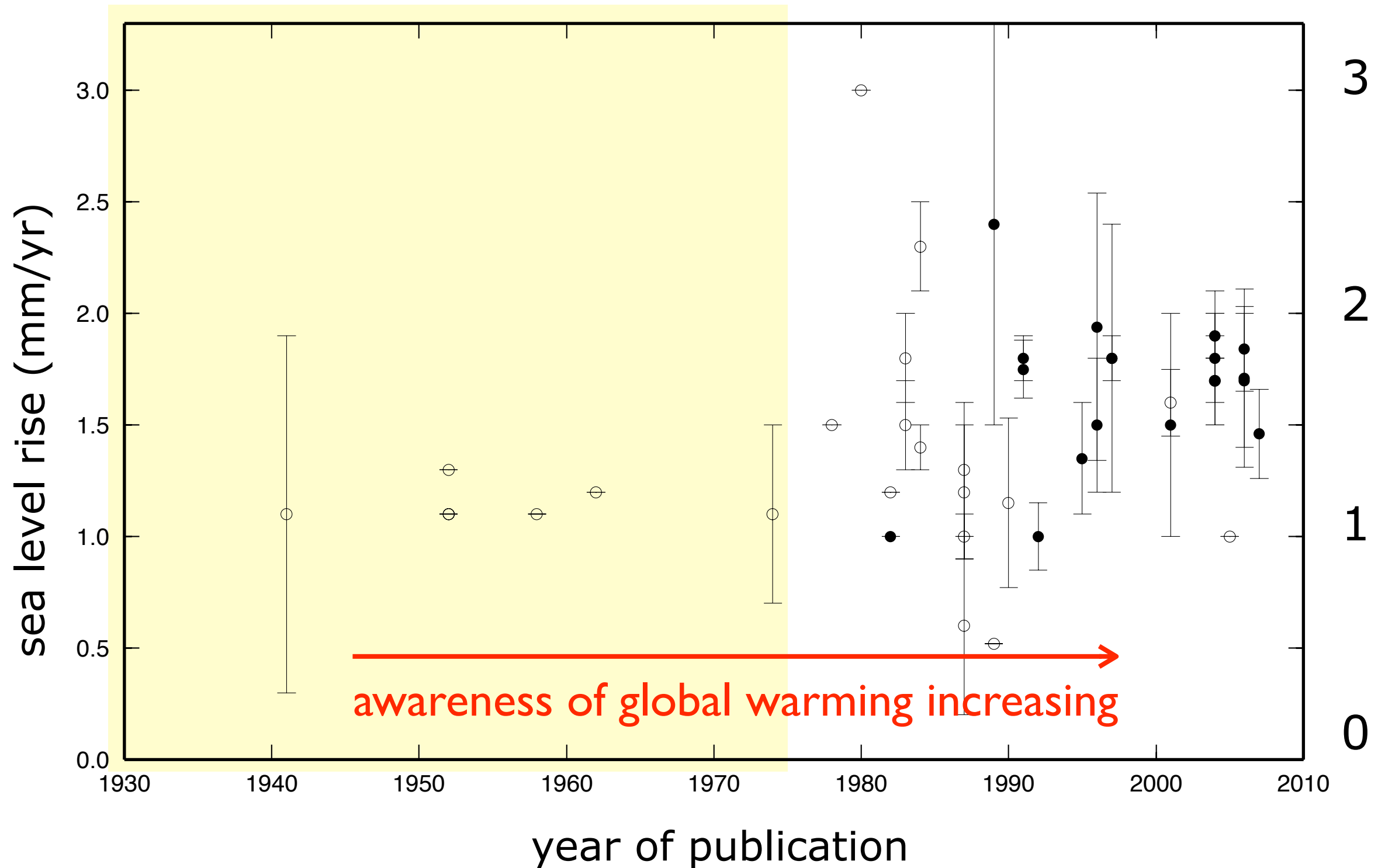
Year and Author(s)	μ^a (mm/yr)	Period ^b	Method(s) ^c	GIA correction ^d
1941 Gutenberg	1.1 ± 0.8	1807–1937	RA	no
1952 Polli	1.1	1871–1940	-???	no
1952 Cailleux	1.3	1885–1951	SA	no
1952 Valentin	1.1	1807–1947	-???	no
1958 Lisitzin	1.1	1807–1943	-???	no
1962 Fairbridge & Krebs	1.2	1900–1950	SA	no
1974 Lisitzin	1.1 ± 0.4	-???	SA	no
1978 Kalinin & Klige	1.5	1860–1960	-???	no
1980 Emery	3	1850–1958	SA	no
1982 Gornitz <i>et al.</i> ¹	1.2	1880–1980	RA	no
" "	1.0	1880–1980	RA	Geological
1983a Barnett	1.5 ± 0.2	1903–1969	EOF	no
1983b Barnett	1.8 ± 0.2	-???	EOF	-???
1984 Barnett ^a	1.4 ± 0.1	1881–1980	EOF, RA	no
" "	2.3 ± 0.2	1930–1980	EOF, RA	no
1987 Gornitz & Lebedeff	0.6 ± 0.4	1880–1982	SA	Geological
" "	1.7 ± 0.3	1880–1982	SA	Geological
" "	1.2 ± 0.3	1880–1982	SA	Geological
" "	1.0 ± 0.1	1880–1982	RA	Geological
1989 Peltier & Tushingham	2.4 ± 0.9	1920–1970	EOF	presumably ICE-3G
1986 Pirazzoli	indeterminable	1807–1984	-	-
1989 Pirazzoli	0.5 – 3.0	1880–1980 Eu	-???	-???
1990a Trupin & Wahr	1.75 ± 0.13	1900–1979	SA	no
1991 Nakiboglu & Lambeck	1.15 ± 0.38	1820–1990	SHA, RA	ANU models
1991 Douglas	1.8 ± 0.1	1880–1980	SA	ICE-3G
1991 Emery & Aubrey	indeterminable	1807–1996	-	-
1992 Shennan & Woodworth	1.0 ± 0.15	1901–1988 Eu	SA	Geological
1993 Gröger & Plag	indeterminable	1807–1992	-	-
1995 Mitrovica & Davis	1.1–1.6	1880–1990	SA	ICE-3G
1996 Davis & Mitrovica	1.5 ± 0.3	1856–1995 USE	SA	ICE-3G
1996 Peltier	1.94 ± 0.56	1920–1970 USE	EOF	ICE-4G
1997 Peltier & Jiang	1.8 ± 0.6	1856–1995 USE	SA	ICE-4G
1997 Douglas	1.8 ± 0.1	1880–1980	SA	ICE-3G
2001 Cabanes <i>et al.</i>	1.6 ± 0.15	1955–1996	SA	no
2001 Church <i>et al.</i>	1.5 ± 0.50	1900–2000	APE	Various models
2001 Mitrovica <i>et al.</i>	1.5 ± 0.1	1880–2000	SA	no
" "	1.8 ± 0.1	1880–2000	SA	ICE-3G
2004 Church <i>et al.</i>	1.8 ± 0.3	1950–2000	EOF	ICE-4G(VM2), L,M
" "	1.75 ± 0.10	1950–2000	EOF	ICE-4G(VM2)
" "	1.89 ± 0.10	1950–2000	EOF	L
" "	1.91 ± 0.10	1950–2000	EOF	M
2004 Holgate & Woodworth	1.7 ± 0.20	1950–?	RA	-???
2005 Nakada & Inoue	1.5	20th century	SA	no
2006 Church & White	1.7 ± 0.30	20th century	EOF	ICE-4G(VM2), L, M
" "	1.71 ± 0.40	1870–1935	EOF	ICE-4G(VM2), L, M
" "	1.84 ± 0.19	1936–2001	EOF	ICE-4G(VM2), L, M
2007 Church <i>et al.</i>	-???	-???	APE	-???
2007 Hagedoorn <i>et al.</i>	1.46 ± 0.20	20th century	RA	ICE-3G
2011 Church & White	1.7 ± 0.2	1900–2009	EOF	as in Church <i>et al.</i> (2004)
" "	1.9 ± 0.4	1961–2009	EOF	" "
" "	2.8 ± 0.8	1993–2009	EOF	" "

+/- ???

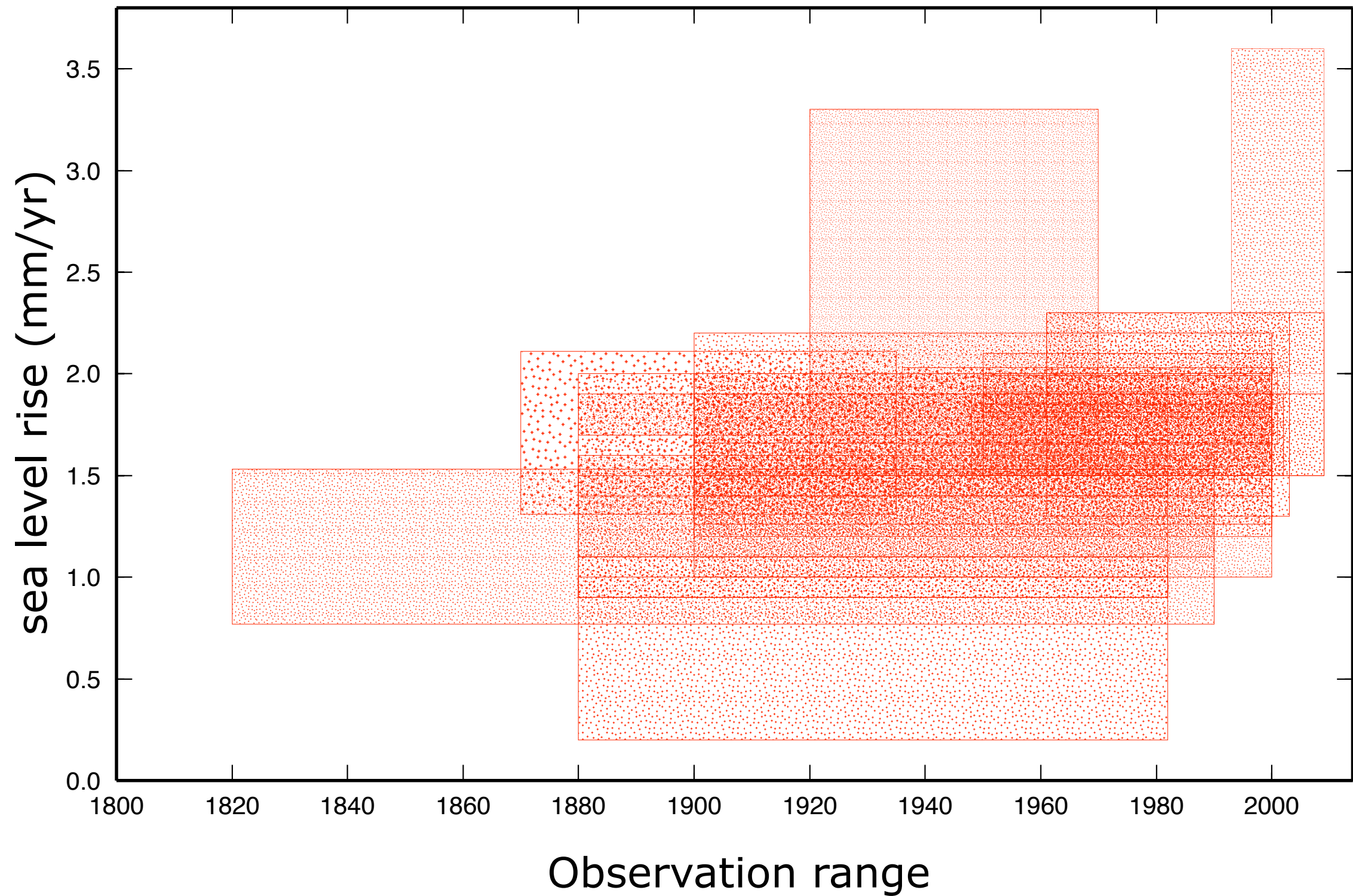
GIA corrections
since ~ 1989

(^a) When made explicit by the Authors, a star (*) denotes *sdom*, a dag (†) *rms*.
(^b) Global data are used, unless otherwise stated (Eu=Europe, USE=United States East coast).
(^c) RA=Regional Average, SA=Simple average from individual TGs, EOF=Empirical Orthogonal Function, SHA=Spherical Harmonics Analysis, APE=Average of Previous Estimates.
(^d) If one is applied, the model is indicated. Geological corrections are based on Holocene RSL curves.

Previous estimates of global sea level rise from TG observations



Previous estimates of global sea level rise



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News

- French Station Records Updated for 2010
- Ponta Delgada's RLR Factor Revised
- Change to Belgian Stations' RLR Factors
- Rickards Appointed IAG Fellow
- Two PSMSL Members Receive IOC Award
- New Sea Level Trend Explorer
- RLR Data from Greek Stations
- Netherlands Stations Switched to RLR
- More News ...

Explore the Dataset



Browse sea level trends

Welcome to the Permanent Service for Mean Sea Level (PSMSL)

PSMSL is the global data bank for long term sea level change information from tide gauges and bottom pressure recorders.

About Us:

Learn about PSMSL, contact us, read news items and annual reports

Data:

Obtain and submit tide gauge and bottom pressure data

Products:

Browse the data set via GoogleEarth or obtain derived products, view regional commentaries and author archives

Training & Information:

A wide variety of [FAQs](#), training and software documentation, information on non-oceanographic signals in tide gauge records (e.g., glacial isostatic adjustment, atmospheric pressure, etc.)

Links:

Links to other networks and programs, as well as international sea level contacts



Tide gauge records updated in the 30 days prior to 05 Oct 2011



ICSU
International Council for Science



National Oceanography Centre
NATURAL ENVIRONMENT RESEARCH COUNCIL



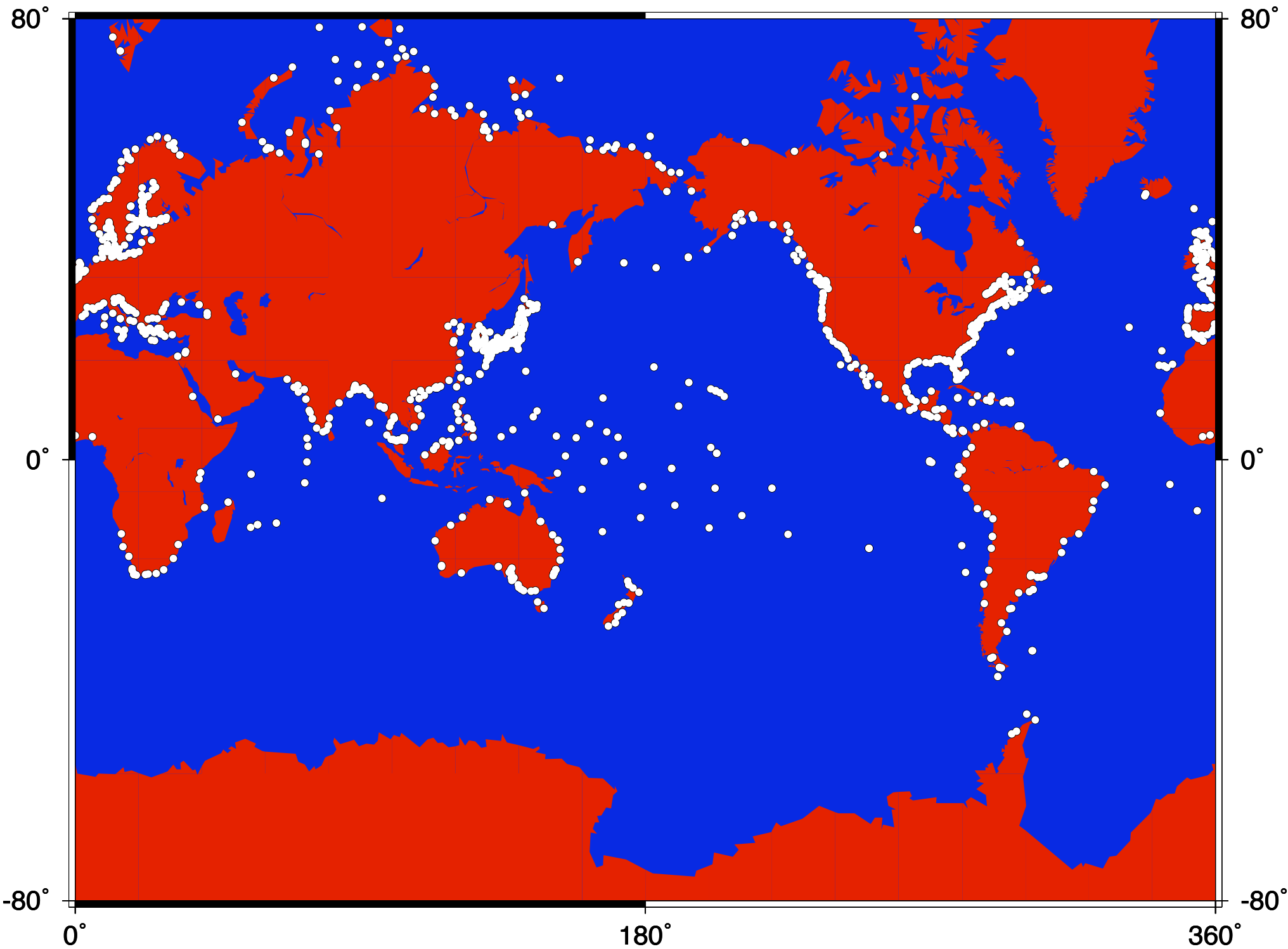
British Oceanographic Data Centre
NATURAL ENVIRONMENT RESEARCH COUNCIL



NATURAL ENVIRONMENT RESEARCH COUNCIL

Distribution of PSMSL stations as of 22 Jan 07
all PSMSL stations

N= 1123



Revised Local Reference (RLR) Definition

- ✓ In order to construct time series of sea level measurements at each station, the monthly and annual means have to be reduced to a common datum.
 - ✓ This reduction is performed by the PSMSL making use of the tide gauge datum history provided by the supplying authority.
 - ✓ To date, approximately **two thirds of the stations** in the PSMSL database have had their data adjusted in this way, forming the 'REVISED LOCAL REFERENCE' (or 'RLR') dataset.
 - ✓ In general, **only RLR data should be used for time series analysis.**
 - ✓ Without the provision of full benchmark datum history information, records generally remain as 'Metric only' in the databank and not as 'RLR'. **In general, 'Metric' records should NEVER be used for time series analysis or for the computation of secular trends.**
-

<http://www.psmsl.org/data/obtaining/rlr.php>

We now give a look into the PSMSL directories...

The individual stations file is:

http://www.pol.ac.uk/psml/psmsl_individual_stations.html

This is actually a link to ALL the information available for the PSMSL stations.

We now browse this archive to get basic information...

PSMSL Monthly and Annual Mean Sea Level Station Files

The following list of PSMSL stations is in PSMSL country/station code order, essentially west to east around the world coastline, starting in the N.E. A Greenland, with the Antarctic following subsequently.

Column 1/2 = PSMSL Country/Station Code. Click on this to get a small map showing station location

Column 3 = Rm. Click on this to obtain RLR monthly data for this station (if an RLR station)

Column 4 = Pm. Click on this to obtain a plot of the RLR monthly data (if an RLR station)

Column 5 = Mm. Click on this to obtain Metric monthly data for this station

Column 6 = Ra. Click on this to obtain RLR annual data for this station (if an RLR station)

Column 7 = Pa. Click on this to obtain a plot of the RLR annual data (if an RLR station)

Column 8 = Docu. Click on this to obtain brief station documentation

Column 9 = GLOSS Code. Click to obtain GLOSS Handbook documentation for this station

Column 10 = Dg. Click on this for an RLR diagram chart (if available)

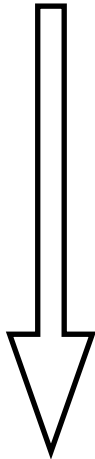
Column 11 = Authority Code (data supplier). Click on this for the authority's address

Column 12/13 = Latitude/Longitude

Column 14 = Station Name

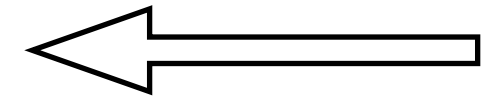
010/001	Rm	Pm	Mm	Ra	Pa	Docu	229	Dg	55	64 09 N	21 56 W	REYKJAVIK
010/011	Rm	Pm	Mm	Ra	Pa	Docu			01	63 50 N	22 26 W	GRINDAVIK
012/001			Mm			Docu	230		04	70 55 N	08 43 W	JAN MAYEN
015/011	Rm	Pm	Mm	Ra	Pa	Docu	237	Dg	61	62 01 N	06 46 W	TORSHAVN
025/001	Rm	Pm	Mm	Ra	Pa	Docu	231	Dg	02	78 04 N	14 15 E	BARENTSBURG
025/002	Rm	Pm	Mm	Ra	Pa	Docu	231	Dg	K7	78 04 N	14 15 E	BARENTSBURG II (SPITSBERGEN)
025/021	Rm	Pm	Mm	Ra	Pa	Docu			04	78 56 N	11 56 E	NY-ALESUND
030/001	Rm	Pm	Mm	Ra	Pa	Docu	99	Dg	02	76 12 N	62 35 E	RUSSKAYA GAVAN
030/003	Rm	Pm	Mm	Ra	Pa	Docu	099	Dg	K7	76 11 N	62 35 E	RUSSKAIA GAVAN II
030/007	Rm	Pm	Mm	Ra	Pa	Docu		Dg	K7	69 36 N	60 13 E	BELYYI NOS
030/014	Rm	Pm	Mm	Ra	Pa	Docu		Dg	K7	80 37 N	58 03 E	KRENKELIA (HEISA OSTROV)
030/016	Rm	Pm	Mm	Ra	Pa	Docu		Dg	K7	72 22 N	52 42 E	MALYE KARMAKULY
030/018	Rm	Pm	Mm	Ra	Pa	Docu	274	Dg	02	68 58 N	33 03 E	MURMANSK

~ 1100 sites



250/053			Mm		Docu		G7	40	50	N	14	18	E	NAPOLI MOLO CARME
250/054			Mm		Docu		G7	40	47	N	14	22	E	TORRE DEL GRECO
250/055			Mm		Docu		G7	40	41	N	14	28	E	CASTELLAMMARE DI STABIA
250/061	Rm	Pm	Mm	Ra	Pa	Docu	23	38	06	N	15	39	E	REGGIO CALABRIA
260/001			Mm		Docu		22	38	12	N	15	34	E	MESSINA
260/011	Rm	Pm	Mm	Ra	Pa	Docu	22	38	08	N	13	20	E	PALERMO
260/021			Mm		Docu		24	37	40	N	12	34	E	MAZARO DEL VALLO
260/028	Rm	Pm	Mm	Ra	Pa	Docu	23	36	40	N	15	18	E	CAPO PASSERO
260/031	Rm	Pm	Mm	Ra	Pa	Docu	23	37	30	N	15	08	E	CATANIA
265/001	Rm	Pm	Mm	Ra	Pa	Docu	J1	35	54	N	14	31	E	VALLETTA
265/002	Rm	Pm	Mm	Ra	Pa	Docu	K5	35	59	N	14	21	E	MELLIEHA BAY
270/006	Rm	Pm	Mm	Ra	Pa	Docu	22	40	26	N	17	16	E	TARANTO
270/011	Rm	Pm	Mm	Ra	Pa	Docu	23	40	08	N	18	30	E	OTRANTO
270/014			Mm		Docu		22	40	38	N	17	56	E	BRINDISI
270/019	Rm	Pm	Mm	Ra	Pa	Docu	23	41	37	N	15	55	E	MANFREDONIA
270/026	Rm	Pm	Mm	Ra	Pa	Docu	23	42	21	N	14	24	E	ORTONA
270/030	Rm	Pm	Mm	Ra	Pa	Docu	23	43	35	N	13	29	E	ANCONA
270/031			Mm		Docu		B6	45	21	N	12	23	E	VENEZIA (DIGA SUD DI LIDO)
270/035	Rm	Pm	Mm	Ra	Pa	Docu	23	44	30	N	12	17	E	PORTO CORSINI
270/041	Rm	Pm	Mm	Ra	Pa	Docu	22	45	25	N	12	21	E	VENEZIA (ARSENALE)
270/051	Rm	Pm	Mm	Ra	Pa	Docu	22	45	25	N	12	20	E	VENEZIA (S.STEFANO)
270/054	Rm	Pm	Mm	Ra	Pa	Docu	K2	45	26	N	12	20	E	VENEZIA (PUNTA DELLA SALUTE)
270/061	Rm	Pm	Mm	Ra	Pa	Docu	Dg 23	45	39	N	13	45	E	TRIESTE
270/071			Mm		Docu		22	44	52	N	13	51	E	POLA
279/002	Rm	Pm	Mm	Ra	Pa	Docu	J9	45	34	N	13	45	E	KOPER
279/003	Rm	Pm	Mm	Ra	Pa	Docu	J9	45	34	N	13	45	E	LUKA KOPER
280/006	Rm	Pm	Mm	Ra	Pa	Docu	E1	45	05	N	13	38	E	ROVINJ
280/009			Mm		Docu		E1	45	19	N	14	27	E	RIJEKA
280/011	Rm	Pm	Mm	Ra	Pa	Docu	E1	45	18	N	14	32	E	BAKAR
280/013	Rm	Pm	Mm	Ra	Pa	Docu	E1	44	07	N	15	14	E	ZADAR
280/014	Rm	Pm	Mm	Ra	Pa	Docu	26	44	05	N	15	16	E	GAZENICA
280/017	Rm	Pm	Mm	Ra	Pa	Docu	26	43	42	N	15	40	E	ZLARIN
280/018			Mm		Docu		E1	43	40	N	15	40	E	ZIRJE
280/021	Rm	Pm	Mm	Ra	Pa	Docu	E1	43	30	N	16	23	E	SPLIT RT MARJANA
280/031	Rm	Pm	Mm	Ra	Pa	Docu	E1	43	30	N	16	26	E	SPLIT HARBOUR
280/040	Rm	Pm	Mm	Ra	Pa	Docu	E1	43	04	N	16	12	E	VIS-CESKA VILA
280/041			Mm		Docu		26	43	04	N	16	12	E	VIS
280/046	Rm	Pm	Mm	Ra	Pa	Docu	E1	43	08	N	17	12	E	SUCURAJ
280/051			Mm		Docu		26	43	01	N	17	27	E	USCE NERETVE
280/056	Rm	Pm	Mm	Ra	Pa	Docu	E1	42	45	N	16	50	E	UBLI
280/061			Mm		Docu		26	42	50	N	17	42	E	MALI STON

Italian
sites



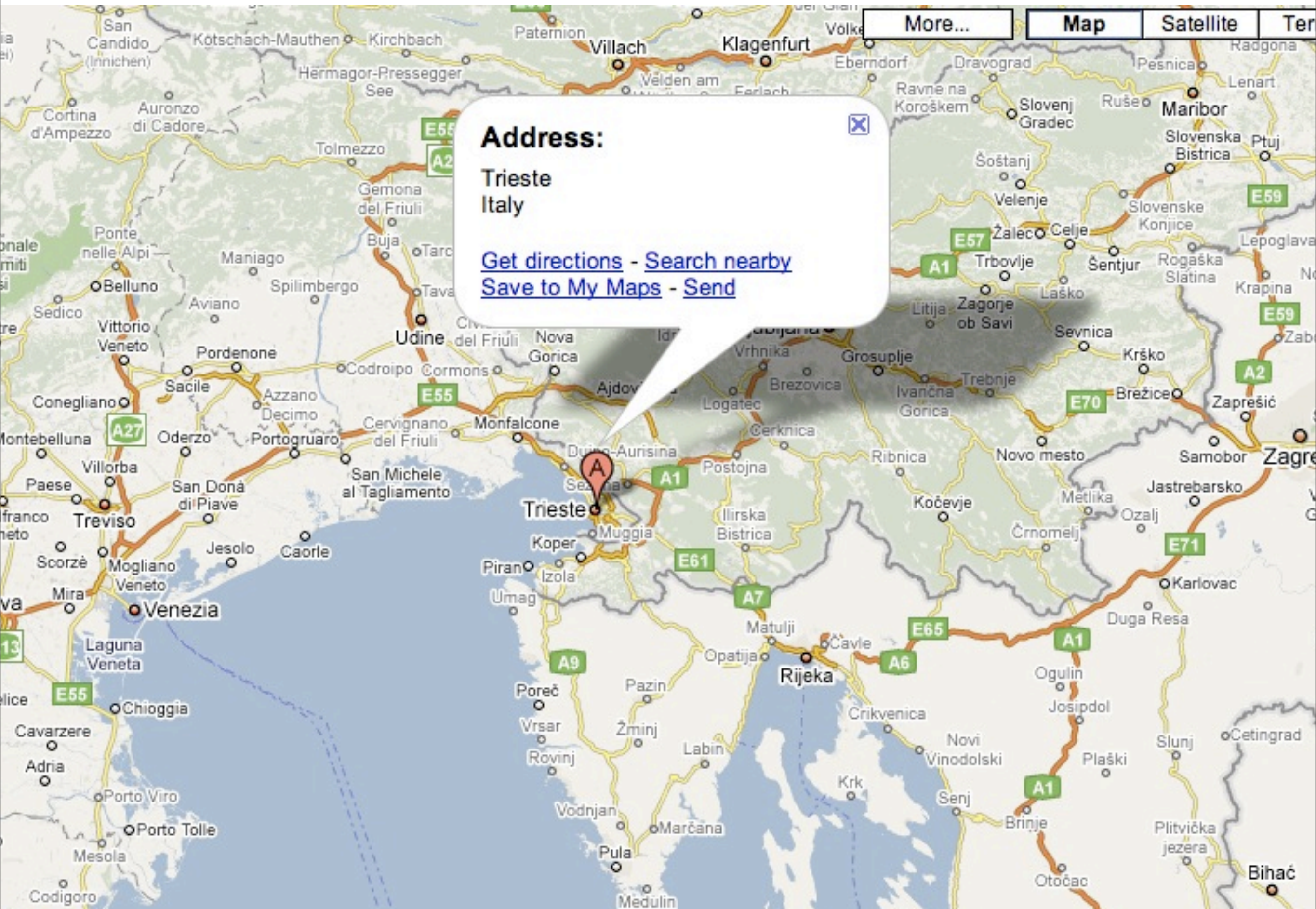
- Column 1/2 = PSMSL Country/Station Code. Small map showing station location
- Column 3 = **Rm**. Click on this to obtain RLR monthly data for this station *(if an RLR station)*
- Column 4 = Pm. Click on this to obtain a plot of the RLR monthly data *(if an RLR station)*
- Column 5 = Mm. Click on this to obtain Metric monthly data for this station
- Column 6 = **Ra**. Click on this to obtain **RLR annual data** for this station *(if an RLR station)*
- Column 7 = Pa. Click on this to obtain a plot of the RLR annual data (if an RLR station)
- Column 8 = **Docu**. Click on this to obtain brief station documentation
- Column 9 = GLOSS Code. Click to obtain GLOSS Handbook documentation for this station
- Column 10 = Dg. Click on this for an RLR diagram chart (if available)
- Column 11 = Authority Code (data supplier). Click on this for the authority's address
- Column 12/13 = Latitude/Longitude
- Column 14 = Station Name

E.g., TRIESTE, ITA:

270/061	Rm	Pm	Mm	Ra	Pa	Docu	Dg	23	45	39	N	13	45	E	TRIESTE
1/2	3	4	5	6	7	8	9	10	12/13			14			

Tide gauge signals

E.g., TRIESTE (Italy)



PSMSL country/station code = 270/061
GLOSS code (if a GLOSS station) =
Location = 45 39 N 13 45 E

Number of years of data = 97
Spanning 1905 to 2007

Station Comments:

DATA 1927-1936, VALUES BASED ON READINGS OF HIGH & LOW WATERS

===== FOLLOWING PSMSL DOCUMENTATION ADDED 14-JUL-94 :
Analysis of Trieste data indicates September 1958 larger than
expected, compared to neighbouring stations; June-July 1961
smaller; December 1954 to February 1955 smaller; and May-June
1955 larger. These values have been checked to be correct as
received from authority.

===== FOLLOWING PSMSL DOCUMENTATION ADDED 2000Jan25 :
Trieste 270/061 RLR(1964) is 9.4m below BM

===== FOLLOWING PSMSL DOCUMENTATION ADDED 2000Oct03 :
Some information on Trieste provided by Fabio Raicich (CNR, Trieste) in
September 2000:

.
**The tide gauge site has always been the same as today, except that
before 1926 the station was 10-20 m away from present location, but
still on the same pier, namely 'Molo Sartorio'. The present position
is 45 deg 38' 50.5" N, 13 deg 45' 30.5" E**

.
Gauges used have included:

*1859-1884: Schaub ; 1884-1911: Strudhoff ;
1911-June 1961 and January 1962-1984: Seibt-Fuess ;
June 1961-December 1961: Pagan (a local manufacturer) ;
1966-present: Buesum-Ott ; 1985-present: Pagan ;*

.
but only float gauges have been used throughout since the very beginning.

===== FOLLOWING PSMSL DOCUMENTATION ADDED 2001Feb13 :
Trieste data 1905-14 and 1939-99 revised November 2000.
The revision has included corrections for the suspect 1958
and 1961 data, but for the 1954 and 1955 queries, no
corrections were found (see previous note).

===== FOLLOWING PSMSL DOCUMENTATION ADDED 15-OCT-07 :
Data from Trieste from 1875-1904 which precede the data in the PSMSL
data bank but which are probably of lower accuracy than later data
can be found in the paper by Fabio Raicich, Journal of Coastal
Research, 23, 1067-1073, 2007.

Basic info

“Anomalies”

A note about
TG location

TG instruments

TG type(s)

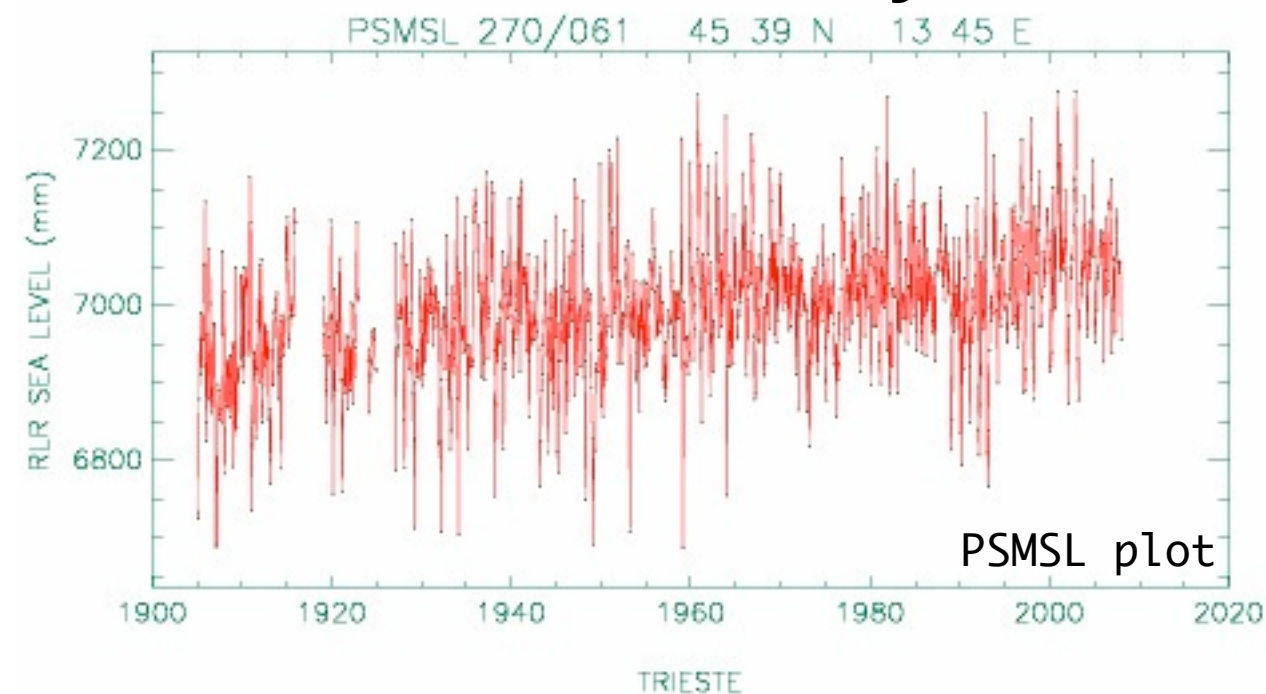
References / contacts

RLR monthly

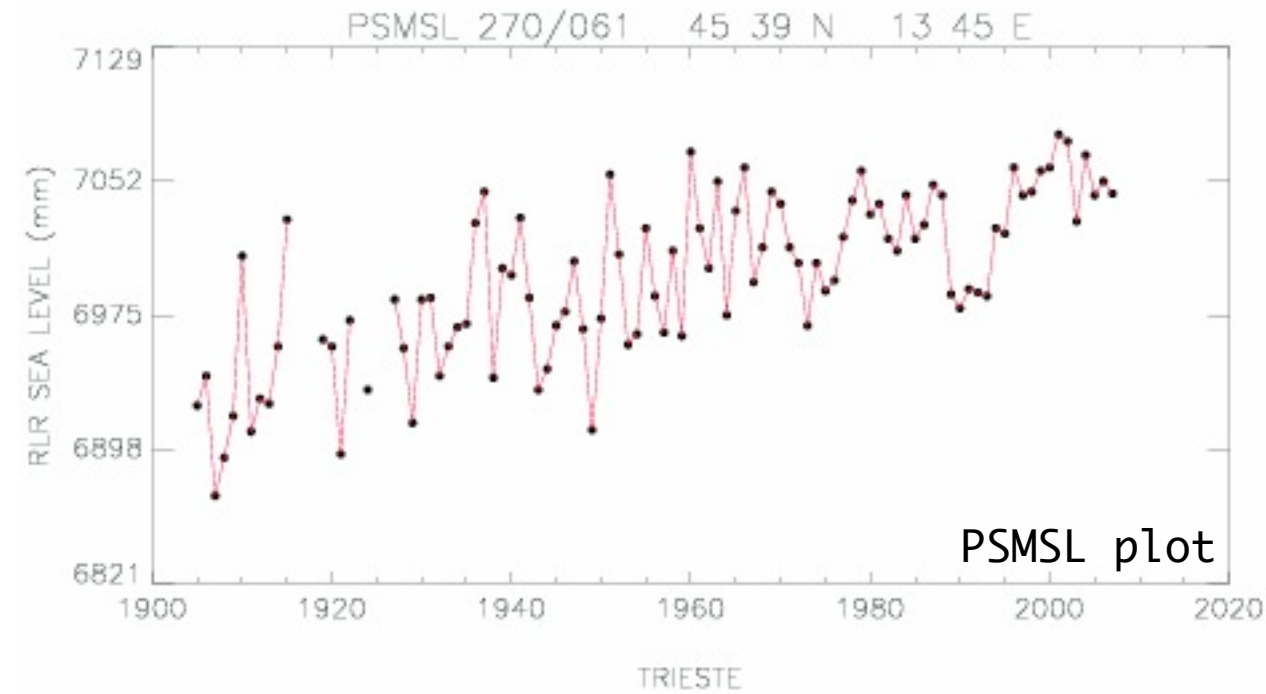
RLR annual

year	Rm (mm)	year	Ra (mm)
1905.042	6734	1905	6923
1905.125	6726	1906	6940
1905.208	6879	1907	6871
1905.292	6957	1908	6893
1905.375	6912	1909	6917
1905.458	6990	1910	7009
1905.542	6922	1911	6908
1905.625	6986	1912	6927
...		1913	6924
...		1914	6957
...		1915	7030
...		1919	6961
2006.708	7126	1920	6957
2006.792	7163	...	
2006.875	7081	...	
2006.958	6939	...	
2007.042	6994	1996	7060
2007.125	7061	1997	7044
2007.208	7061	1998	7046
2007.292	6965	1999	7058
2007.375	7109	2000	7060
2007.458	7124	2001	7079
2007.542	7068	2002	7075
2007.625	7056	2003	7029
2007.708	7042	2004	7067
2007.792	7055	2005	7044
2007.875	7057	2006	7052
2007.958	6956	2007	7045

RLR monthly

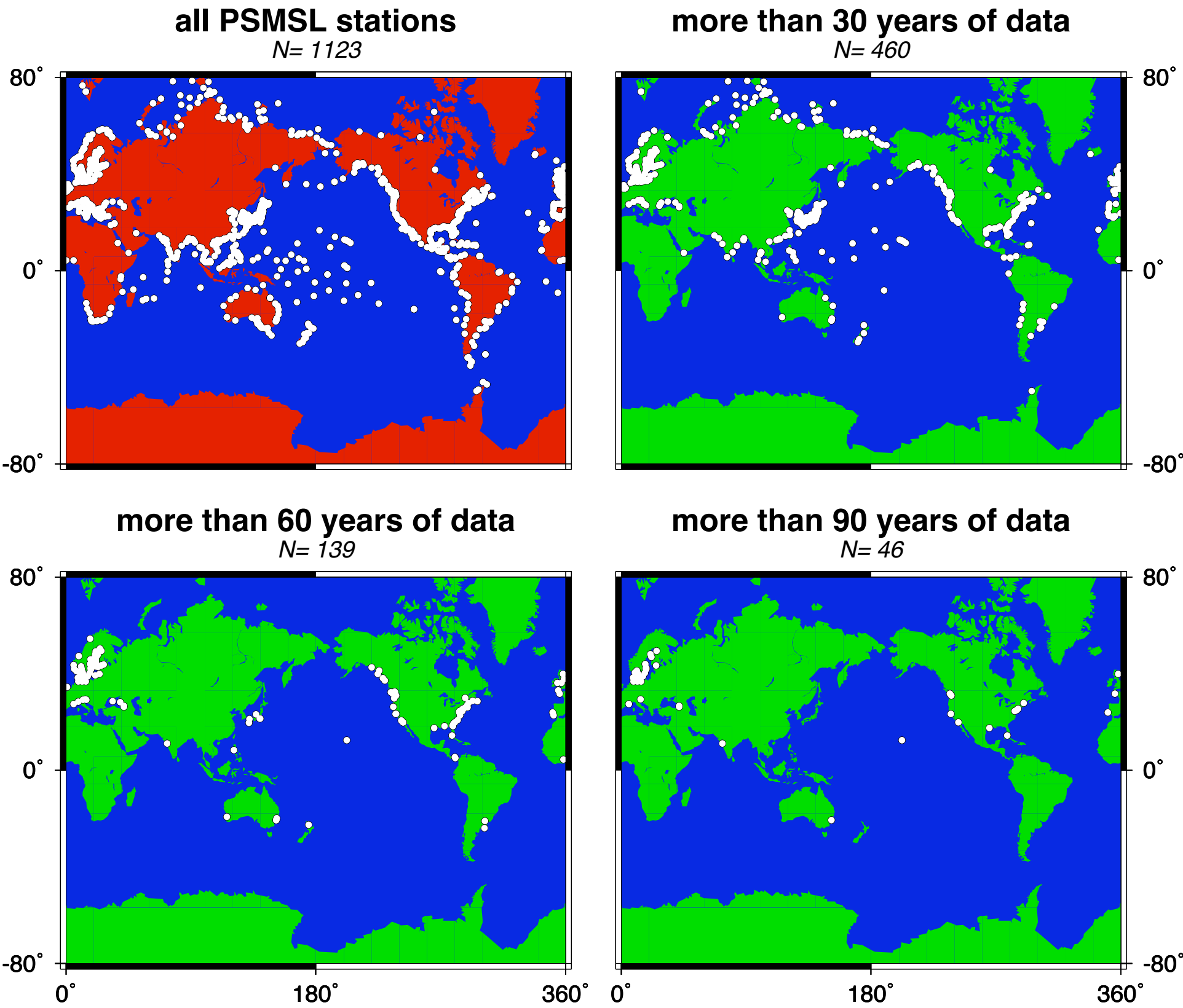


RLR annual



Epoch (years)

Distribution of PSMSL stations as of 22 Jan 07



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- 1). Motivations, previous work, relevance
- 2). Data: RLR tide gauge (TG) observations since 1880
- 3). Obtaining sea level trends from TG time series**
- 4). Corrections in general and GIA corrections
- 5). Some new estimates of the secular sea level rise
- 6). Outlook

GLOBAL SEA RISE: A REDETERMINATION

BRUCE C. DOUGLAS

Department of Geography, University of Maryland, College Park, MD 20742, USA

a very influential paper: Douglas 1997 (D97)

Abstract. It is well established that sea level trends obtained from tide gauge records shorter than about 50-60 years are corrupted by interdecadal sea level variation. However, only a fraction ($<25\%$) of even the long records exhibit globally consistent trends, because of vertical crustal movements. The coherent trends are from tide gauges not at collisional plate boundaries, and not located in or near areas deeply ice-covered during the last glaciation. Douglas (1991), using ICE-3G values for the postglacial (PGR) rebound correction, found 21 usable records (minimum length 60 years, average 76) in 9 oceanographic groups that gave a mean trend for global sea level rise of $1.8 \text{ mm/yr} \pm 0.1$ for the period 1880–1980. In that analysis, a significant inconsistency of PGR-corrected U.S. east coast trends was noted, but not resolved. Now, even after eliminating those trends, more (24) long records (minimum 60 years, average 83) are available, including series in the southern hemisphere

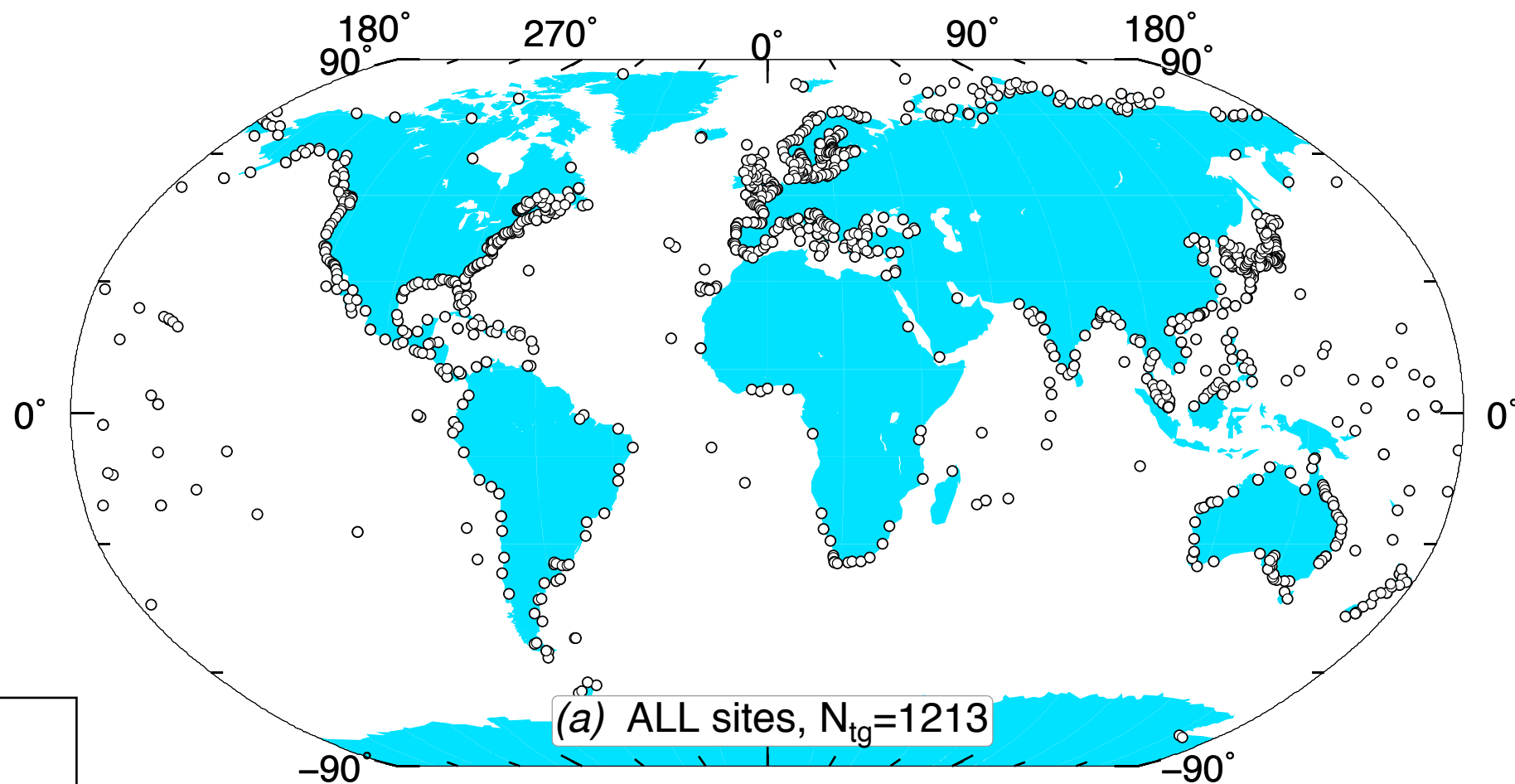
(ICE-3G GIA-corrected)
mean trend of global secular sea level rise:
 $1.8 \pm 0.1 \text{ mm/yr}$

The D97 requirements on PSMSL data

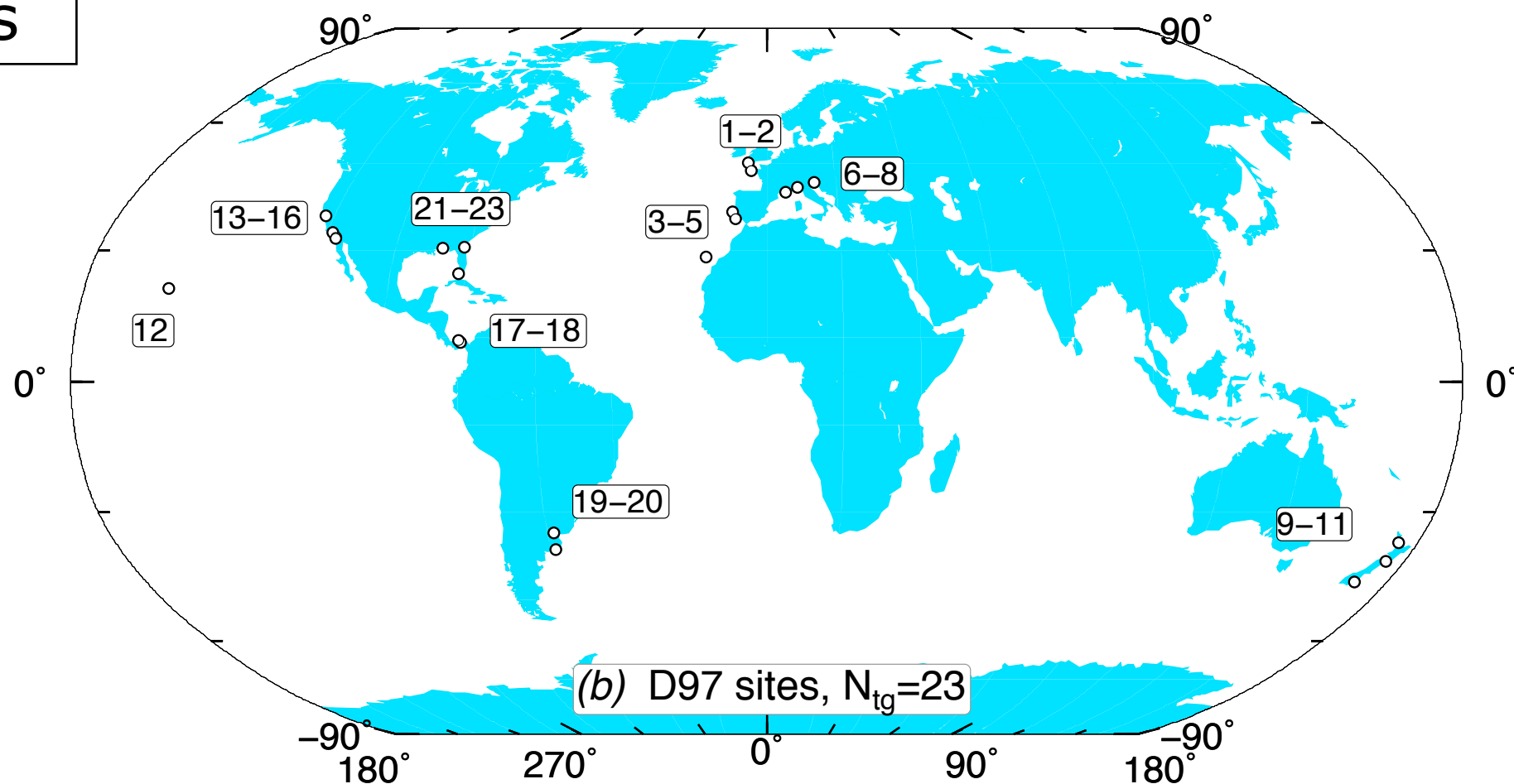
- I) be at least 60 years in length
- II) not be from sites at collisional tectonic plate boundaries
- III) 80% complete or better
- IV) in reasonable agreement (at low frequencies) with records from nearby gauges that sample the same water mass
- V) not from areas deeply covered by ice during the last glacial maximum (D91). ---> Strengthened to eliminate also records from sites in the area of the peripheral bulge immediately adjacent to formerly deeply ice covered regions.

(D91) Douglas (1991, JGR) "Global Sea Level rise"

RLR
records

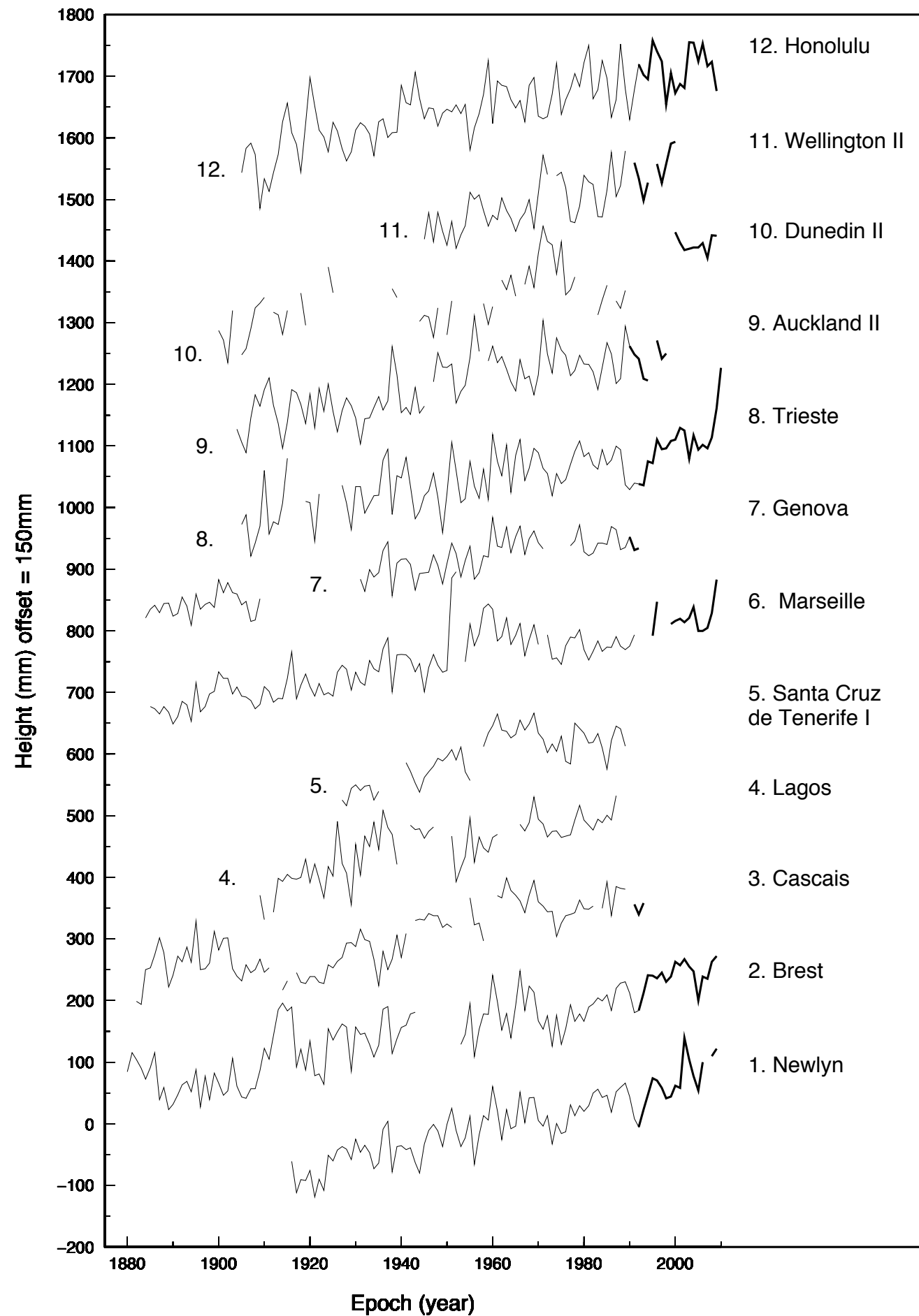
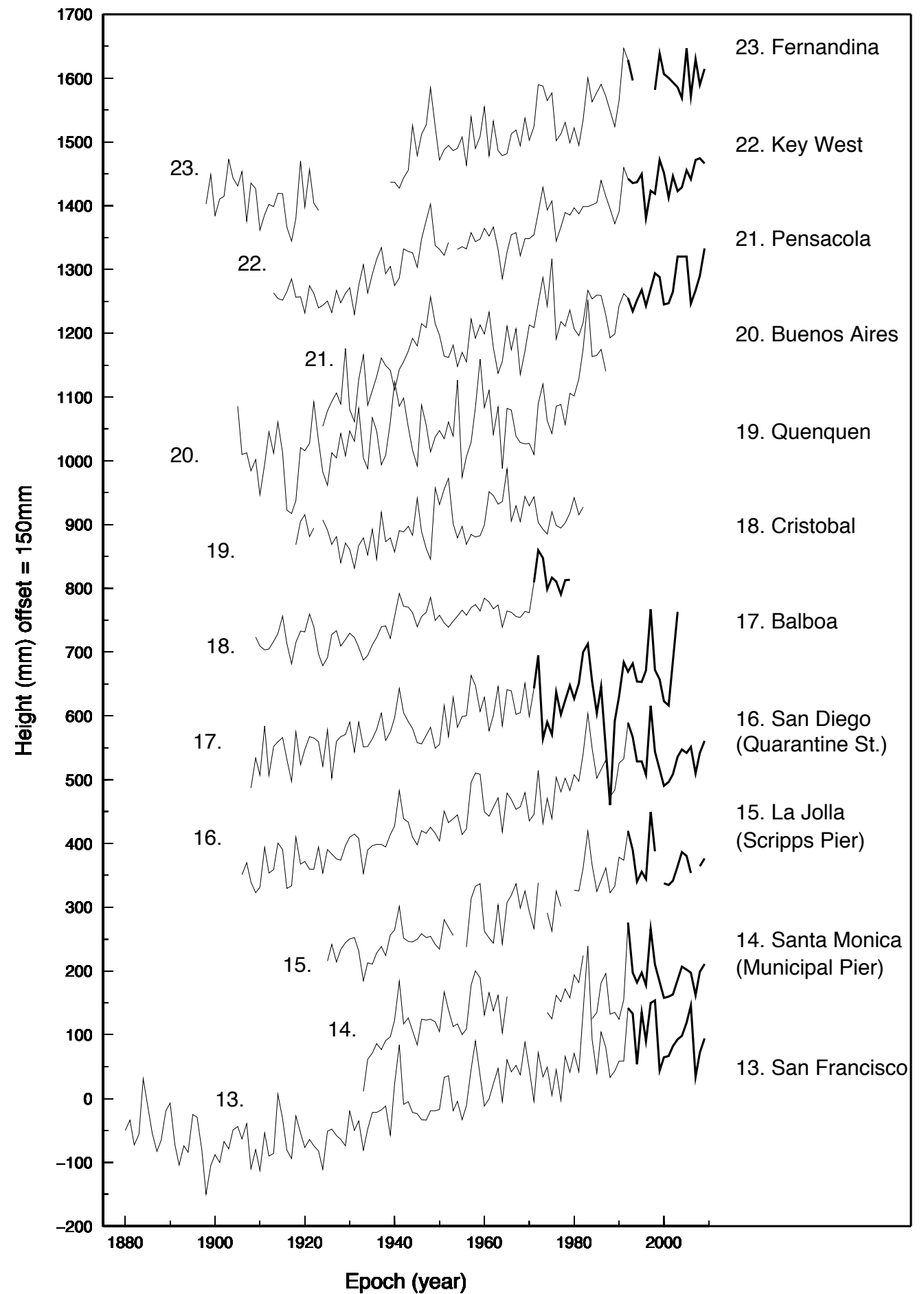


ALL
(1123)



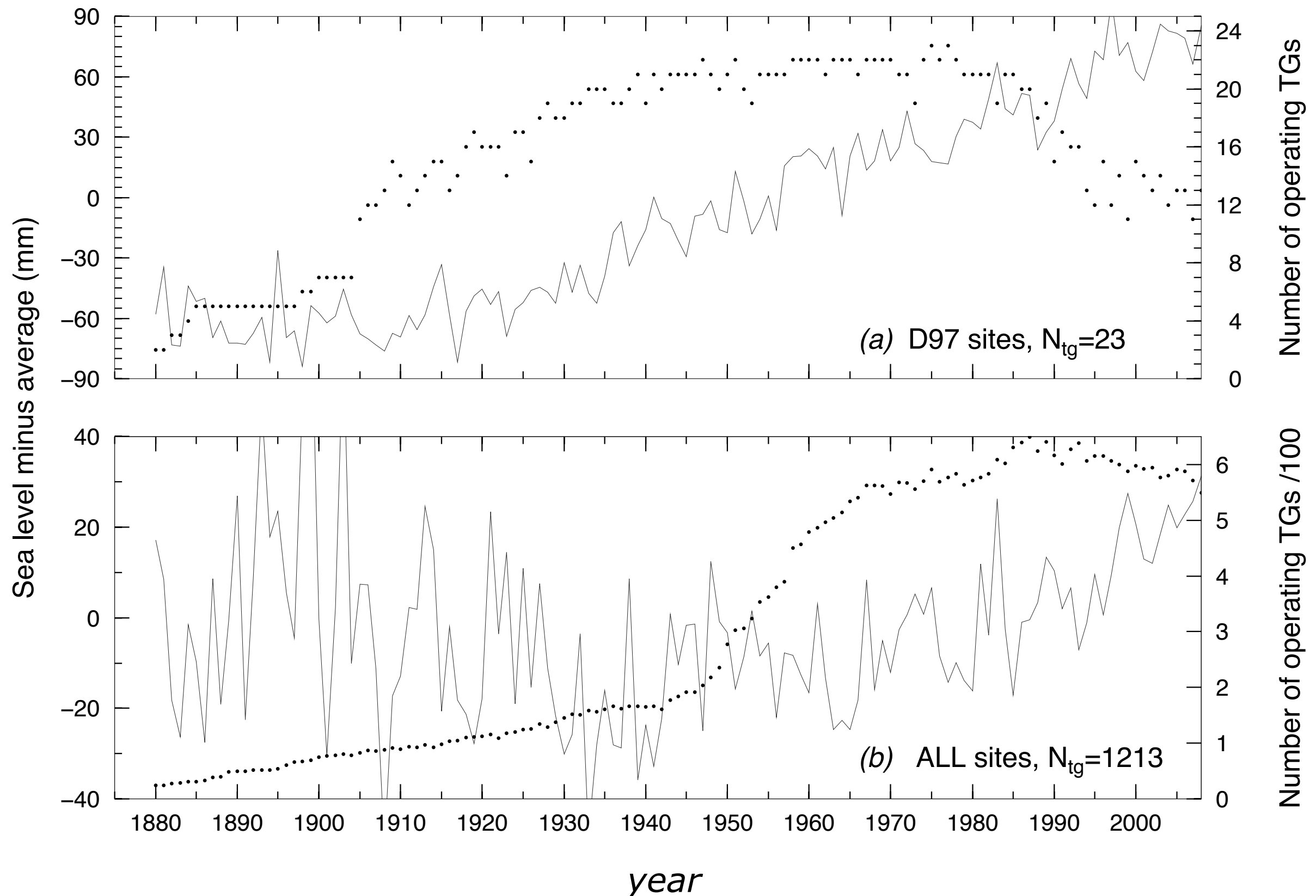
D97
(23)

The 23 D97 PSMSL time series



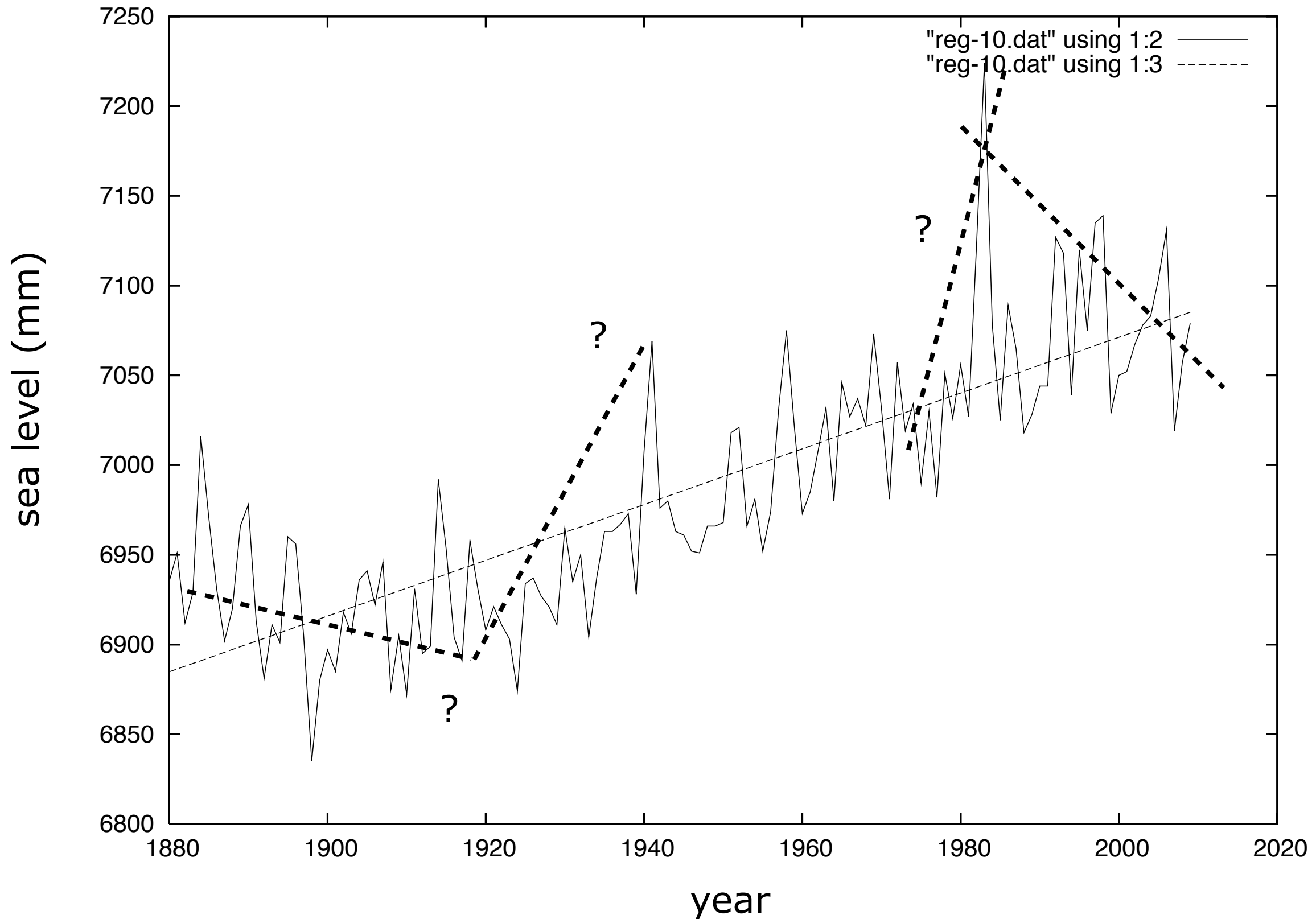
Stacking of global sea level rise time series

Thanks to Marco Olivieri for advice



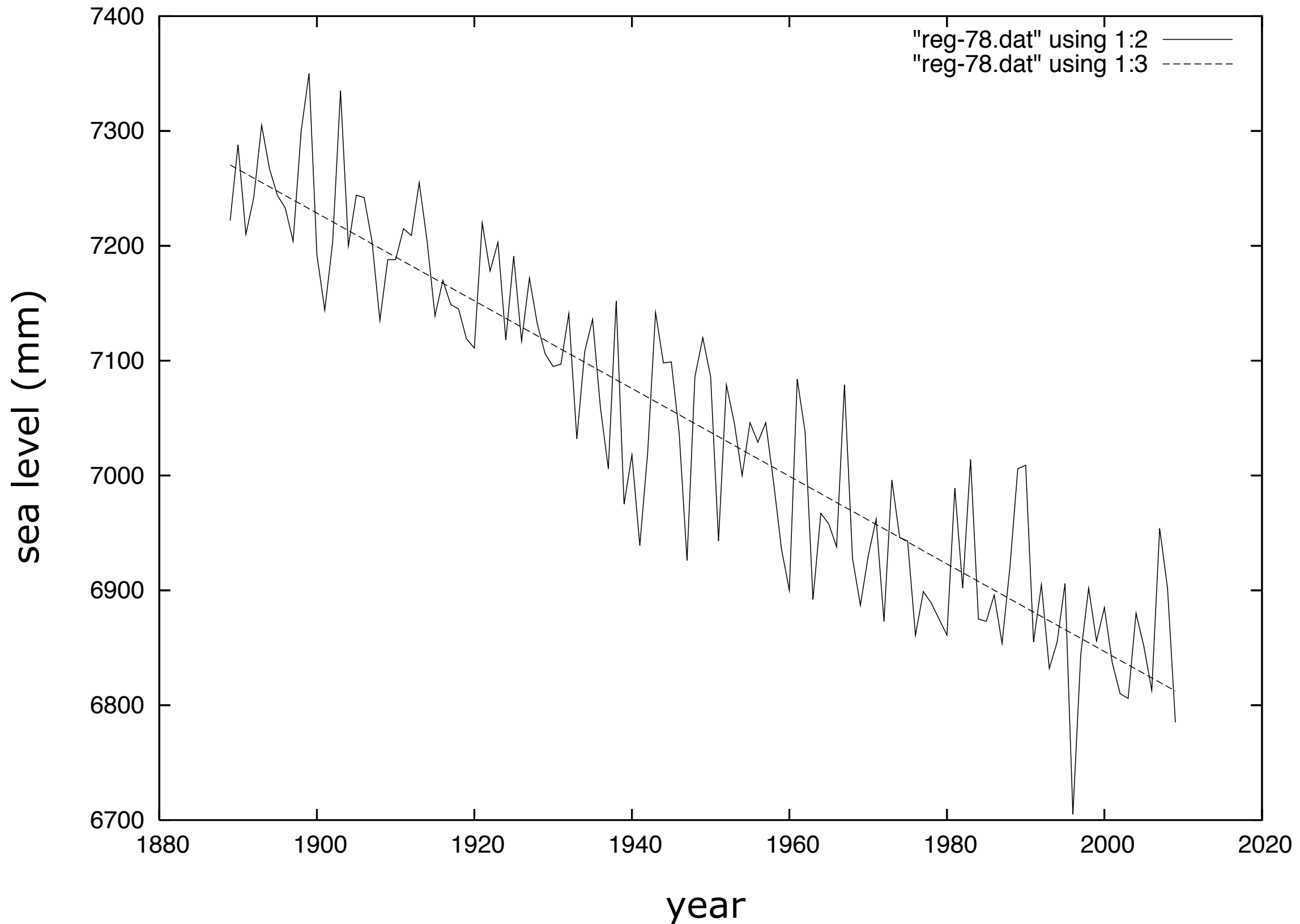
Nature of the (annual) TG record

San Francisco



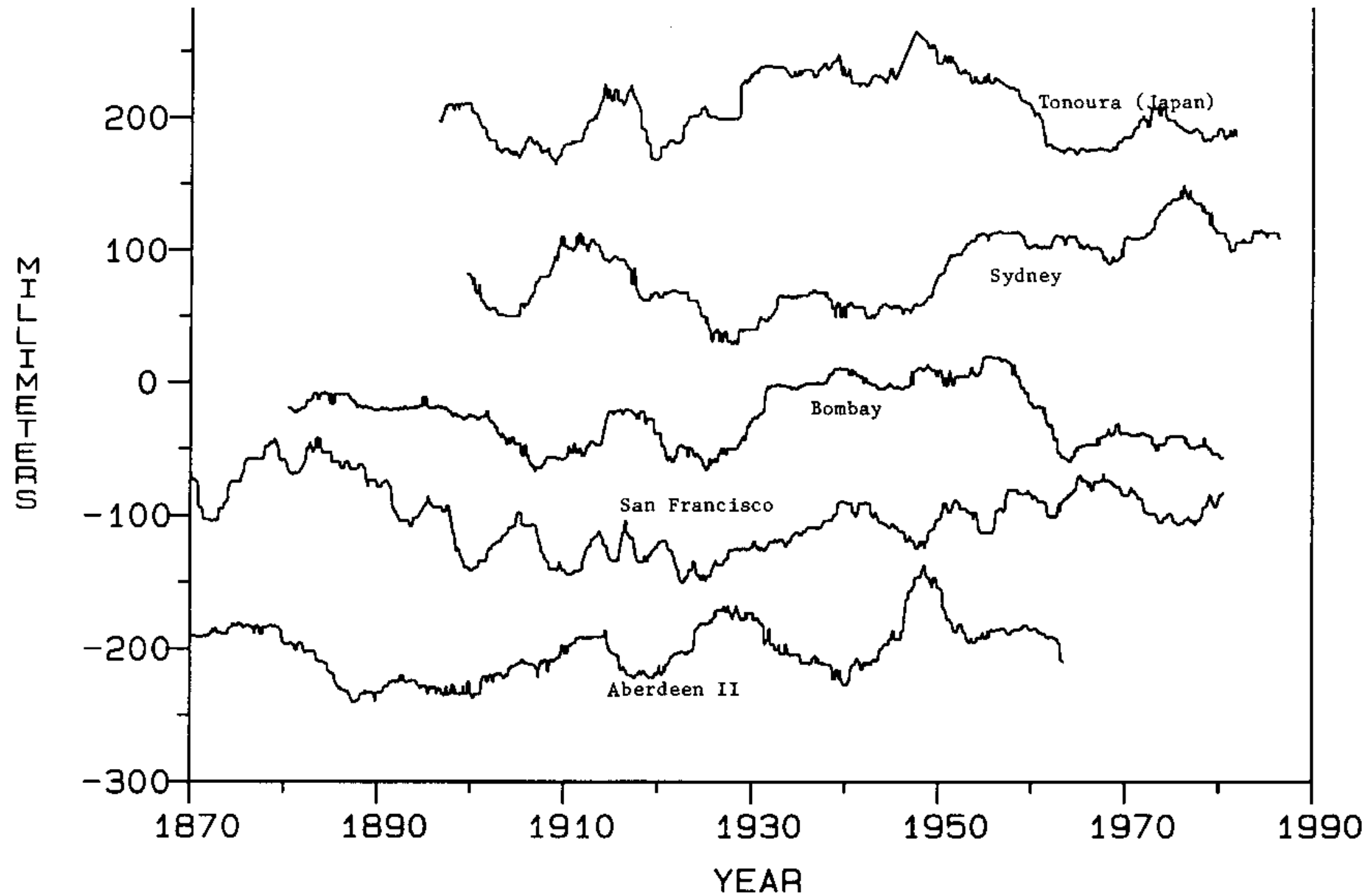
Nature of the (annual) TG record

Stockholm



Nature of the (annual) TG record

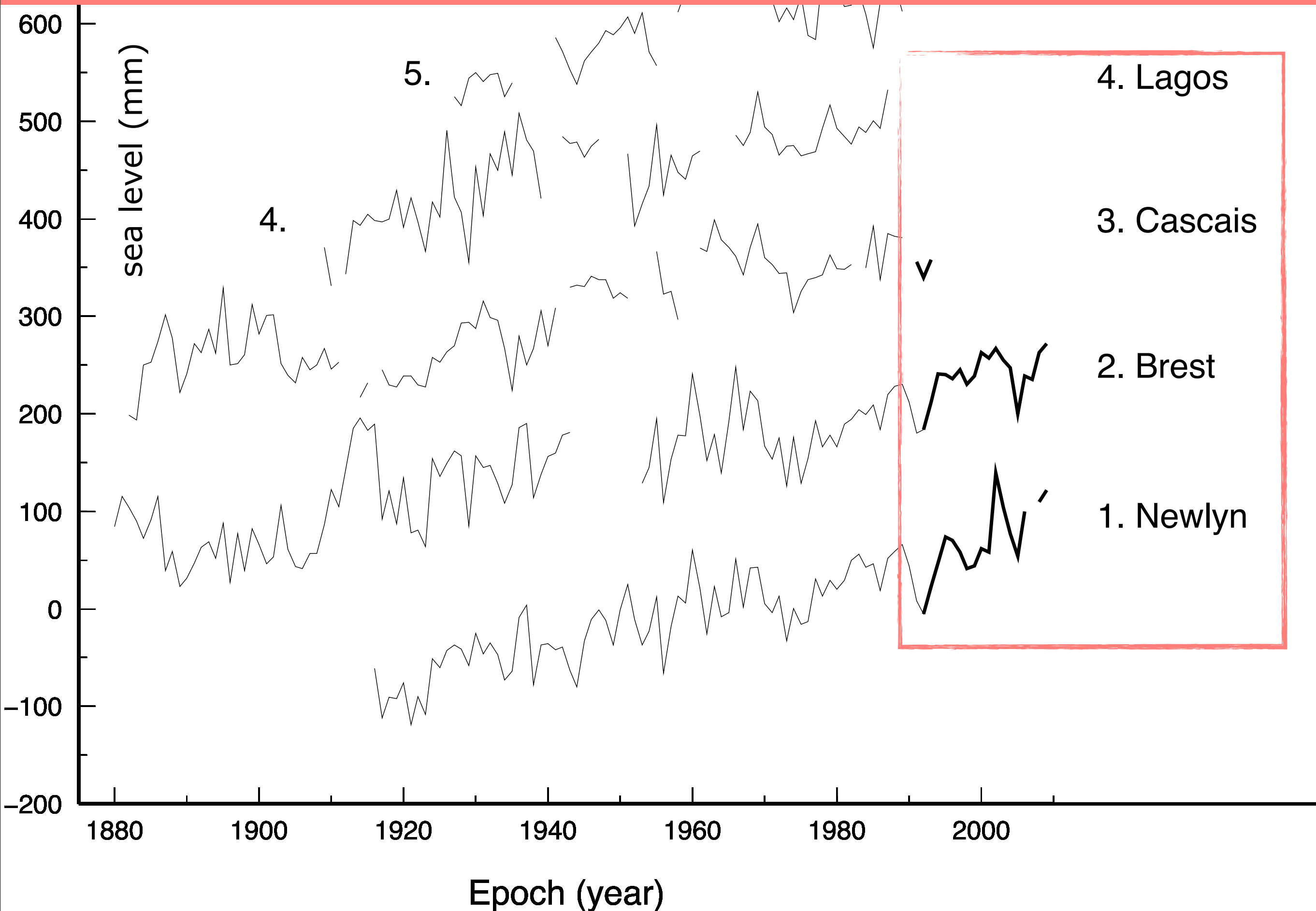
Decade oscillations in the TG series



3. Median filtered and detrended sea level records for five widely distributed tide gauge sites. Note the apparent correlations of the records at low frequencies.

Douglas, 1991 JGR

Nature of the (annual) TG record



Obtaining a trend from the TG record

A simple “pencil and ruler” approach (Sturges & Hong 2001)

“Best-fit rate:”

$$r_k = \frac{N_k^v \sum_j x_j y_j - \left(\sum_j x_j \right) \left(\sum_j y_j \right)}{N_k^v \left(\sum_j x_j^2 - \sum_j y_j^2 \right)}, \quad k = 1, \dots, N_{tg},$$

where:

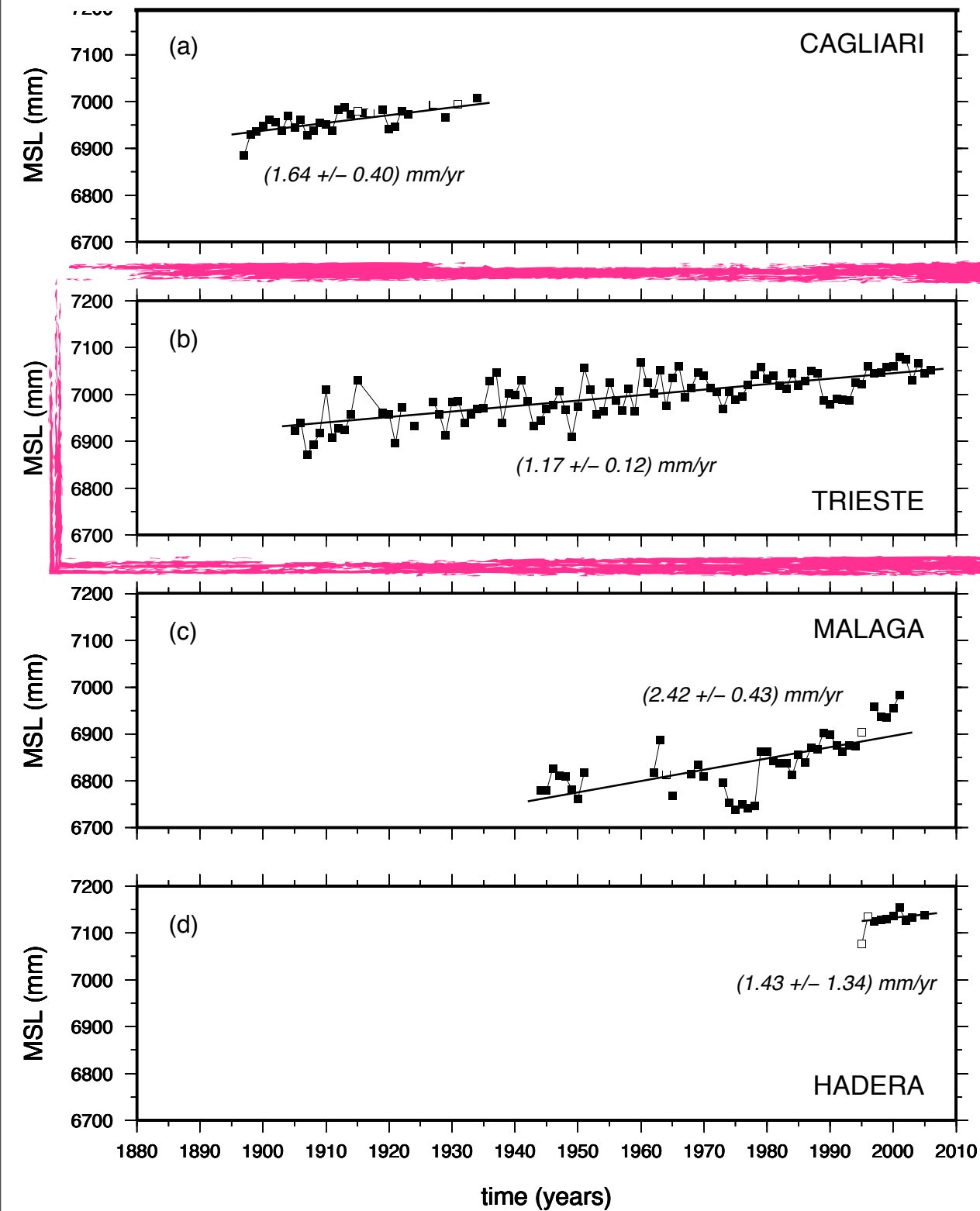
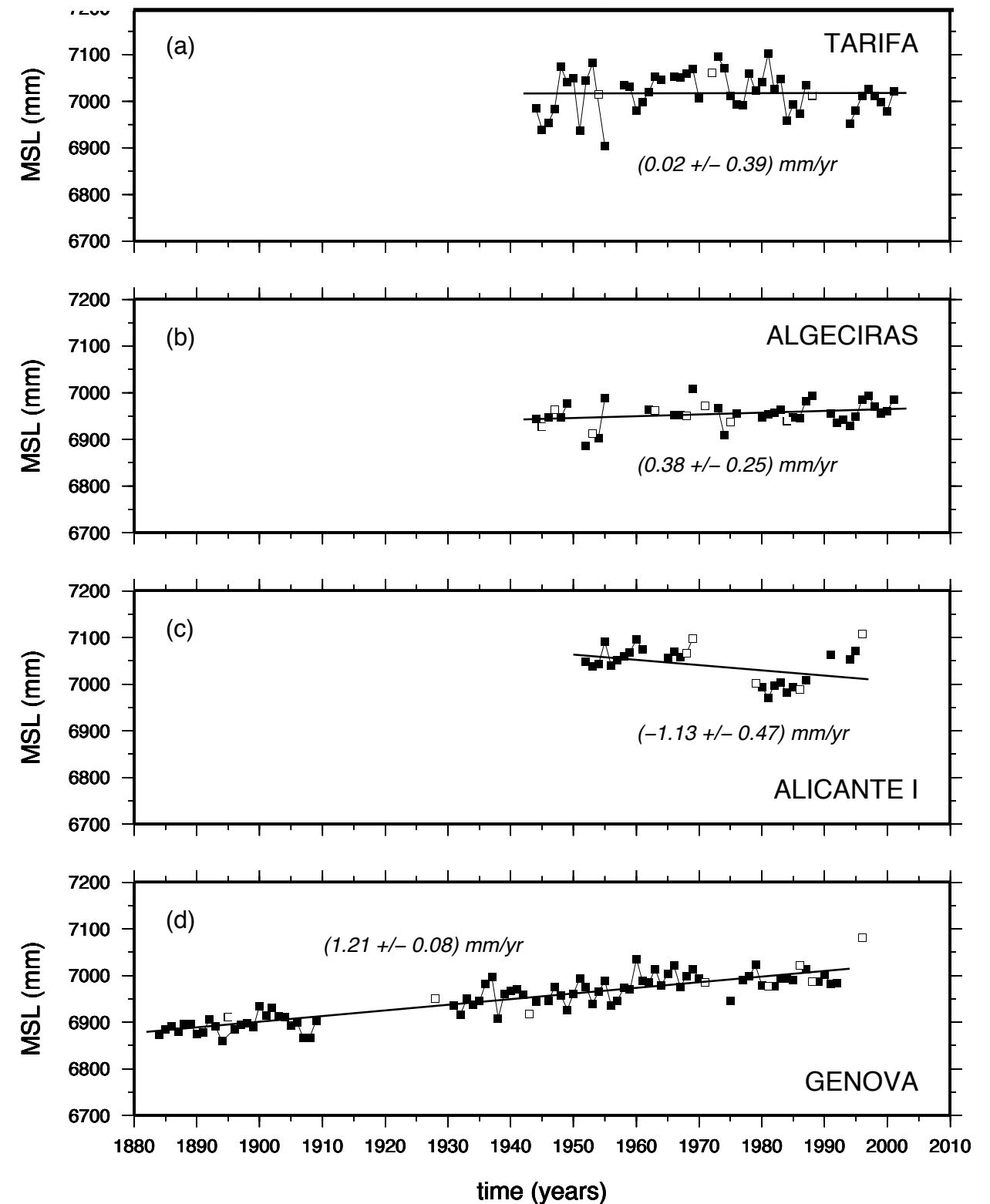
y_j is sea level at time x_j ($j = 1, \dots, N_k^v$)

N_k^v is number of valid yearly data in the time series (twelve monthly observations available)

σ_k is the uncertainty on the trend (95% confidence), obtained using the Student t distribution

So, the tide gauge rate (with uncertainty) is: $\rho_k = r_k \pm \sigma_k$

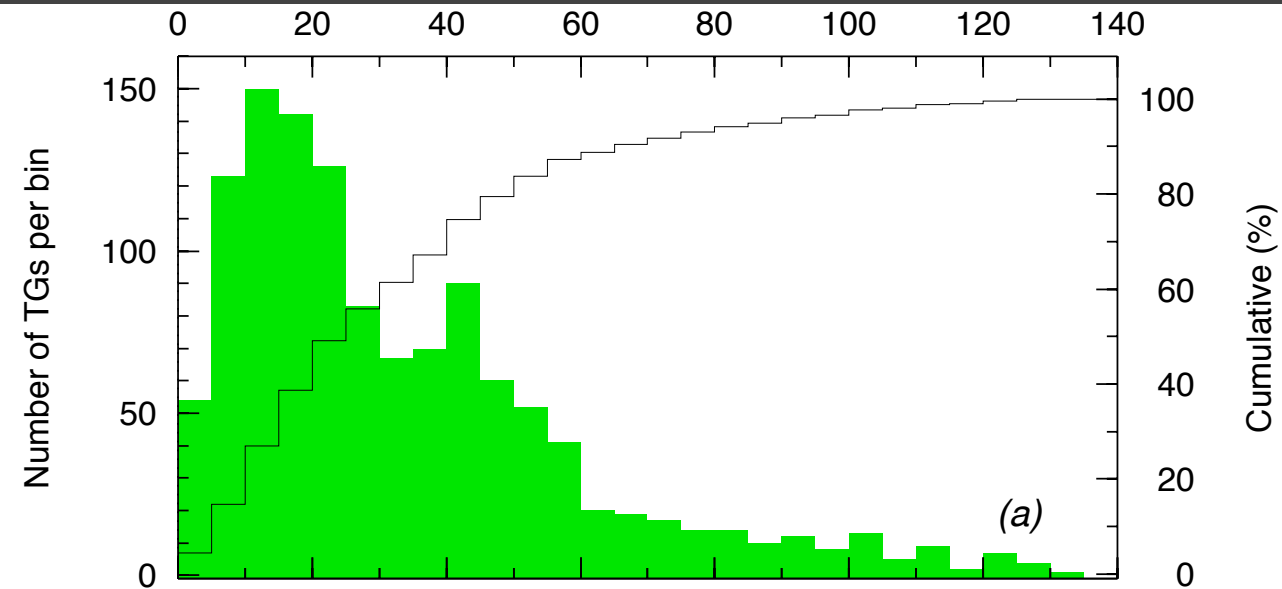
Obtaining a trend from the TG record



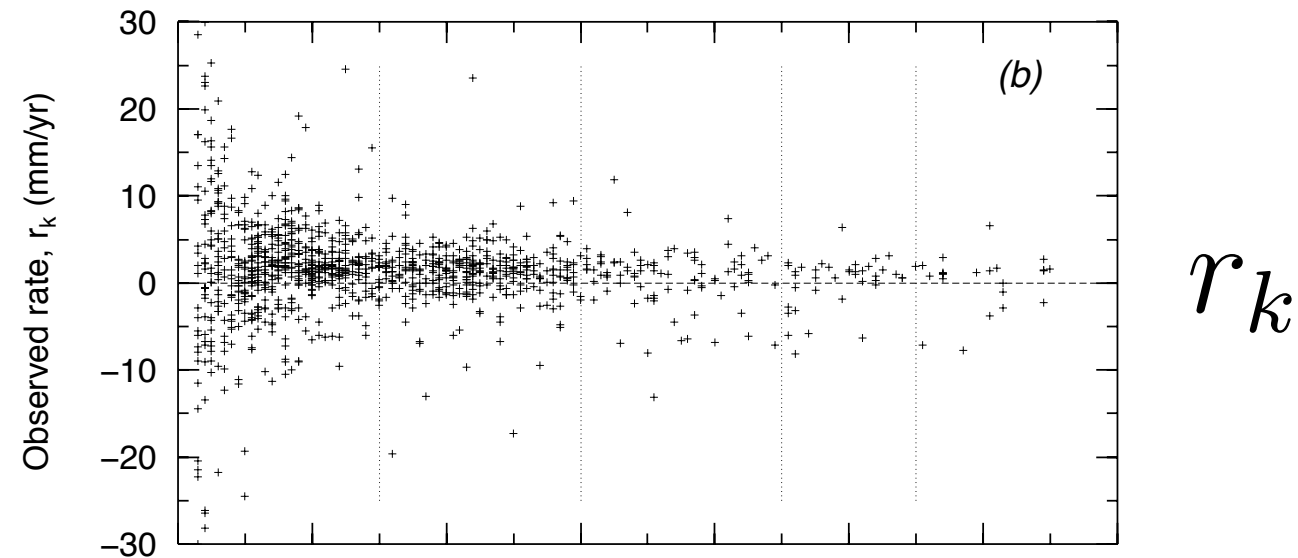
From: P. Stocchi & G. Spada, Tectonophysics (2009),
available from <http://www.fis.uniurb.it/spada>

Statistics of the RLR PSMSL TG trends

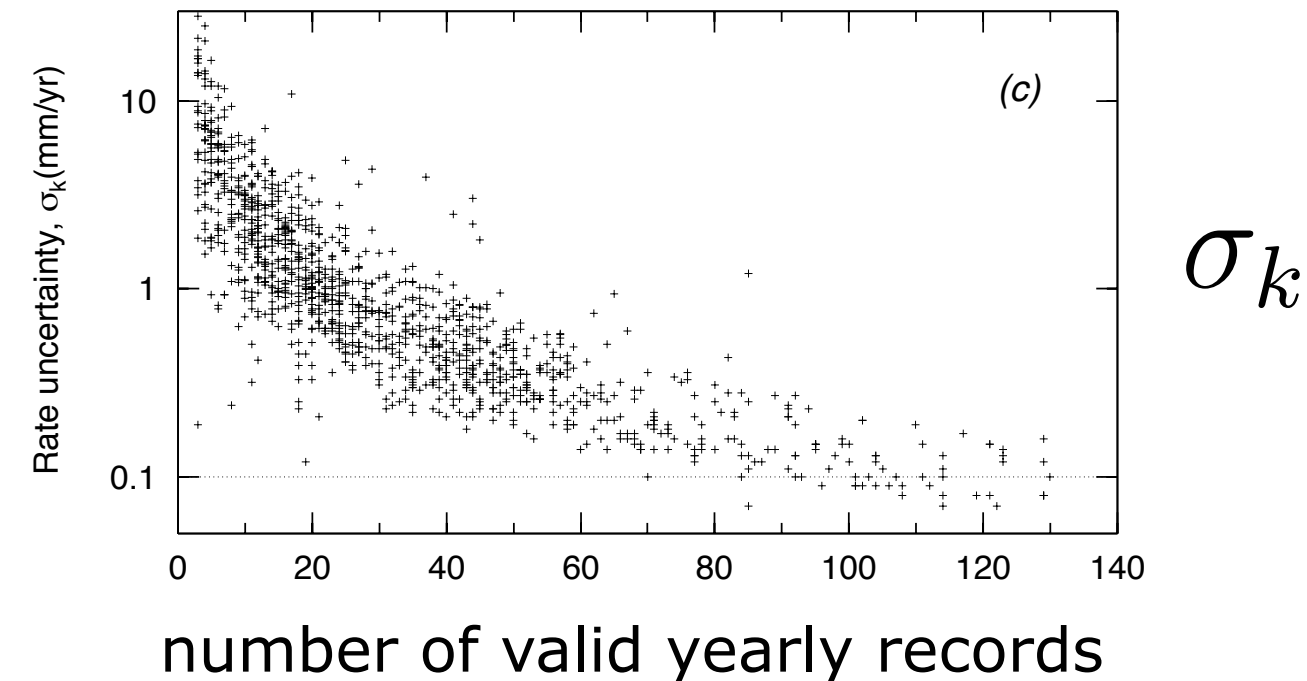
*Number of TGs
per bin*



*computed
best fit rate*



*uncertainties on
individual rates*



Comparing “our” computed trends with D97

Region	Tide gauge site	Period year–year	span _k years	N_k^v years	r_k (D97 ^a) mm/yr	$\rho_k = r_k \pm \sigma_k$ mm/yr	r_k^{gia} mm/yr
English Channel	1. Newlyn*	1916–2009	94	93	1.7	1.8 ± 0.1	+0.2
	2. Brest*	1880–2009	130	121	1.4	1.4 ± 0.1	+0.2
Atlantic	3. Cascais*	1882–1993	112	101	1.3	1.3 ± 0.1	−0.2
	4. Lagos*	1909–1987	79	69	1.5	1.4 ± 0.2	−0.2
	5. S. C. Tenerife I*	1927–1989	63	56	1.5	1.6 ± 0.2	−0.0
Mediterranean Sea	6. Marseille*	1885–2009	125	119	1.2	1.2 ± 0.1	−0.1
	7. Genova*	1884–1996	113	85	1.2	1.2 ± 0.1	−0.2
	8. Trieste*	1905–2010	106	100	1.2	1.3 ± 0.1	−0.2
New Zeland	9. Auckland II*	1904–1998	95	92	1.3	1.3 ± 0.1	−0.4
	10. Dunedin II*	1900–2009	110	64	1.4	1.2 ± 0.1	−0.4
	11. Wellington II*	1945–2000	56	53	1.7	2.0 ± 0.3	−0.5
Pacific	12. Honolulu*	1905–2009	105	105	1.5	1.5 ± 0.1	−0.2
North American West Coast	13. San Francisco	1880–2009	130	130	1.5	1.6 ± 0.1	−0.1
	14. Santa Monica ^b	1933–2009	77	67	1.4	1.4 ± 0.2	−0.2
	15. La Jolla ^c	1925–2009	85	78	2.1	2.1 ± 0.1	−0.3
	16. San Diego ^d	1906–2009	104	101	0.1–0.4 mm/yr		
Central America	17. Balboa*	1908–2003	96	95			
	18. Cristobal*	1909–1979	71	71	1.0	1.4 ± 0.1	−0.2
South America	19. Quequen*	1918–1982	65	64	0.8	0.9 ± 0.2	−0.1
	20. Buenos Aires*	1905–1987	83	83	1.5	1.6 ± 0.2	−0.5
South East	21. Pensacola	1924–2009	86	84	2.2	2.2 ± 0.2	−0.1
North America	22. Key West	1913–2009	97	96	2.2	2.3 ± 0.1	−0.1
	23. Fernandina	1898–2009	112	91	1.8	2.0 ± 0.1	−0.0

Obtaining a “global mean rate of sea level rise”

$$m = \frac{\sum_k r_k}{N_{tg}}$$

Arithmetic mean

“best estimate” of the GMSLR

$$rms = \sqrt{\frac{\sum_k (r_k - m)^2}{N_{tg} - 1}}$$

Root mean square

average uncertainty of individual trends

$$sdom = \frac{rms}{\sqrt{N_{tg}}}$$

Standard deviation of the mean

uncertainty of the best estimate m

$$wrms = \sqrt{\frac{\sum_k (r_k - m)^2 w_k}{\sum_k w_k}}$$

Weighted root mean square

uncertainty of the best estimate m

$$w_k = 1/\sigma_k^2$$

Global mean sea level rise:

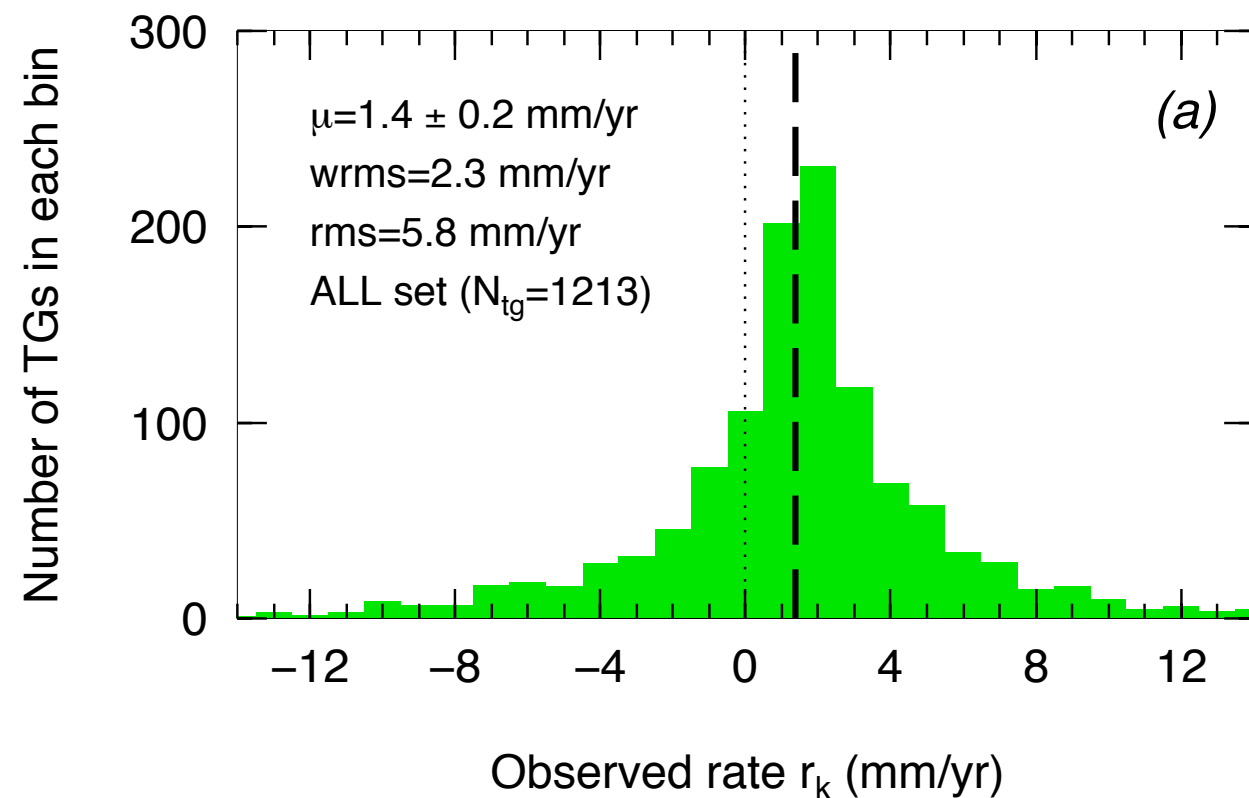
$$\mu = m \pm sdom$$

$$(rsm = \dots, wrms = \dots)$$

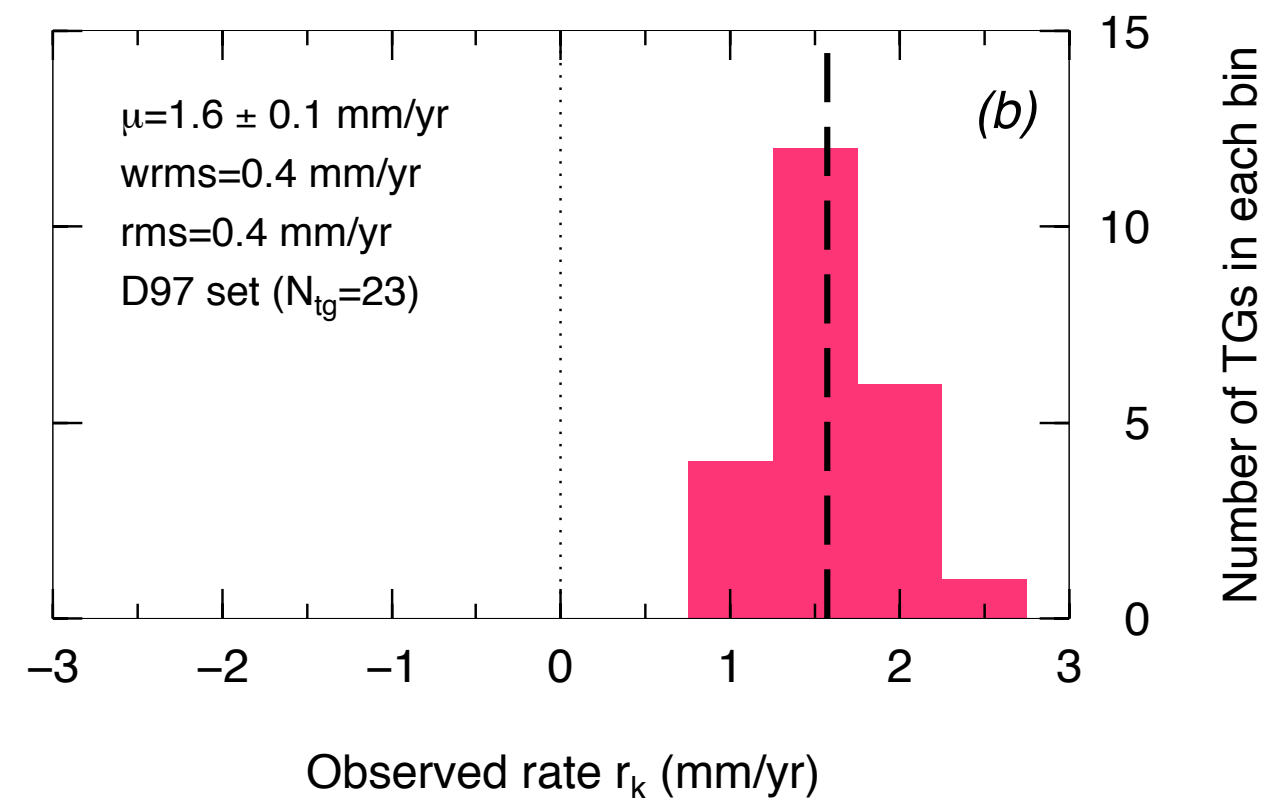
see Taylor

A first guess

ALL
(1123)



D97
(23)



$$\mu = 1.4 \pm 0.2 \text{ mm/yr}$$

$$rms \approx 6 \text{ mm/yr}$$

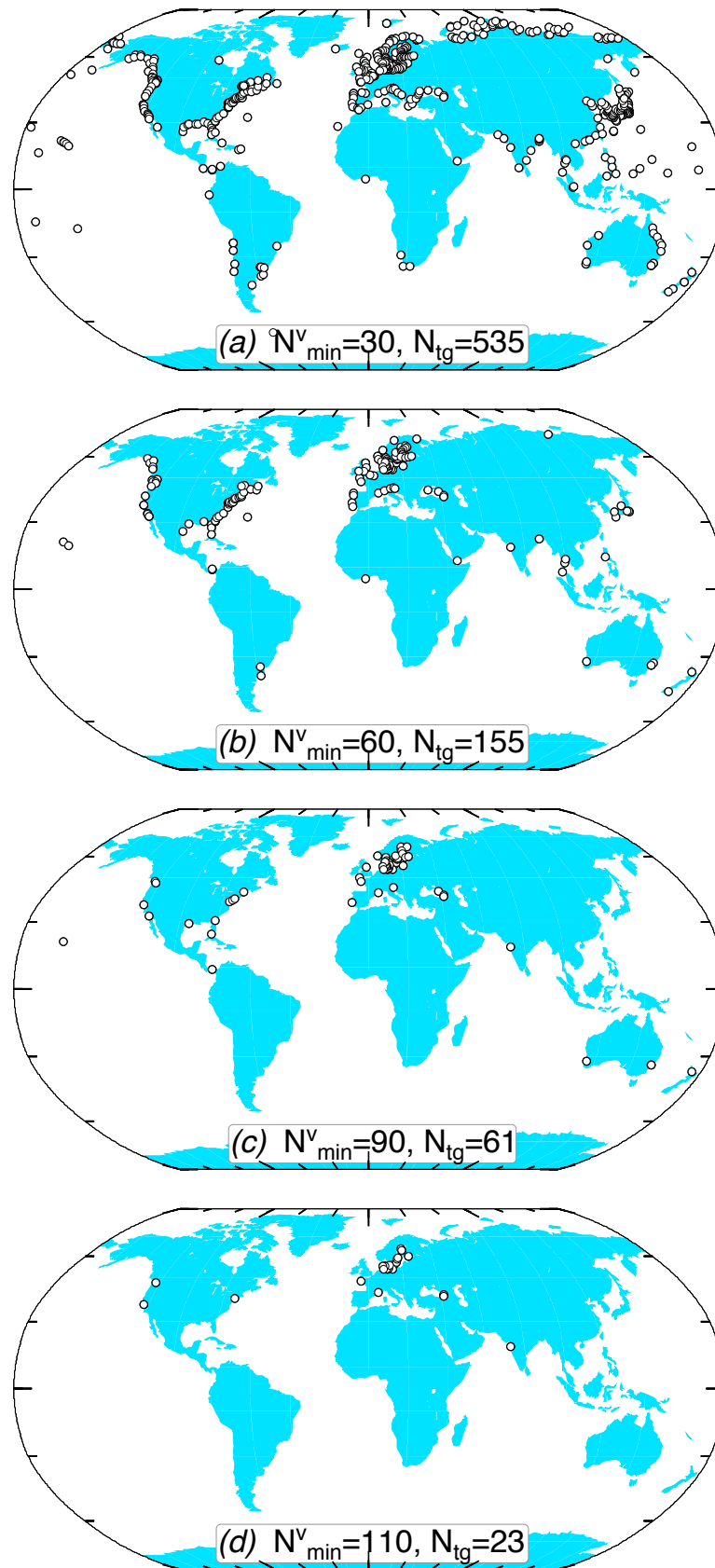
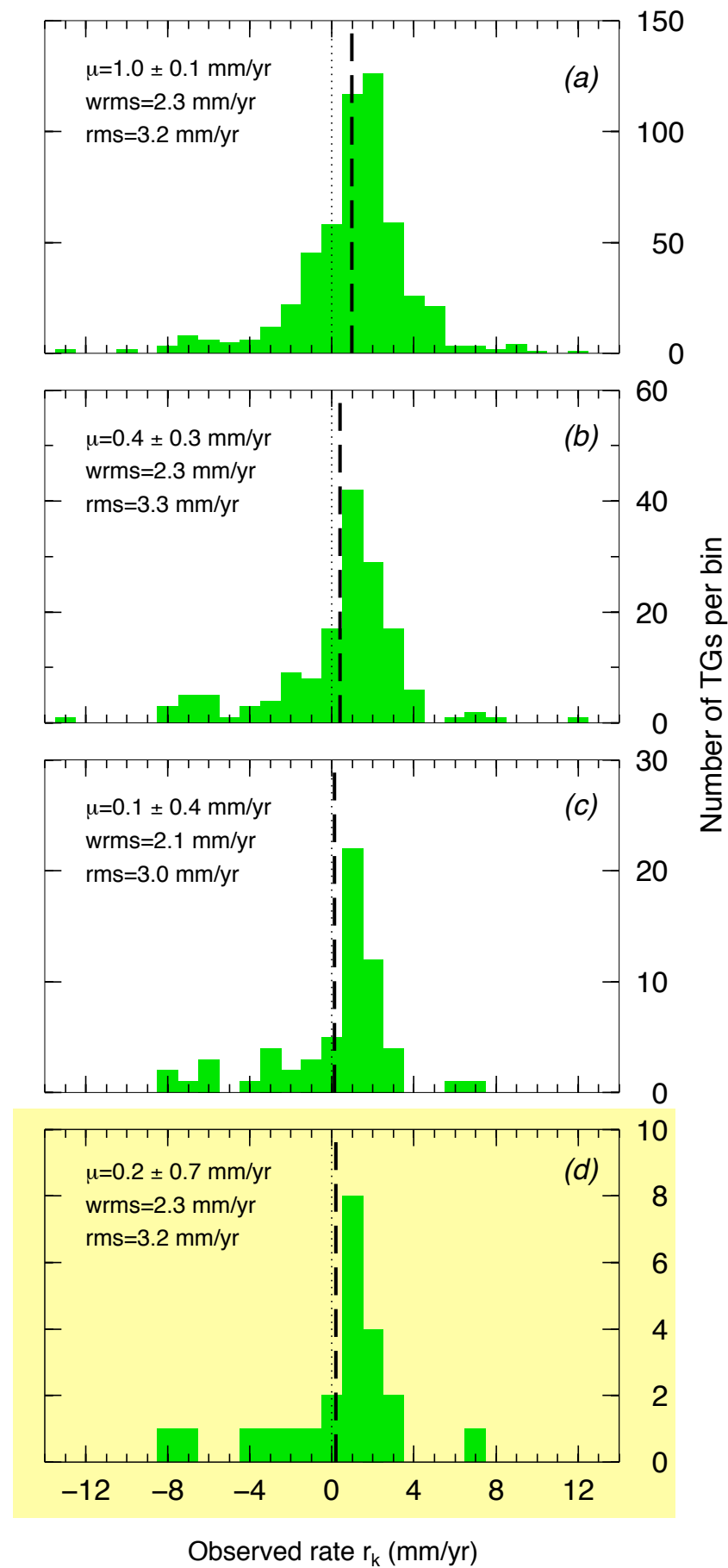
$$\mu = 1.6 \pm 0.1 \text{ mm/yr}$$

$$rms \approx 0.5 \text{ mm/yr}$$

Decimation of TGs according to the length criterion

The minimum number of valid years increases

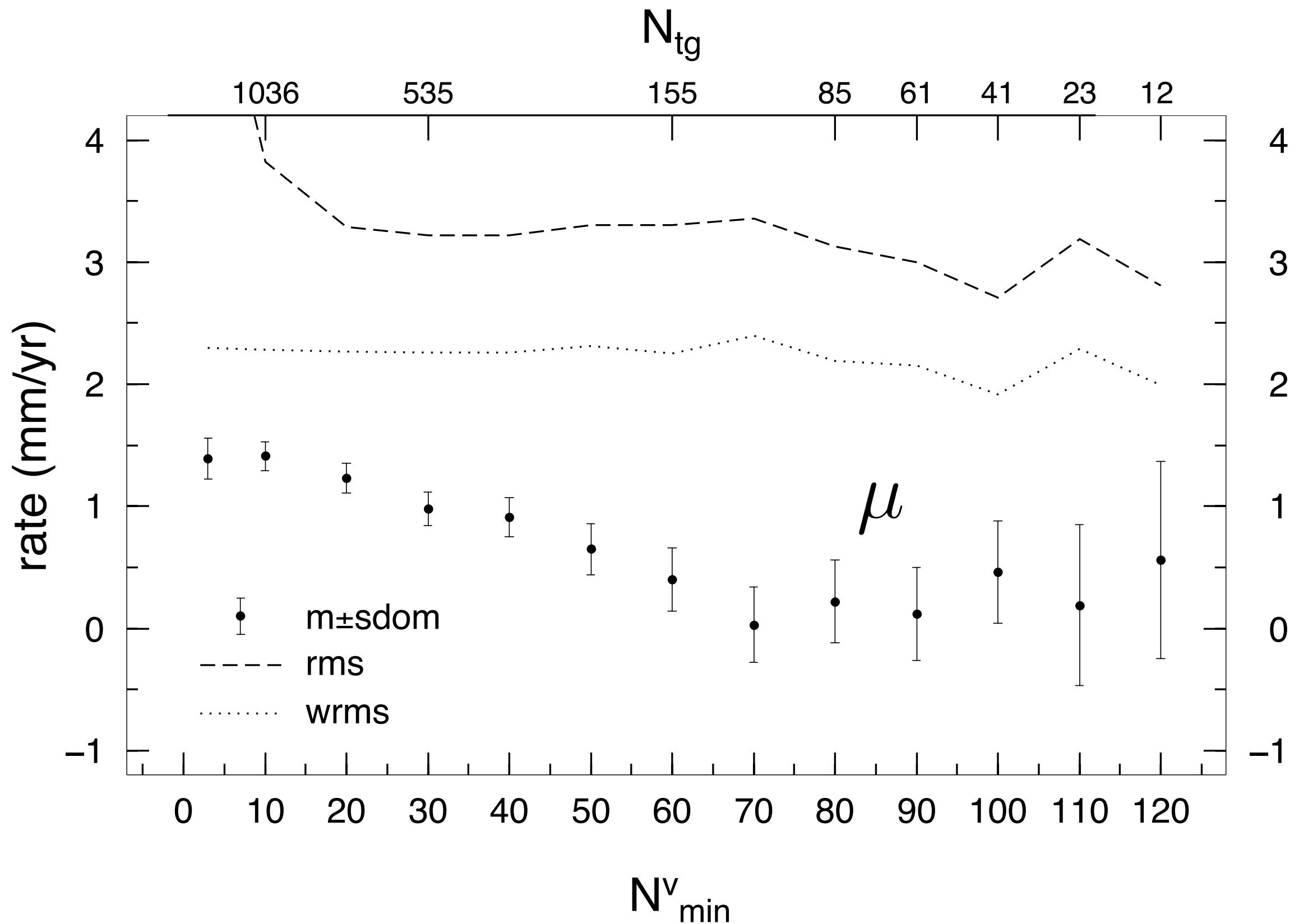
The number of TGs decreases



The rms does NOT vary

The SDOM increases

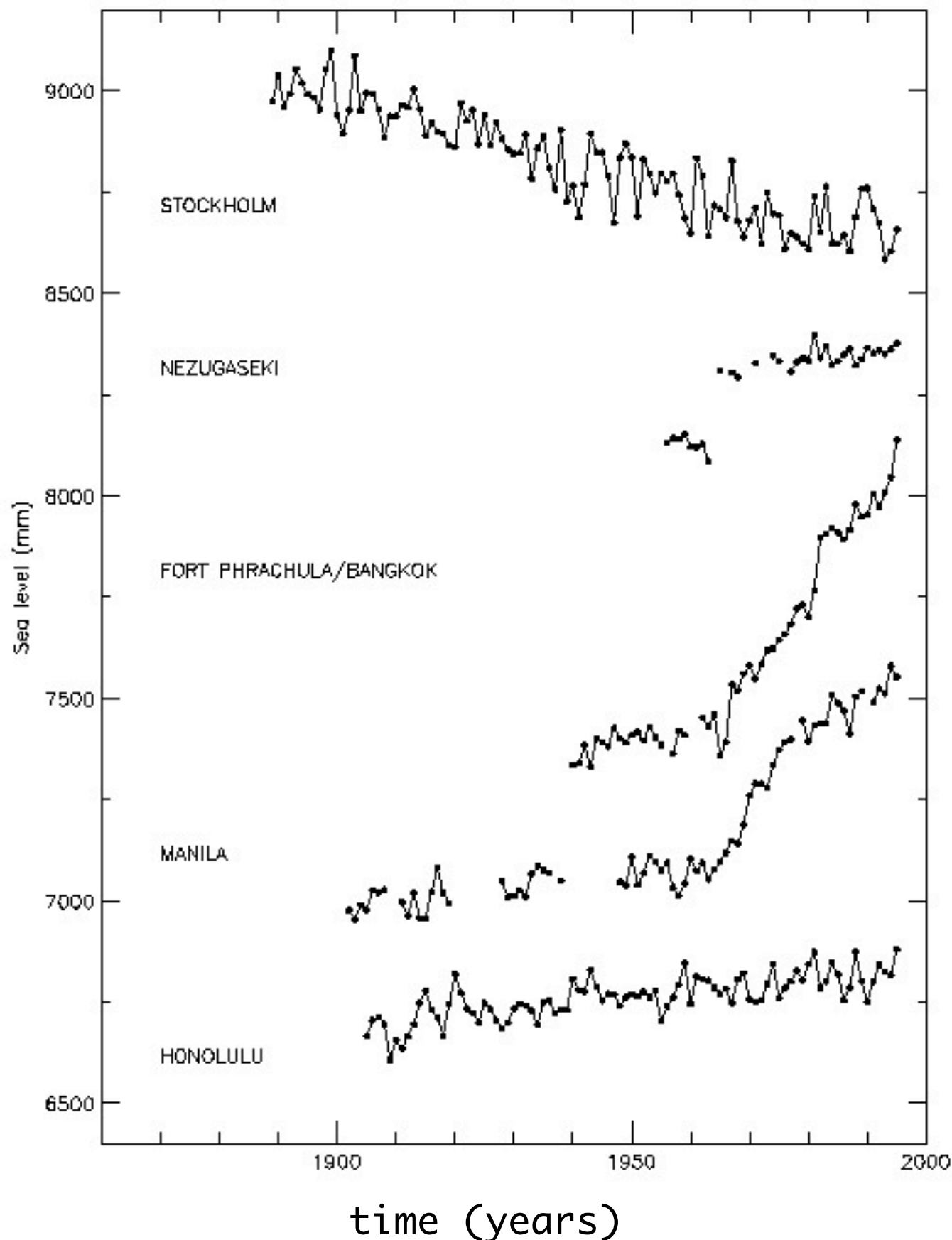
Decimation of TGs according to the length criterion



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“we do not believe any land to be completely stable”



This figure demonstrates signals from vertical land movements due to a number of different geological processes: Stockholm, Sweden as above (sea level fall due to Glacial Isostatic Adjustment), Nezugaseki, Japan (abrupt jump in sea level record following earthquake in 1964), Fort Phrachula Bangkok, Thailand (sea level rise due to increased groundwater extraction since about 1960), Manila, Philippines (recent deposit from river discharges and reclamation works) and Honolulu, Hawaii (a site in the PGR 'far field' without evident strong tectonic signals on timescales comparable to the length of the tide gauge record and with secular trend 1.5 mm/year).

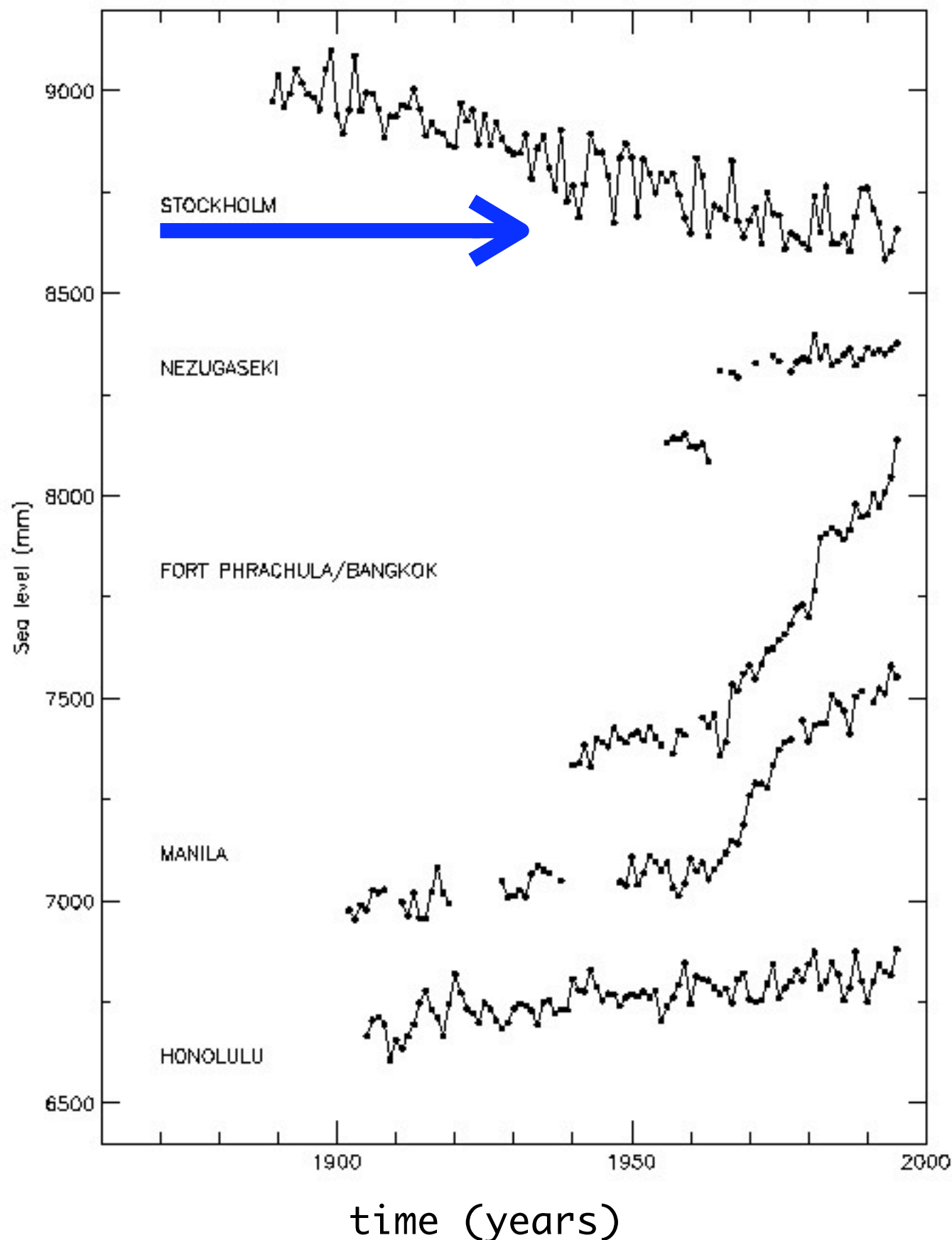
(The Honolulu record is shown above incidentally for some sort of comparison only. It should not be interpreted as suggesting the Hawaiian islands to be completely 'stable', as is obvious from their volcanic history. Similar comments would apply to other far field sites with long records but for different geological reasons depending on the location; in brief,

we do not believe any land to be completely 'stable',

which is the main motivation for interest in measuring vertical land movements.)

<http://www.pol.ac.uk/psmsl/landmove.html>

“we do not believe any land to be completely stable”



This figure demonstrates signals from vertical land movements due to a number of different geological processes: Stockholm, Sweden as above (sea level fall due to Glacial Isostatic Adjustment), Nezugaseki, Japan (abrupt jump in sea level record following earthquake in 1964), Fort Phrachula Bangkok, Thailand (sea level rise due to increased groundwater extraction since about 1960), Manila, Philippines (recent deposit from river discharges and reclamation works) and Honolulu, Hawaii (a site in the PGR 'far field' without evident strong tectonic signals on timescales comparable to the length of the tide gauge record and with secular trend 1.5 mm/year).

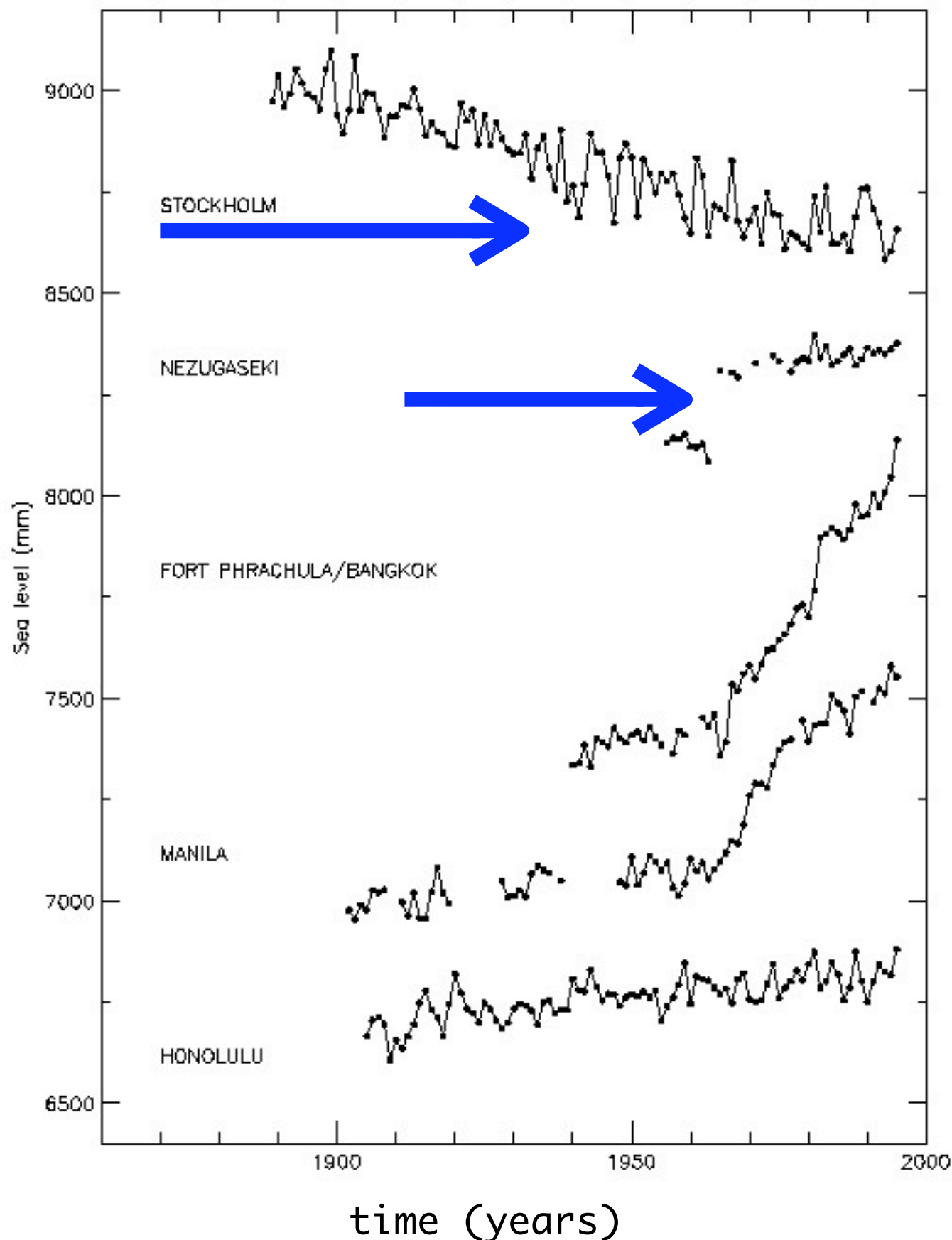
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<http://www.pol.ac.uk/psmsl/landmove.html>

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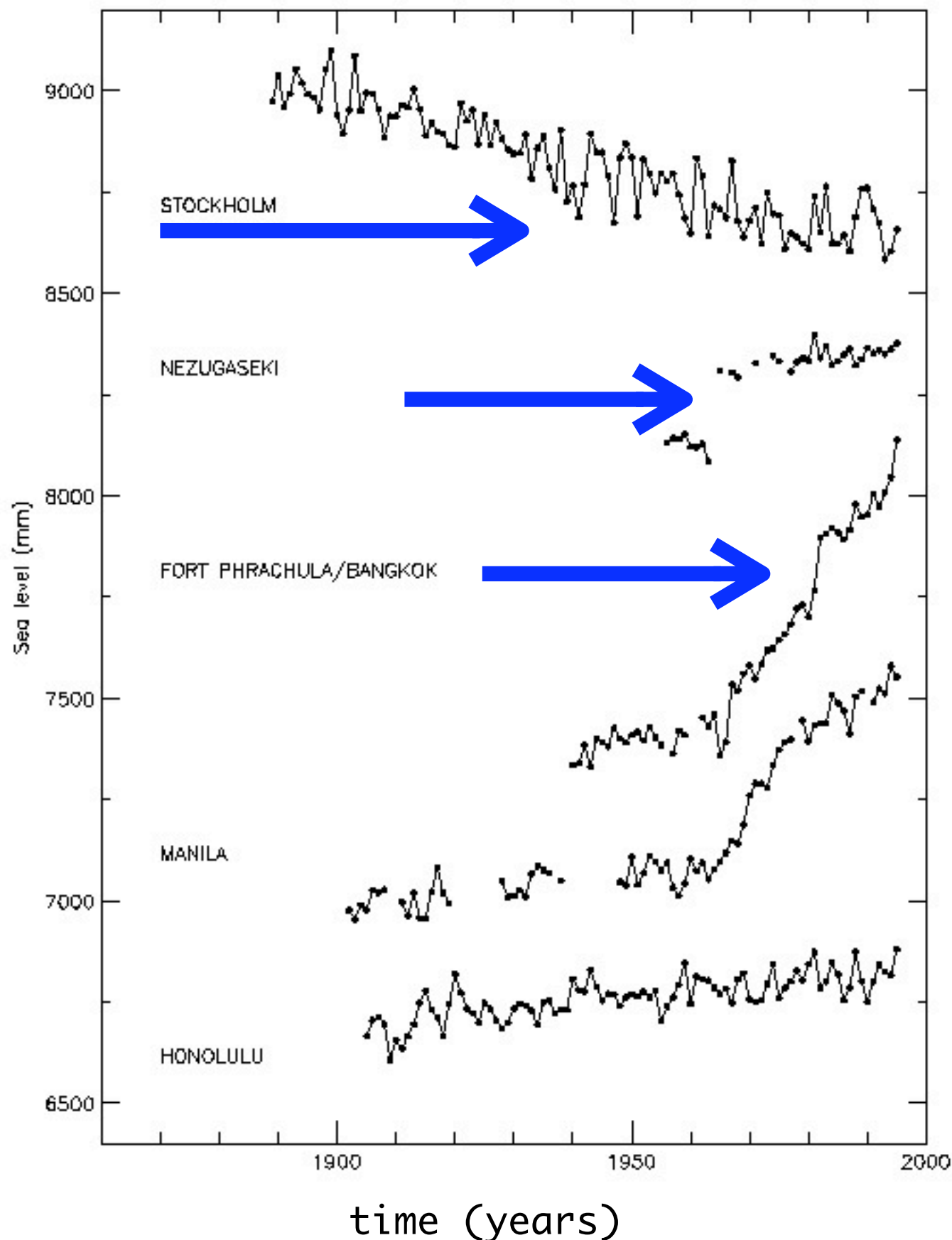
(The Honolulu record is shown above incidentally for some sort of comparison only. It should not be interpreted as suggesting the Hawaiian islands to be completely 'stable', as is obvious from their volcanic history. Similar comments would apply to other far field sites with long records but for different geological reasons depending on the location; in brief,

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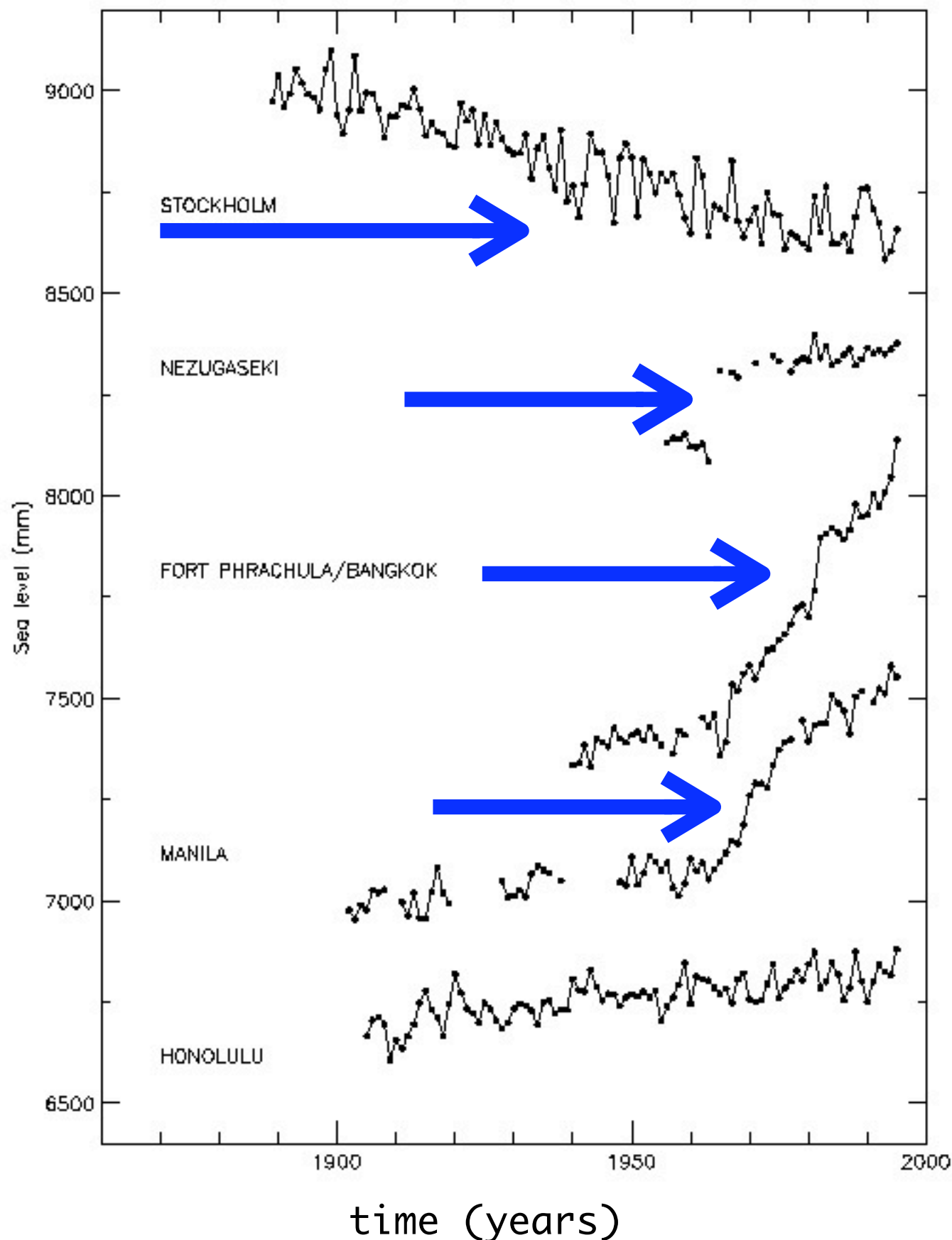
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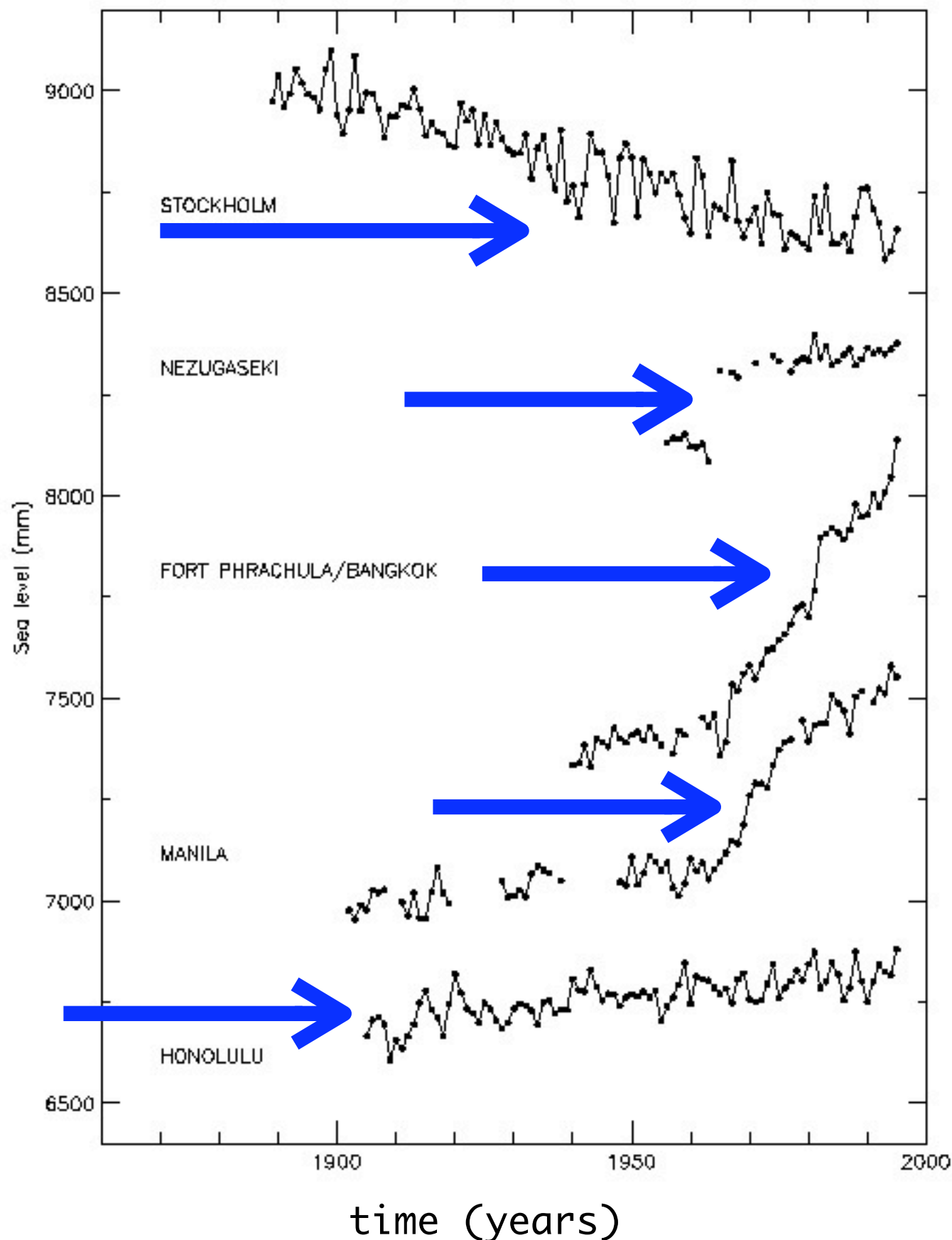
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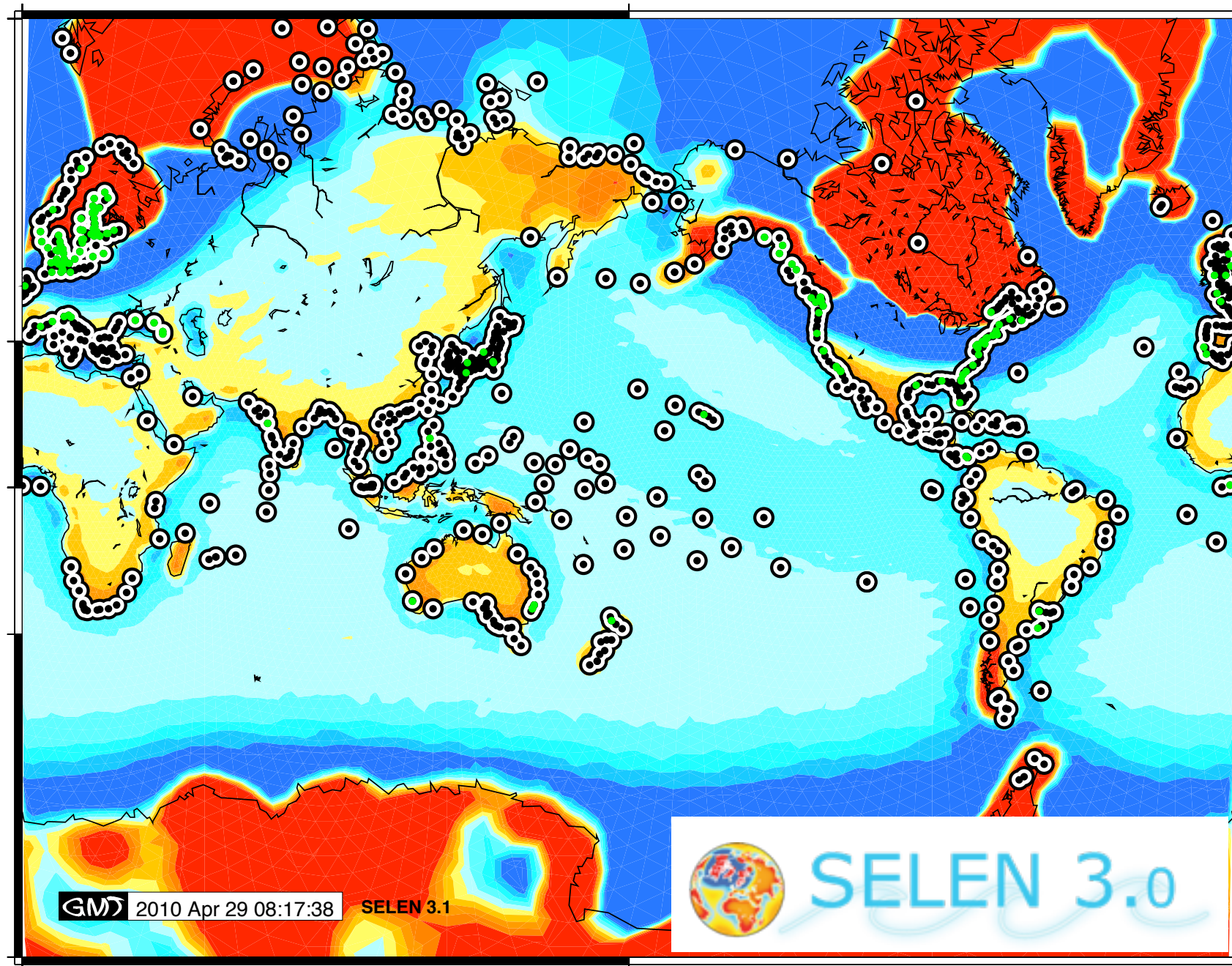
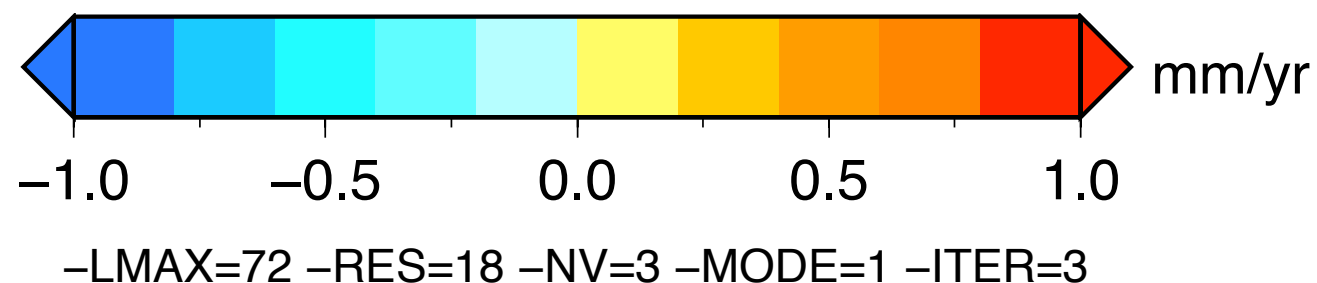
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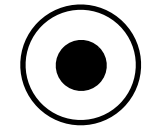
<http://www.pol.ac.uk/psmsl/landmove.html>

Rate of vertical displacement today

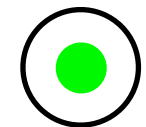
–Ice model: ICE5G –ALMA rheology: ./VSC/vsca_BENCH.dat



All PSMSL tide gauges
(~ 1200)



All PSMSL tide gauges
with $T > 60$ years
(~ 140)

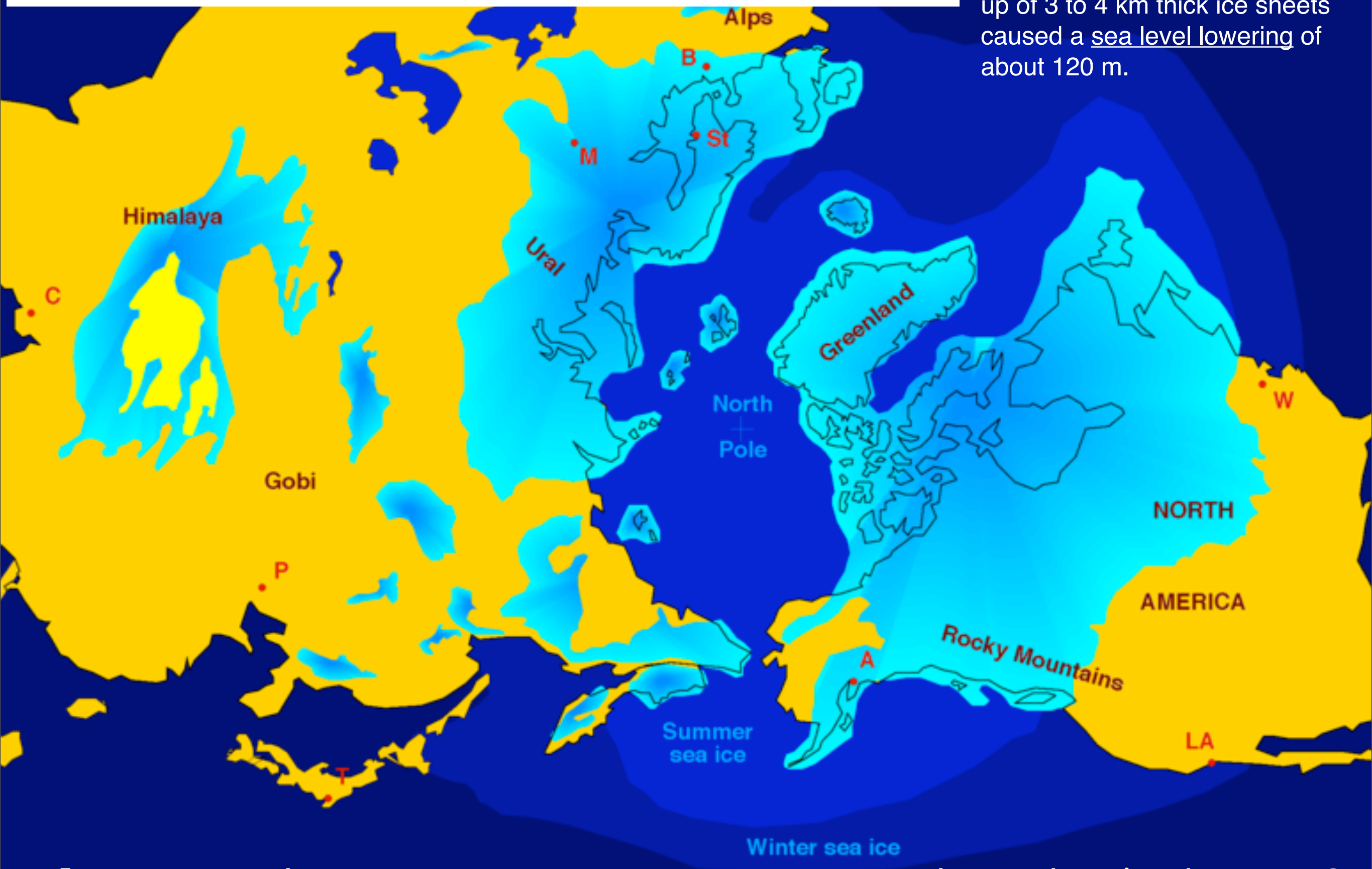


Most (all?) tide gauges
are in regions of
considerable
GIA disequilibrium

(formerly)
ICE COVERED areas
&
forebulge regions

Last Glacial maximum (~ 21 kyrs BP)

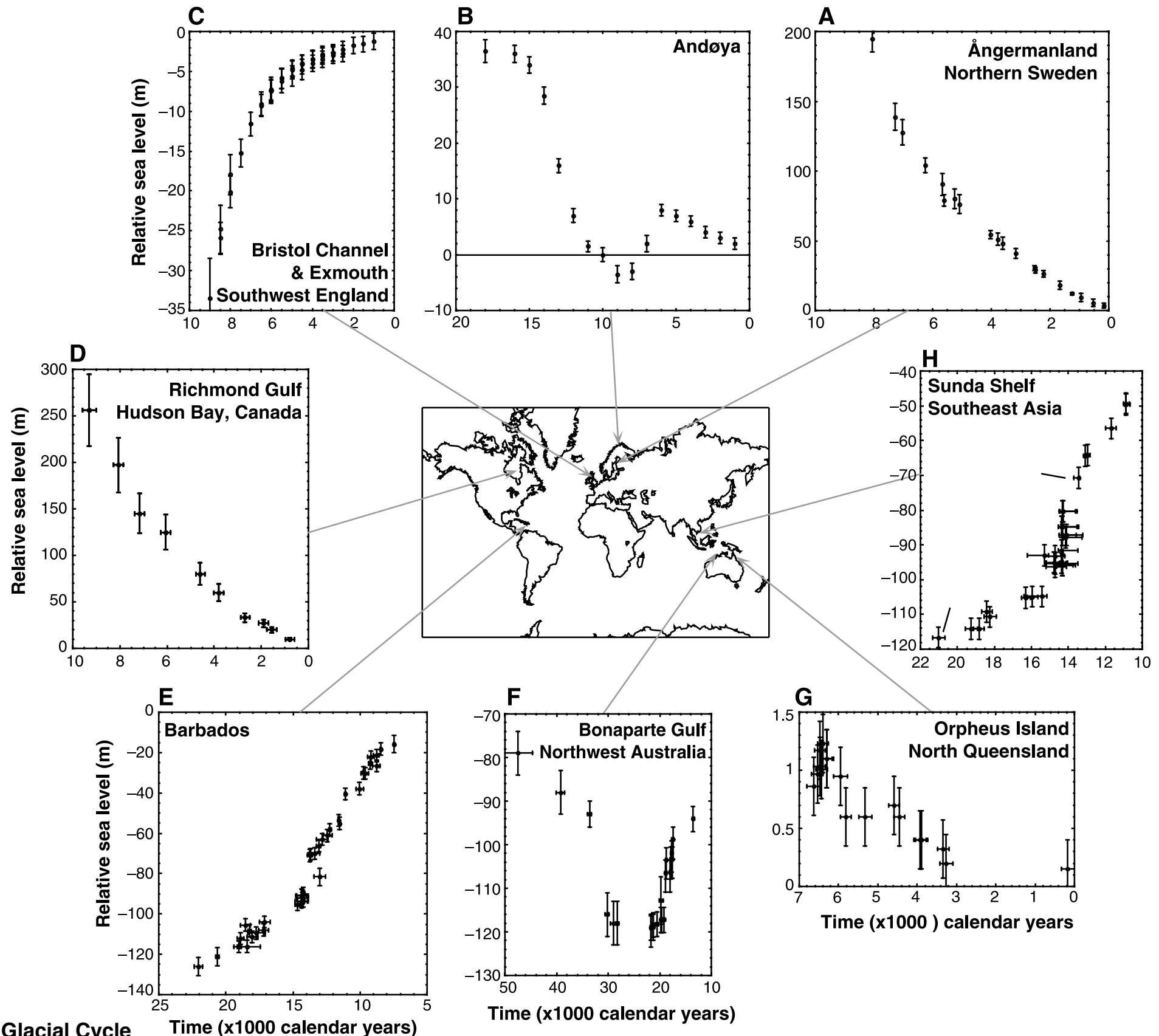
Northern hemisphere glaciation during the last ice ages. The set up of 3 to 4 km thick ice sheets caused a sea level lowering of about 120 m.



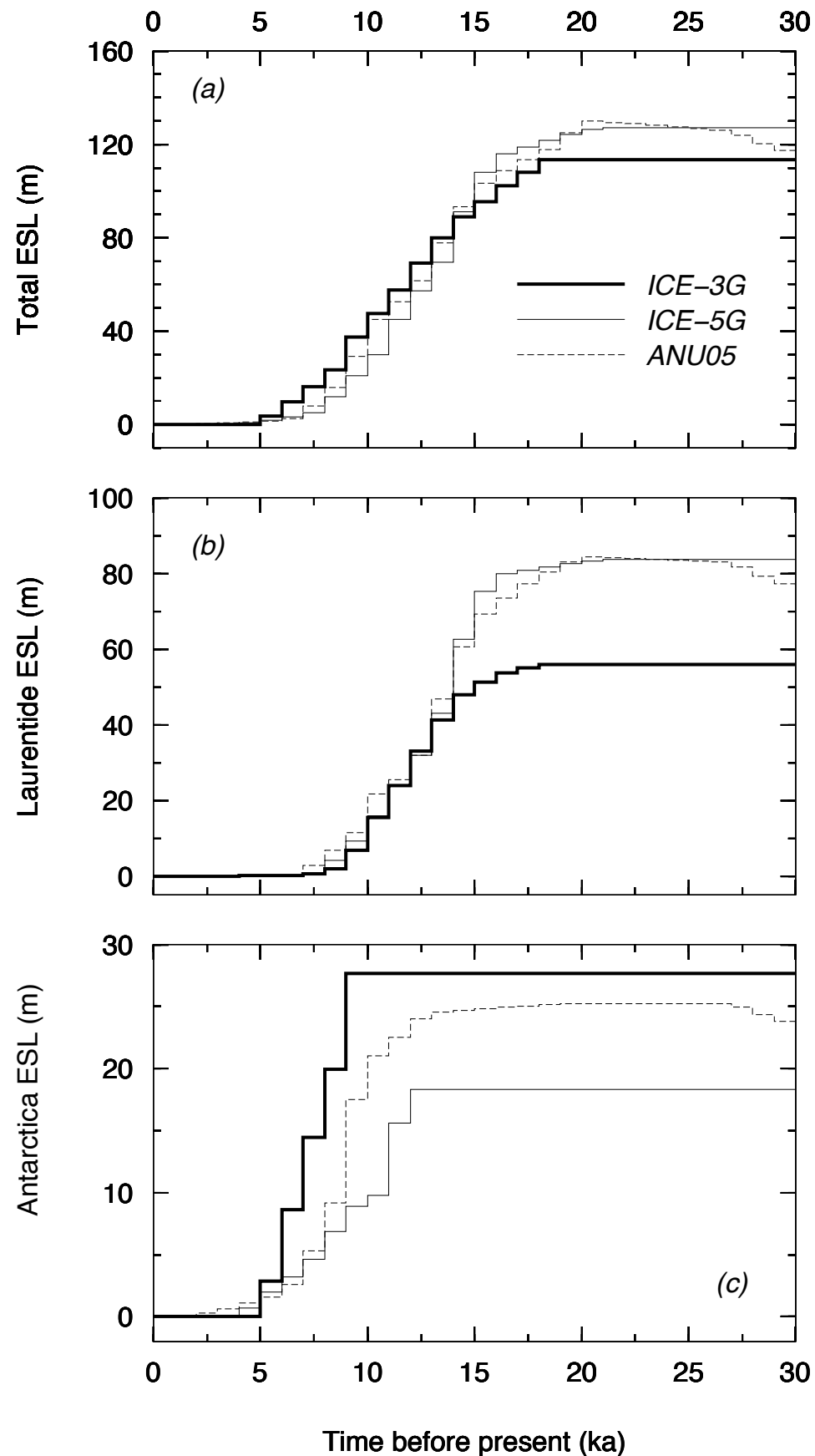
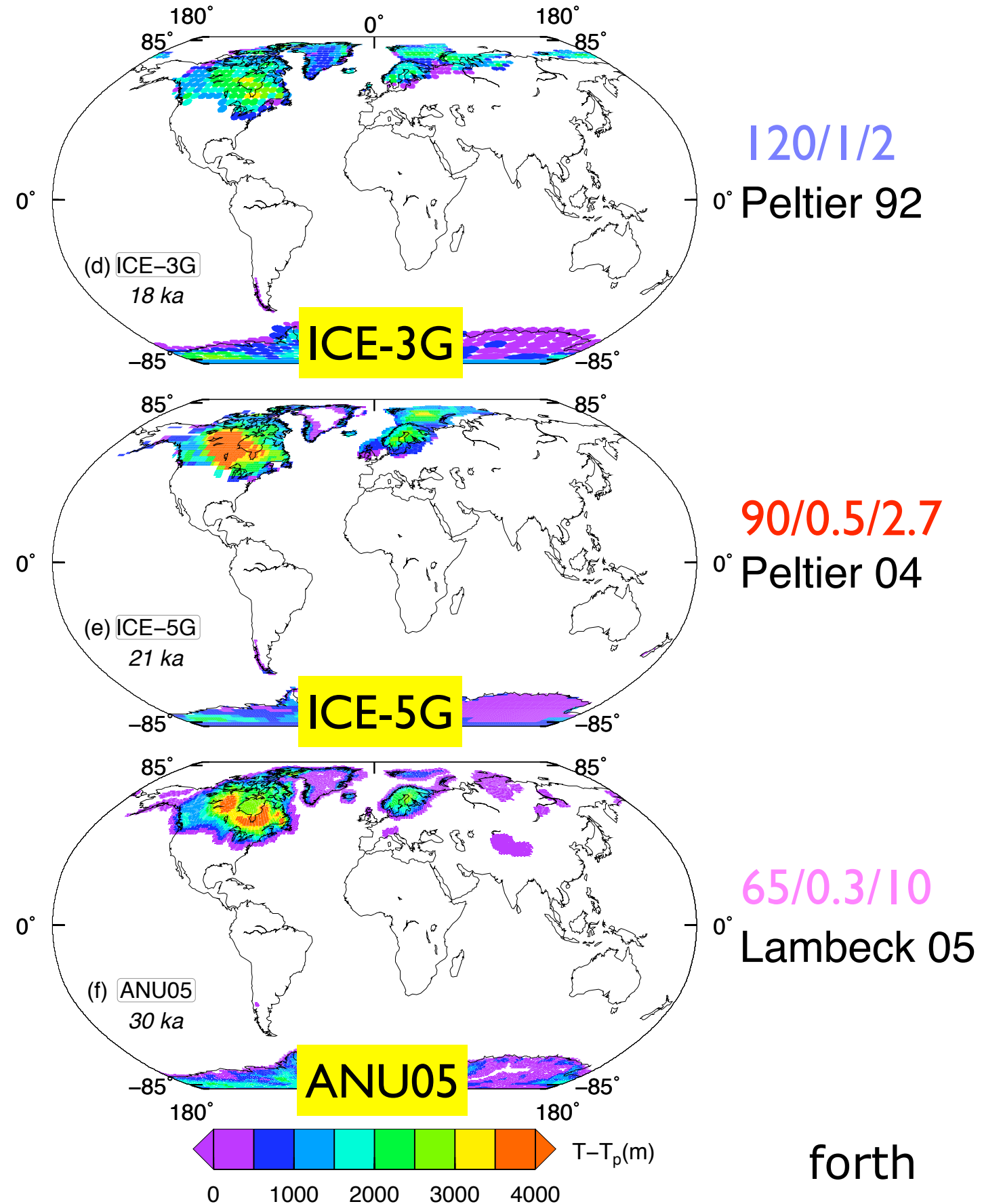
Paleogeography

northern hemisphere LGM

Fig. 2. Observed spatial variability of sea level change since the time of the LGM from tectonically stable areas or areas where the tectonic rate is known and has been removed from the observed signal. (A) Ångerman, Gulf of Bothnia, Sweden (13). (B) Andøya, Nordland, Norway (12). (C) South of England (14). (D) Hudson Bay, Canada (4). (E) Barbados (16–18). (F) Bonaparte Gulf, northwest Australia (27). (G) Orpheus Island, North Queensland, Australia [(23) and unpublished Australian National University data]. (H) Sunda Shelf, southeast Asia (15). Note the different time and amplitude scales. In the examples illustrated, all observed depths or elevations of the sea level indicators have been reduced to mean sea level. All time scales are in calendar years.



A GIA-independent sea-level correction?



Summary of relevant equations for GIA modeling

Farrell (1976) has shown that the “original” SLE:

$$S = N - U$$

can be transformed into:

$$S = \frac{\rho_i}{\gamma} G_s \otimes_i I + \frac{\rho_w}{\gamma} G_s \otimes_o S - \frac{m_i}{\rho_w A_o} - \frac{\rho_i}{\gamma} \overline{G_s \otimes_i I} - \frac{\rho_w}{\gamma} \overline{G_s \otimes_o S}$$

with:

S = sea level change

m_i = ice mass variation

ρ_i, ρ_w = ice and water density

A_o = area of the oceans

G_s = sea level Green function

$\otimes_i, \otimes_o$ = 3(2+1)D convolutions

I = ice thickness variation

$\overline{(\dots)}$ = ocean average

Summary of relevant equations for GIA modeling

$$S(\omega, t) = S^{gi} + S^e + S^{hi} \quad \text{\textit{Sea Level Equation}}$$

Glacial Isostasy S^{gi}

Hydro Isostasy S^{hi}

Eustasy S^e

functions of (θ, λ, t)

function of t

Summary of relevant equations for GIA modeling

$$S(\omega, t) = S^{gi} + S^e + S^{hi}$$

Sea Level Equation

Glacial Isostasy S^{gi}

Hydro Isostasy S^{hi}

functions of (θ, λ, t)

Eustasy S^e

function of t

$$S^e(t) = -\frac{m_i(t)}{\rho_w A_o}$$

Eustatic term

Summary of relevant equations for GIA modeling

$$S(\omega, t) = S^{gi} + S^e + S^{hi}$$

Sea Level Equation

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Eustatic term

$$\overline{S} = S^e$$

*a remarkable property of the
ocean averaged sea level*

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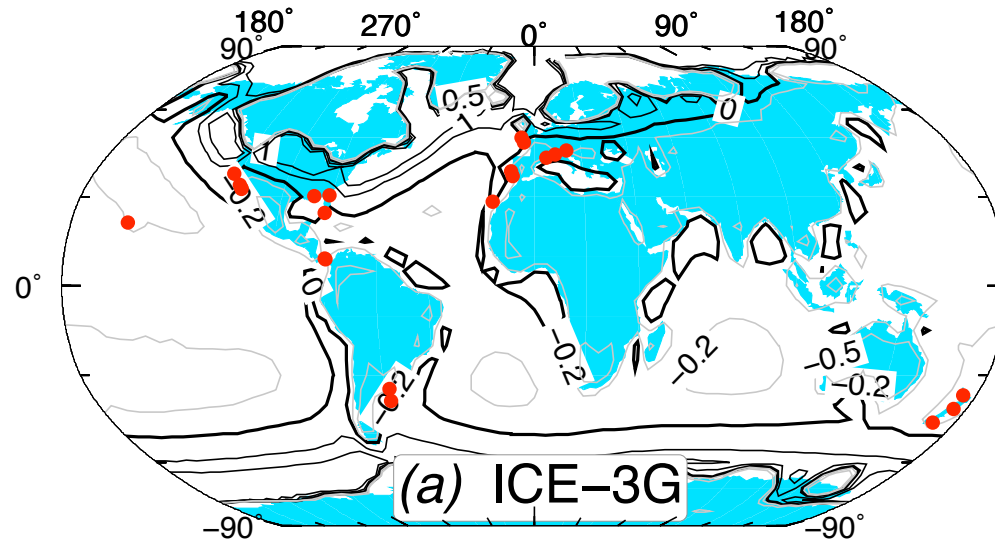
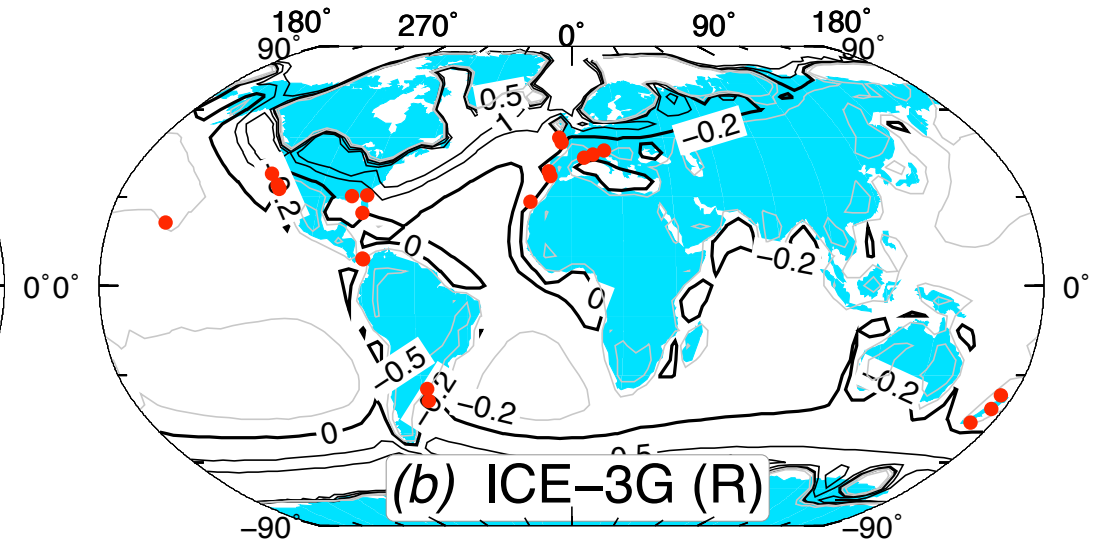
$$\overline{S} = 0$$

*the GIA sea level change is
zero ON AVERAGE if there is
no mass exchange*

Present-day GIA rate of sea level change

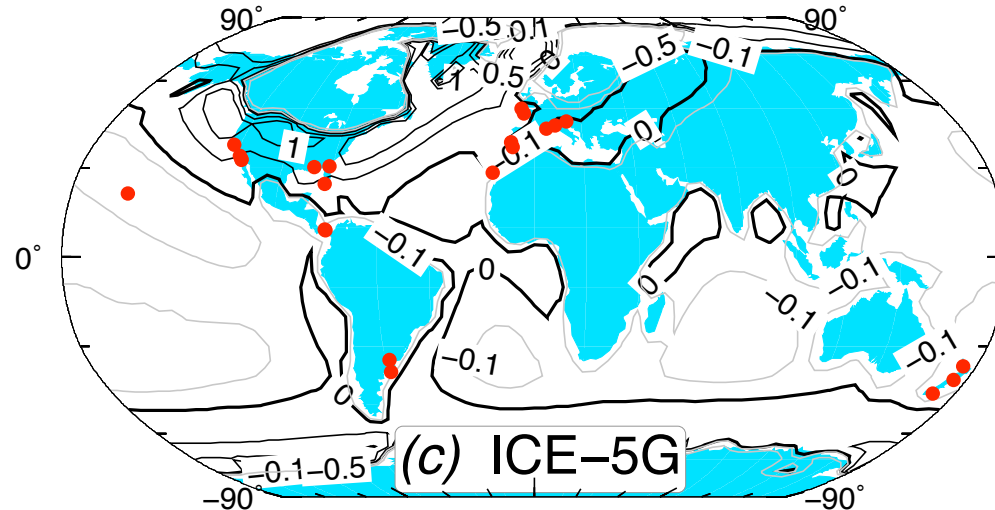
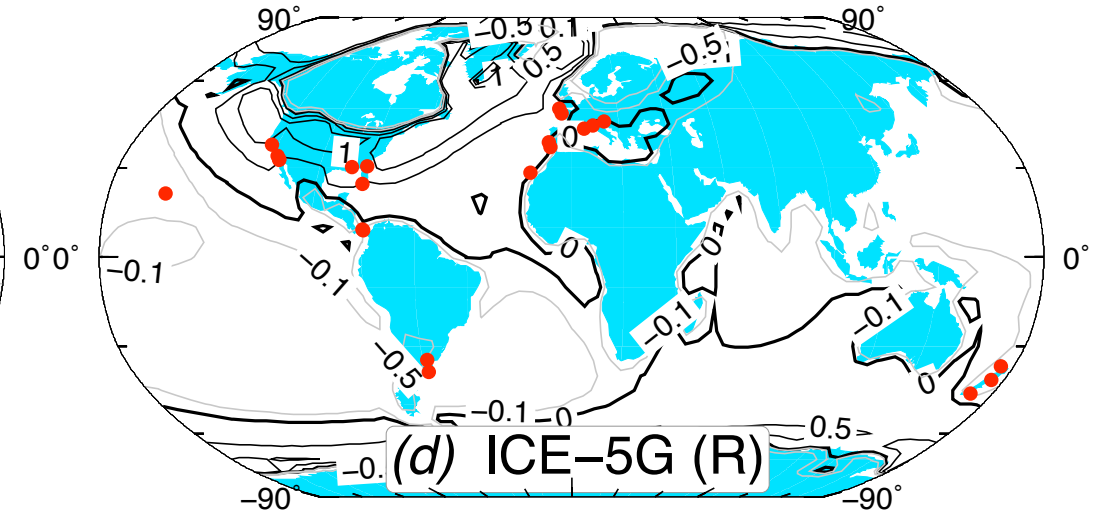
ICE-3G

120/1/2



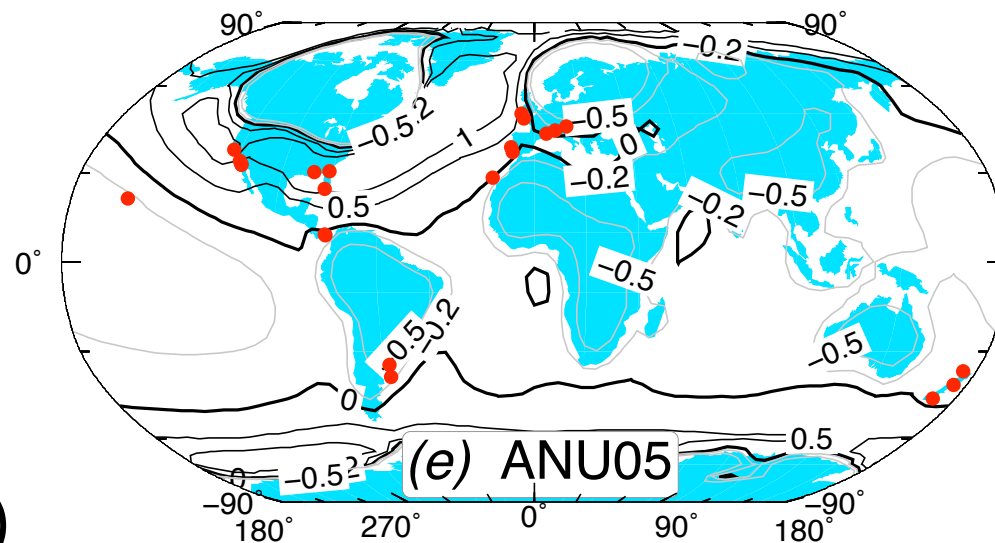
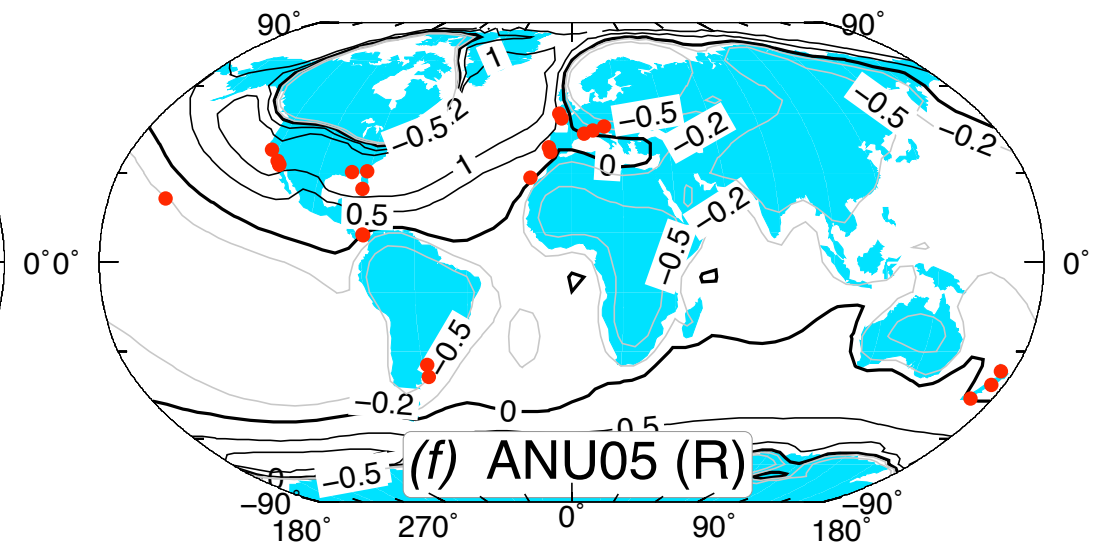
ICE-5G

90/0.5/2.7



ANU05

65/0.3/10



● D97 (23)

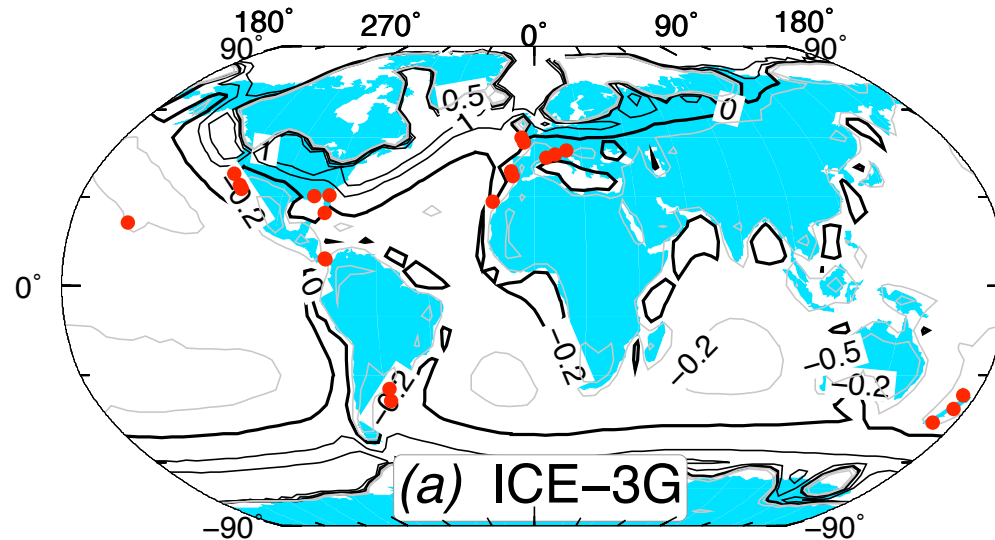
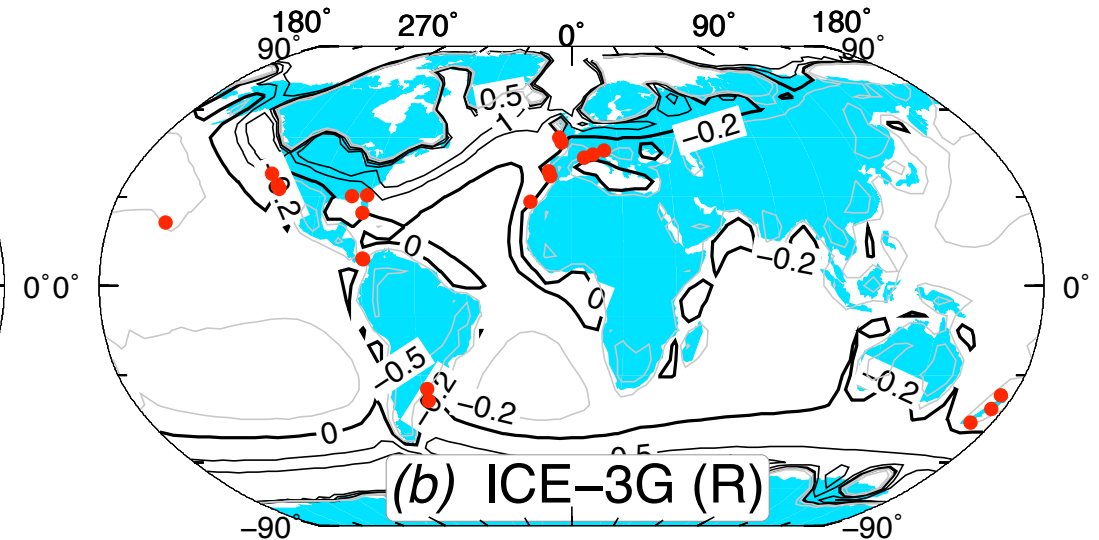
Rotational FB OFF

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Present-day GIA rate of sea level change

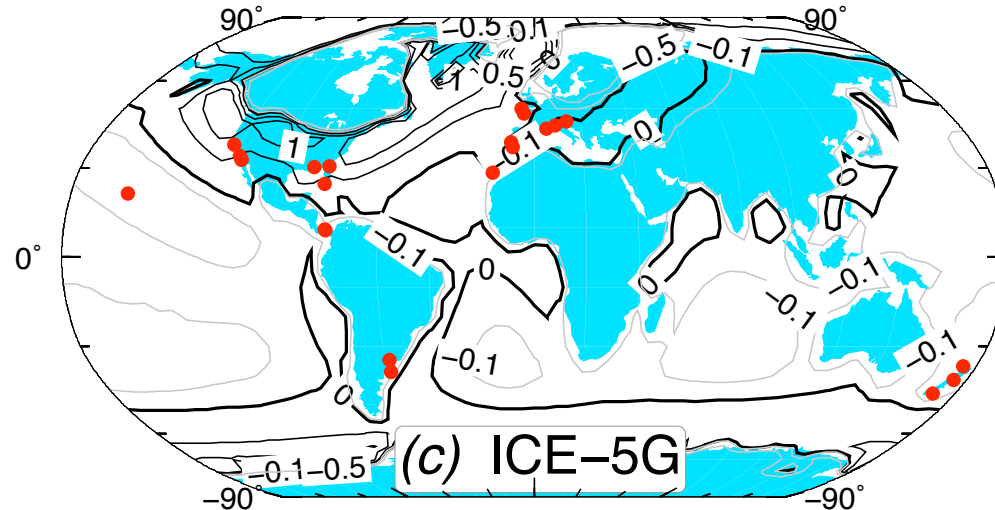
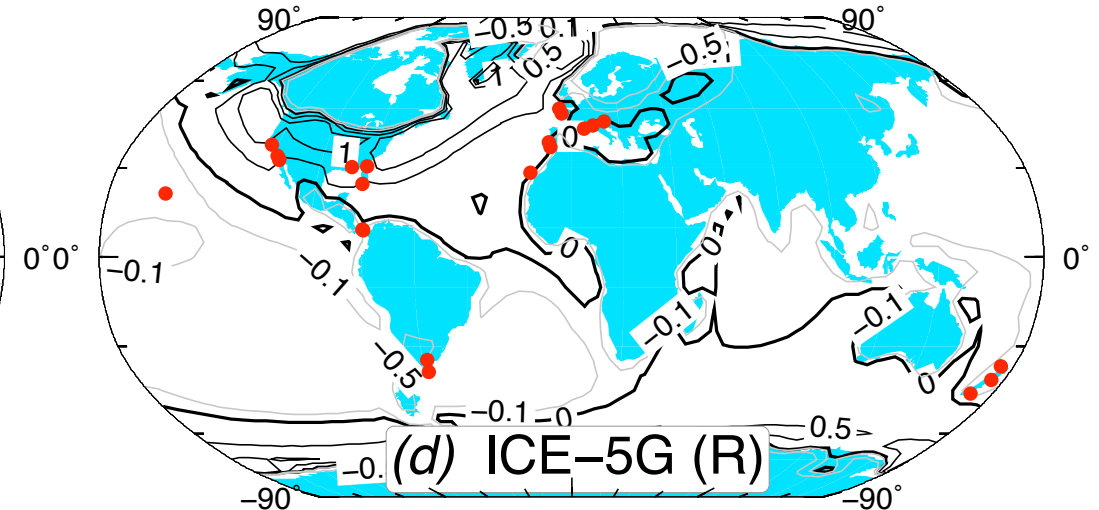
ICE-3G

120/1/2



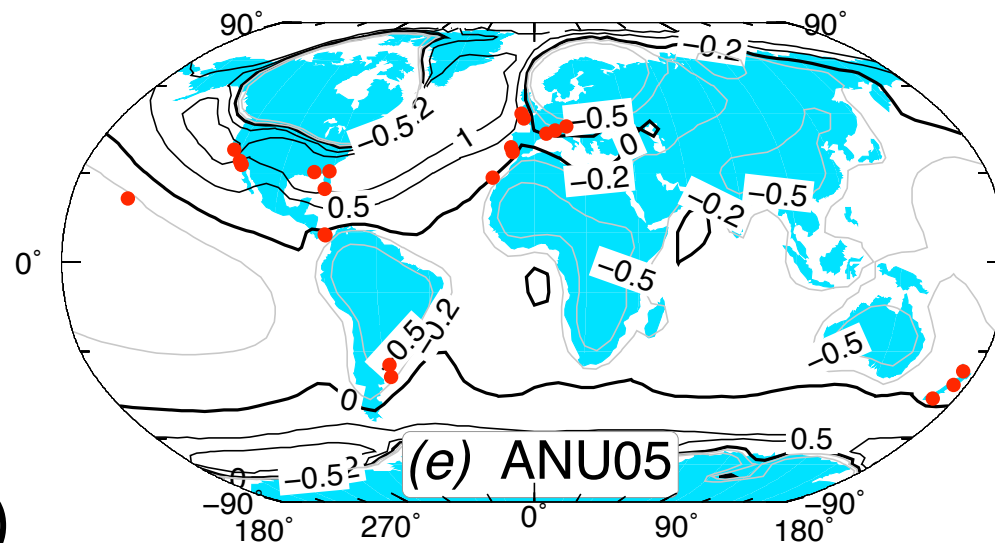
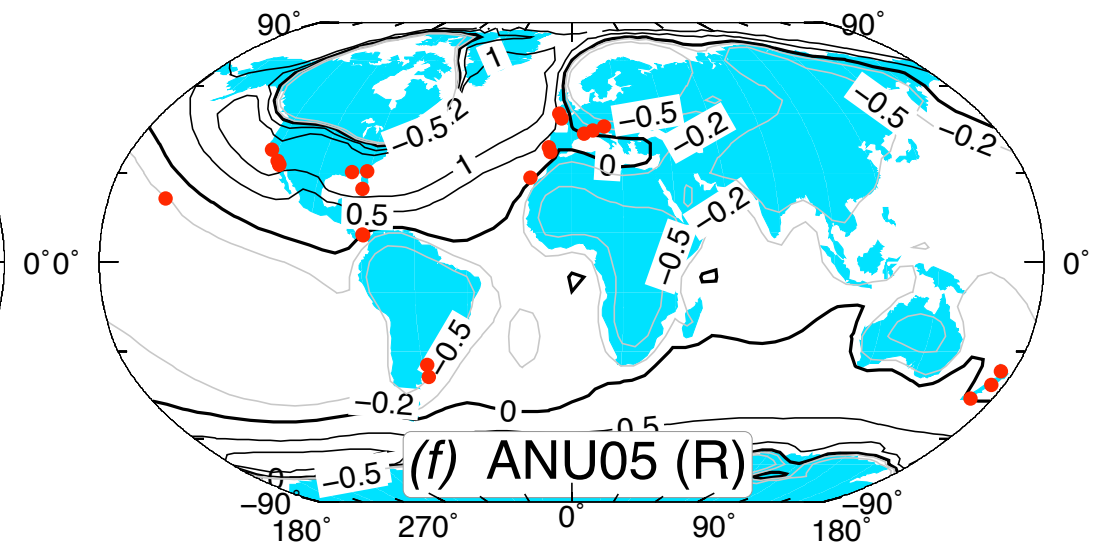
ICE-5G

90/0.5/2.7



ANU05

65/0.3/10



● D97 (23)

Rotational FB OFF

Rotational FB ON

GIA corrections at tide-gauges

$$r'_k = r_k - r_k^{gia} \quad \text{Corrected trend}$$

$$r_k^{gia} = \frac{dS}{dt}(\theta_k, \lambda_k, t) \quad \text{GIA correction definition}$$

$$\rho'_k = r'_k \pm \sigma_k$$

*Corrected trend with
uncertainty , assuming "exact"
knowledge of GIA effects*

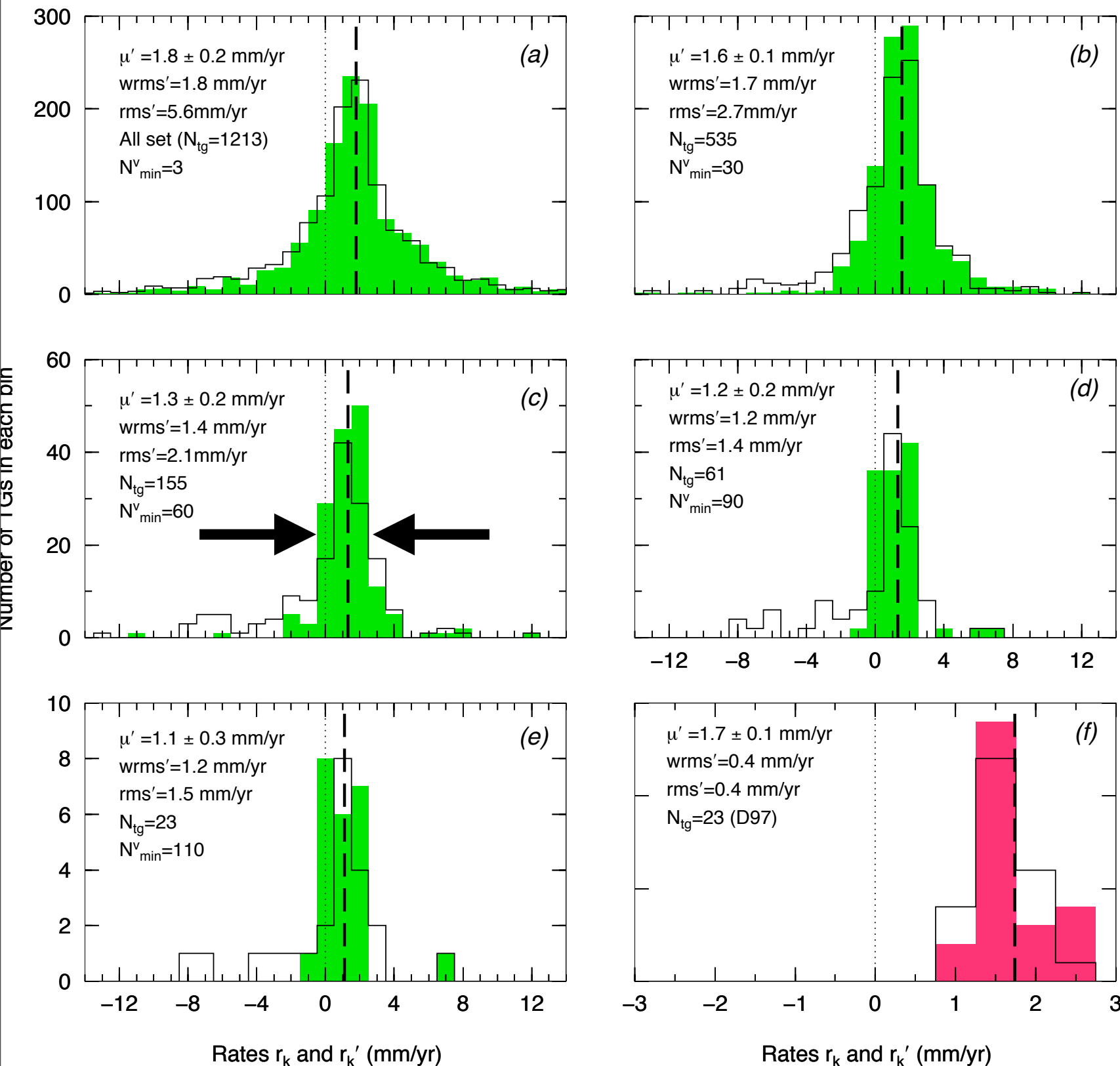
$$m' = m - \frac{1}{N_{tg}} \sum_{k=1}^{N_{tg}} r_k^{gia} \quad \text{Corrected GMSLR}$$

$$m' = m$$

*Ideal case of a uniformly
spaced grid of TGs across the
oceans*

Decimation of TGs according to the length criterion

GIA correction by ICE-3G



1.

$$\mu' = 1.7 \pm 0.1 \text{ mm/yr}$$

D97 (23)

vs

$$\mu' = 1.8 \pm 0.1 \text{ mm/yr}$$

(original D97 data)

a slight sea level *de*celeration?

2.

$$\mu' = 1.1 \pm 0.3 \text{ mm/yr}$$

from the 23 longest records (N Europe)

ASSUMES
 GIA modeling is precise
 to the ~ 0.5 mm/yr level
 in *de*-glaciated areas

Contents:

- 1). Motivations, previous work, relevance
- 2). Data: RLR tide gauge (TG) observations since 1880
- 3). Obtaining sea level trends from TG time series
- 4). Corrections in general and GIA corrections
- 5). Some new estimates of the secular sea level rise**
- 6). Outlook

“Forebulge dilemma”

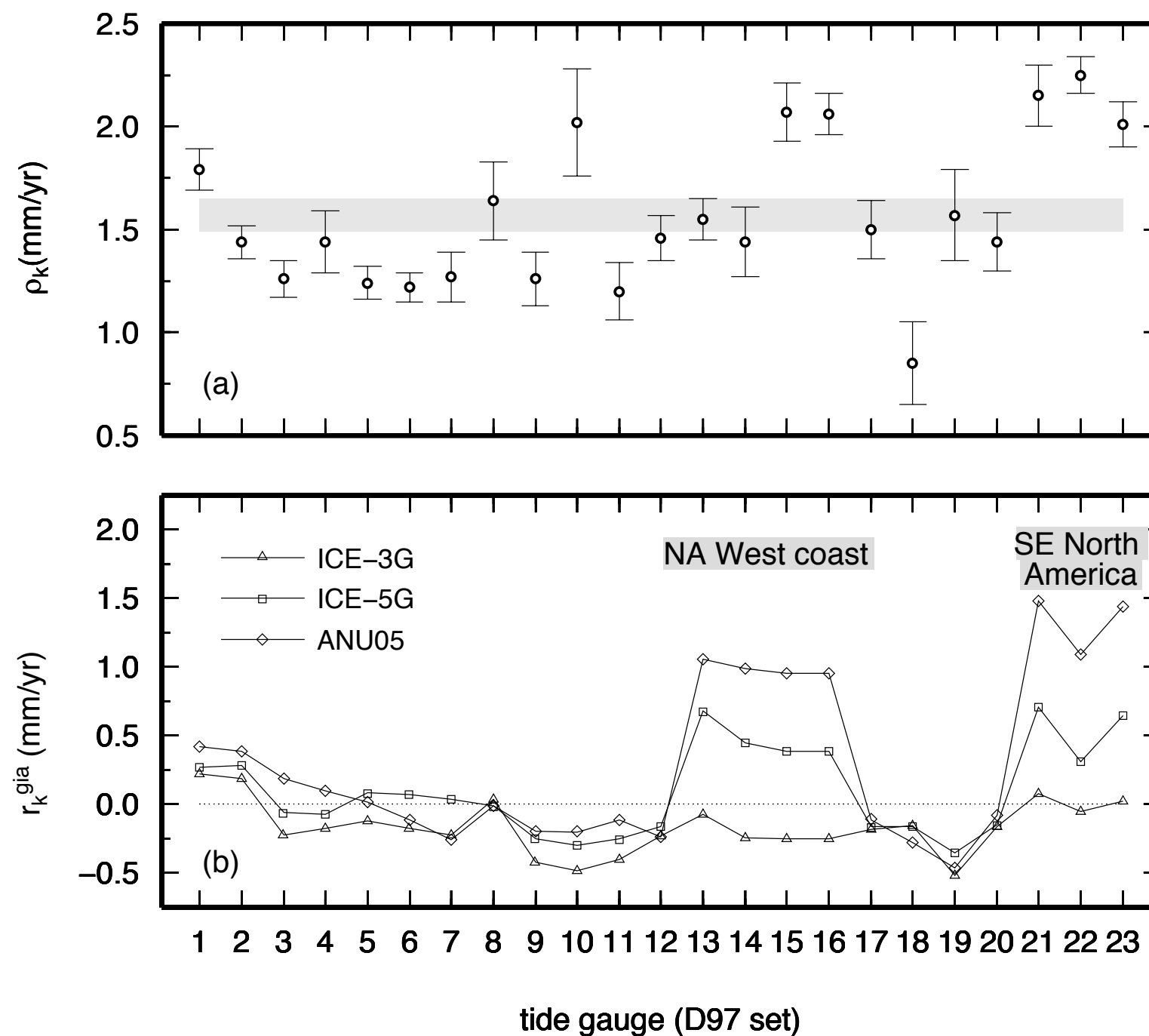
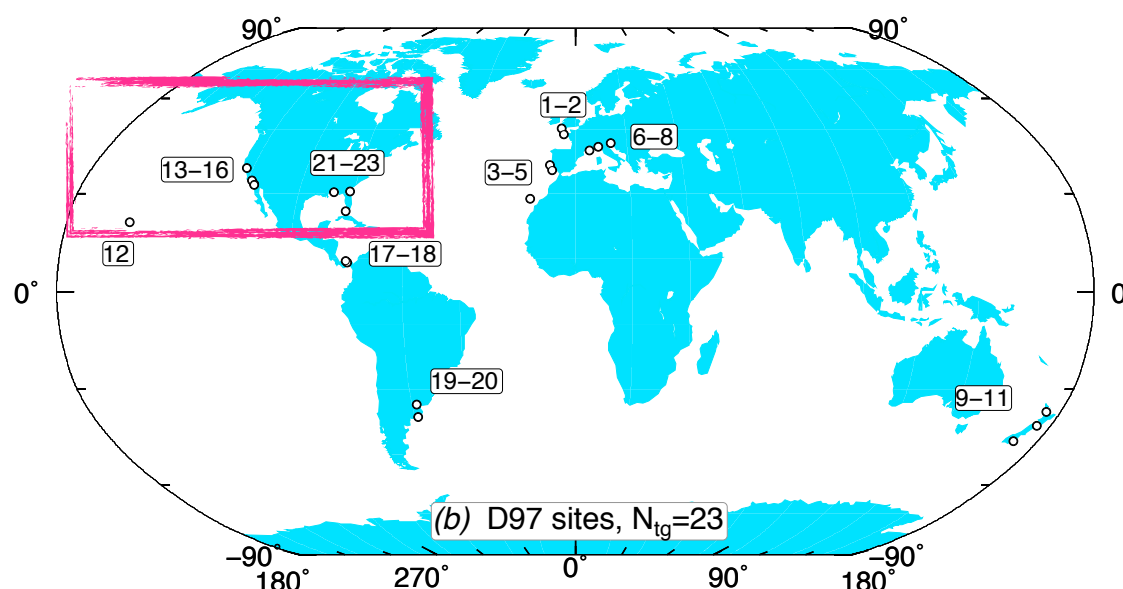
GIA models developed so far (ICE-3G, ICE-5G, ANU05) provide *largely inconsistent predictions* at the US coasts tide gauges:

NA West coast (13-16)

- 13. San Francisco
- 14. Santa Monica
- 15. La Jolla
- 16. San Diego

SE North America (21-23)

- 21. Pensacola
- 22. Key West
- 23. Fernandina



The D97R set

Region	Tide gauge site	Period year–year	span_k years	N_k^v years	r_k (D97 ^a) mm/yr	$\rho_k = r_k \pm \sigma_k$ mm/yr	r_k^{gia} mm/yr
English Channel	1. Newlyn*	1916–2009	94	93	1.7	1.8 ± 0.1	+0.2
	2. Brest*	1880–2009	130	121	1.4	1.4 ± 0.1	+0.2
Atlantic	3. Cascais*	1882–1993	112	101	1.3	1.3 ± 0.1	−0.2
	4. Lagos*	1909–1987	79	69	1.5	1.4 ± 0.2	−0.2
	5. S. C. Tenerife I*	1927–1989	63	56	1.5	1.6 ± 0.2	−0.0
Mediterranean Sea	6. Marseille*	1885–2009	125	119	1.2	1.2 ± 0.1	−0.1
	7. Genova*	1884–1996	113	85	1.2	1.2 ± 0.1	−0.2
	8. Trieste*	1905–2010	106	100	1.2	1.3 ± 0.1	−0.2
New Zeland	9. Auckland II*	1904–1998	95	92	1.3	1.3 ± 0.1	−0.4
	10. Dunedin II*	1900–2009	110	64	1.4	1.2 ± 0.1	−0.4
	11. Wellington II*	1945–2000	56	53	1.7	2.0 ± 0.3	−0.5
Pacific	12. Honolulu*	1905–2009	105	105	1.5	1.5 ± 0.1	−0.2
North American West Coast	13. San Francisco	1880–2009	130	130	1.5	1.6 ± 0.1	−0.1
	14. Santa Monica ^b	1933–2009	77	67	1.4	1.4 ± 0.2	−0.2
	15. La Jolla ^c	1925–2009	85	78	2.1	2.1 ± 0.1	−0.3
	16. San Diego ^d	1906–2009	104	101	2.1	2.1 ± 0.1	−0.2
Central America	17. Balboa*	1908–2003	96	95	1.6	1.5 ± 0.1	−0.2
	18. Cristobal*	1909–1979	71	71	1.0	1.4 ± 0.1	−0.2
South America	19. Quequen*	1918–1982	65	64	0.8	0.9 ± 0.2	−0.1
	20. Buenos Aires*	1905–1987	83	83	1.5	1.6 ± 0.2	−0.5
South East	21. Pensacola	1924–2009	86	84	2.2	2.2 ± 0.2	−0.1
North America	22. Key West	1913–2009	97	96	2.2	2.3 ± 0.1	−0.1
	23. Fernandina	1898–2009	112	91	1.8	2.0 ± 0.1	−0.0

Our estimates so far...

Estimate n.	TG set	N_{tg}	$\mu = m \pm s_{dom}$ mm/yr	rms ($wrms$) mm/yr	GIA correction
1.	ALL	1123	1.4 ± 0.2	5.8 (2.3)	no
2.	"	"	1.8 ± 0.2	5.6 (1.8)	ICE-3G
3.	D97	23	1.6 ± 0.1	0.4 (0.4)	no
4.	"	"	1.7 ± 0.1	0.4 (0.4)	ICE-3G
5.	"	"	1.5 ± 0.1	0.4 (0.3)	ICE-5G
6.	"	"	1.3 ± 0.1	0.5 (0.4)	ANU05
7.	D97R	16	1.4 ± 0.1	0.3 (0.2)	no
8.	"	"	1.6 ± 0.1	0.3 (0.2)	ICE-3G
9.	"	"	1.5 ± 0.1	0.3 (0.3)	ICE-5G
10.	"	"	1.5 ± 0.1	0.3 (0.3)	ANU05

Inconsistent

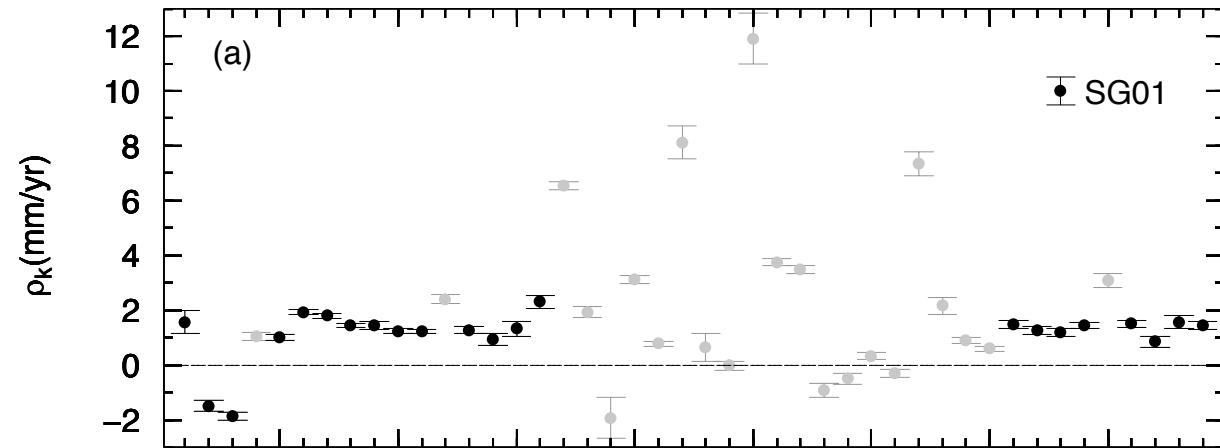
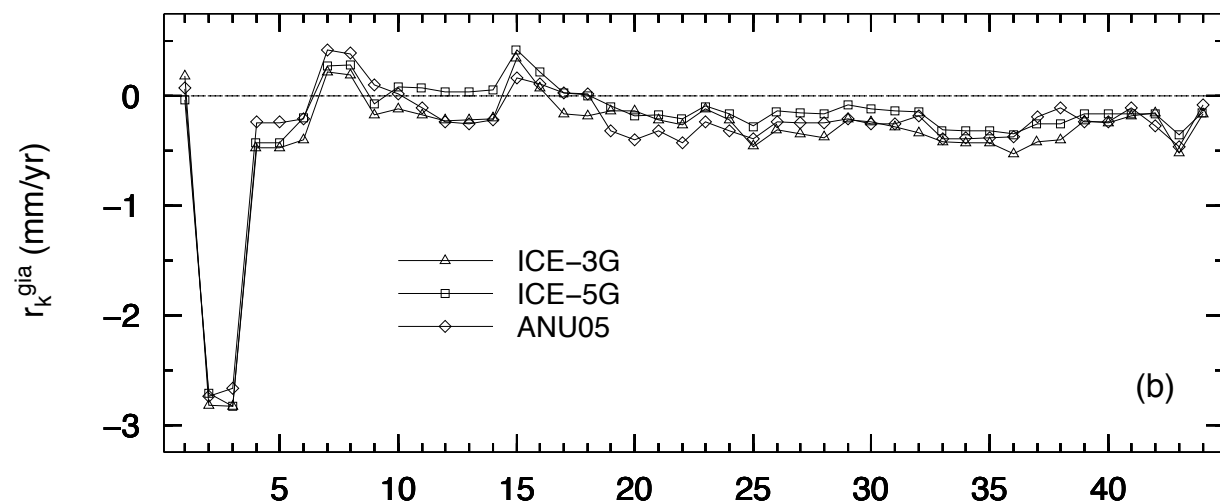
Consistent

This suggests a new strategy that differs from D97:

<< valuable TG gauges (for the GMSLR) assessment are among those for which the GIA correction is largely independent on modeling...>>

... and are, of course, free from other accidents.

Searching for GIA-modeling-insensitive tide gauges

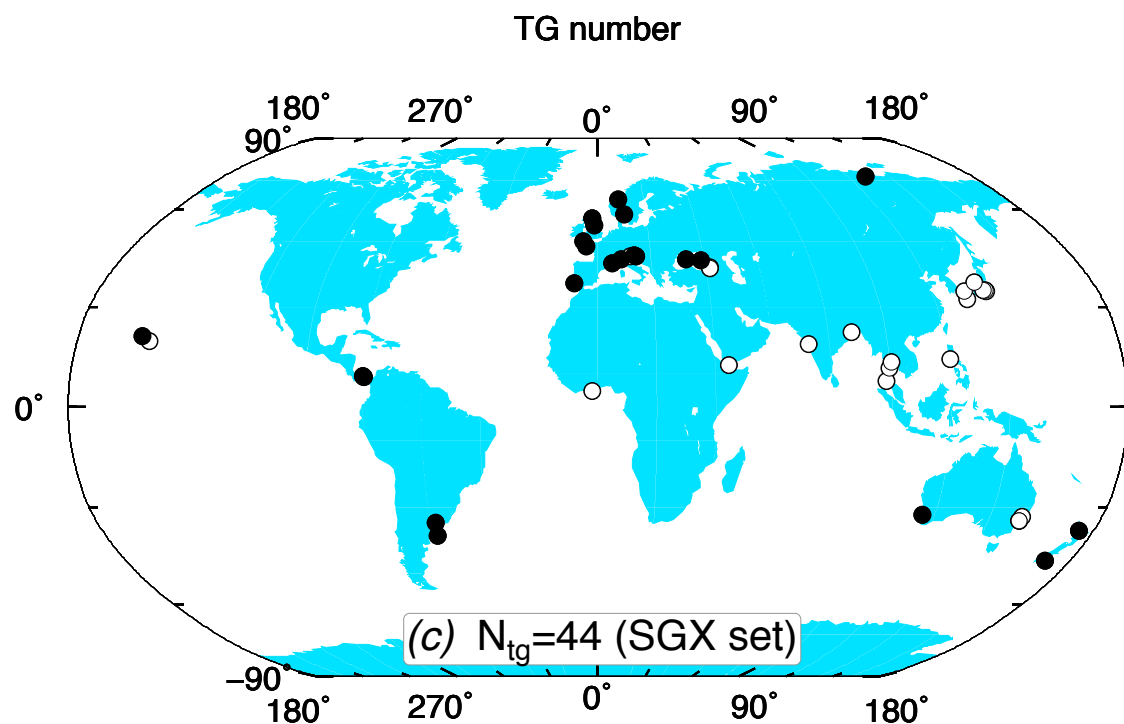
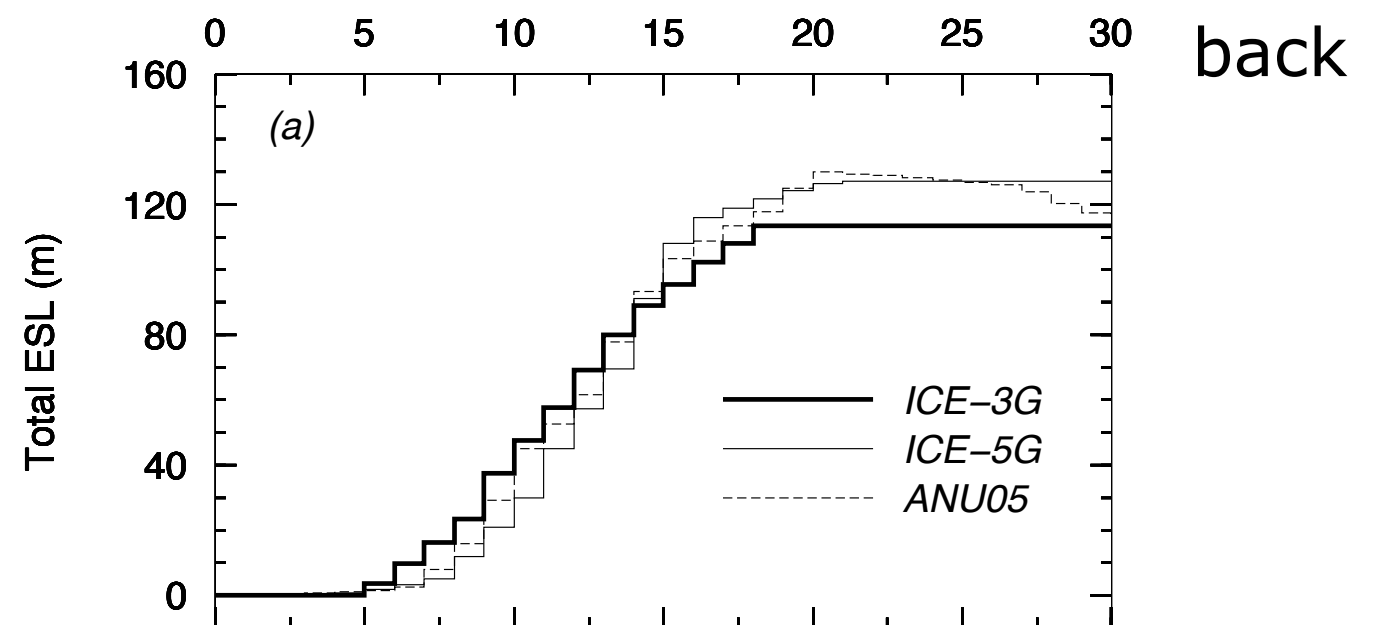


$$|r_{M1}^{gia} - r_{M2}^{gia}| < 0.3 \text{ mm/yr}$$

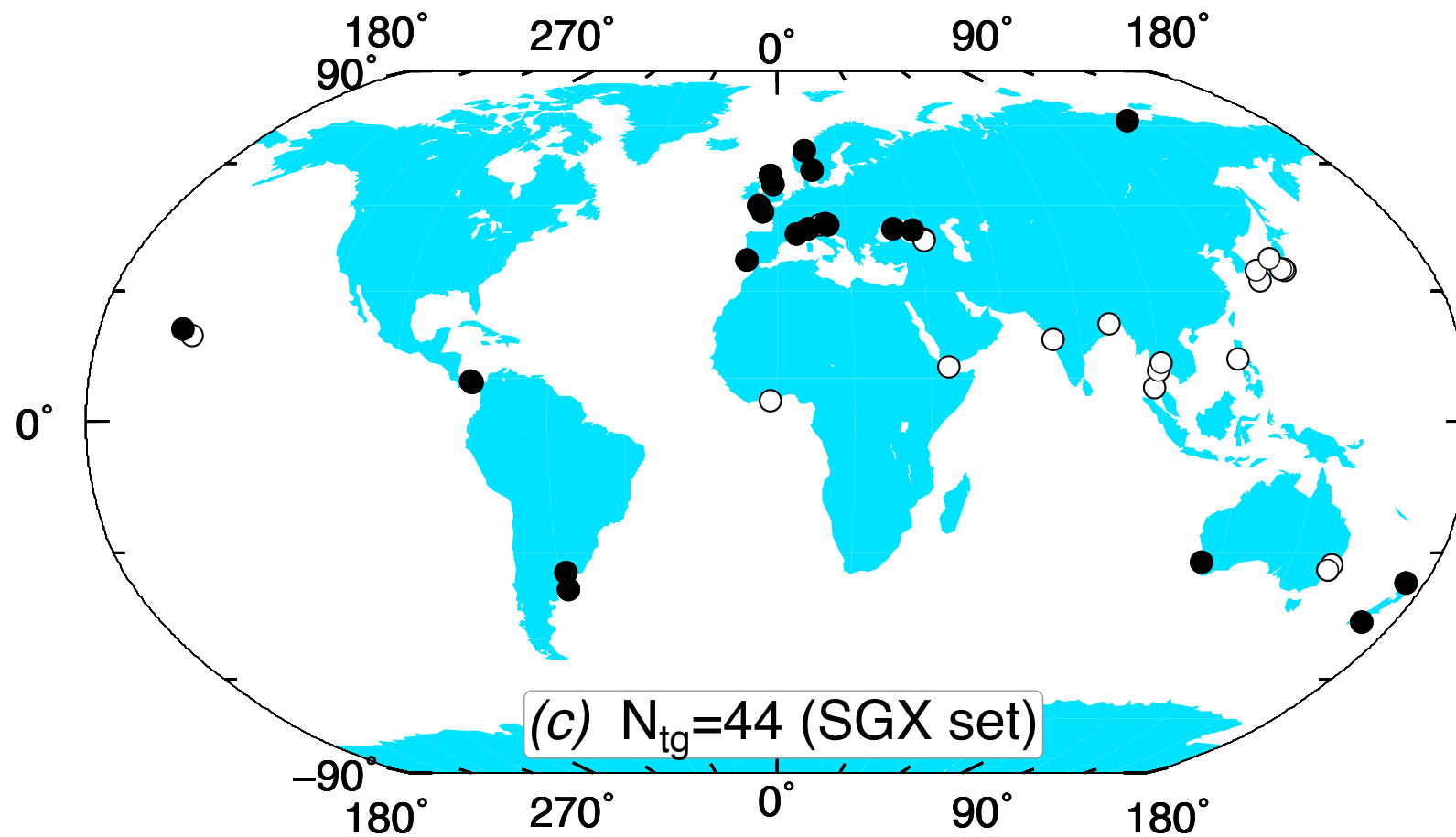
SXG set (44)

SGX TGs are found in the “far field” of the LGM ice sheets, where...

... *GIA effects are mostly dependent from the melt-water load, controlled by the history of ice volume*



The final preferred set SG01 (22) ●



... is obtained from SGX after decimation of:

- 1) *too short records ($N^v < 60$),*
- 2) *sites in tectonically active (?) regions*
- 3) *sites showing "suspect accelerations..."*
- 4) *regionally inconsistent records ... other ...*

The final preferred set SG01 (22)

Region	Tide gauge site	Period year–year	Span years	N_k^v years	$\rho_k = r_k \pm \sigma_k$ mm/yr	r_k^{gia} mm/yr	$r_k^{gia(b)}$ mm/yr
Siberia	1. Tiksi Bukhta	1949–2009	61	61	1.6 ± 0.4	−0.0	−0.2
Northern Europe	2. Heimsjo	1928–2009	82	71	-1.5 ± 0.2	−2.7	−2.7
	3. Smogen	1911–2009	99	99	-1.9 ± 0.2	−2.8	−2.8
Scotland	4. Aberdeen II	1880–1965	86	85	1.0 ± 0.1	−0.4	−0.4
	5. North Shields	1896–2009	114	103	1.9 ± 0.1	−0.2	−0.2
English Channel	6. Newlyn ^a	1916–2009	94	93	1.8 ± 0.1	+0.3	+0.3
	7. Brest ^a	1880–2009	130	121	1.4 ± 0.1	+0.3	+0.3
Atlantic	8. Lagos ^a	1909–1987	79	69	1.4 ± 0.2	+0.0	−0.0
Mediterranean Sea	9. Marseille ^a	1885–2009	125	119	1.2 ± 0.1	+0.1	+0.1
	10. Genova ^a	1884–1996	113	85	1.2 ± 0.1	+0.1	+0.1
	11. Trieste ^a	1905–2010	106	100	1.3 ± 0.1	+0.0	+0.0
Black Sea	12. Bakar	1930–2008	79	66	0.9 ± 0.2	+0.0	+0.0
	13. Sevastopol	1910–1994	85	82	1.3 ± 0.3	+0.4	+0.3
	14. Tuapse	1917–2009	93	91	2.3 ± 0.2	+0.2	+0.1
Australia	15. Fremantle	1897–2009	113	100	1.5 ± 0.2	−0.3	−0.2
New Zeland	16. Auckland II ^a	1904–1998	95	92	1.3 ± 0.1	−0.3	−0.2
	17. Dunedin II ^a	1900–2009	110	64	1.2 ± 0.1	−0.3	−0.2
Central America	18. Balboa ^a	1908–2003	96	95	1.5 ± 0.1	−0.2	−0.1
	19. Cristobal ^a	1909–1979	71	71	1.4 ± 0.1	−0.2	−0.1
South America	20. Quenquen ^a	1918–1982	65	64	0.9 ± 0.2	−0.2	−0.4
	21. Buenos Aires ^a	1905–1987	83	83	1.6 ± 0.2	−0.4	−0.5
Pacific	22. Honolulu ^a	1905–2009	101	105	1.5 ± 0.1	−0.2	−0.1

D97 TGs are marked in yellow

Our estimates (the preferred is marked in sky)

Estimate n.	TG set	N_{tg}	$\mu = m \pm sdom$ mm/yr	$rms (wrms)$ mm/yr	GIA correction
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2.	”	”	1.8 ± 0.2	5.6 (1.8)	ICE-3G
3.	D97	23	1.6 ± 0.1	0.4 (0.4)	no
4.	”	”	1.7 ± 0.1	0.4 (0.4)	ICE-3G
5.	”	”	1.5 ± 0.1	0.4 (0.3)	ICE-5G
6.	”	”	1.3 ± 0.1	0.5 (0.4)	ANU05
7.	D97R	16	1.4 ± 0.1	0.3 (0.2)	no
8.	”	”	1.6 ± 0.1	0.3 (0.2)	ICE-3G
9.	”	”	1.5 ± 0.1	0.3 (0.3)	ICE-5G
10.	”	”	1.5 ± 0.1	0.3 (0.3)	ANU05
11.	SG01	22	1.1 ± 0.2	1.0 (0.7)	no
12.	”	”	1.5 ± 0.1	0.4 (0.3)	ICE-3G
13.	”	”	1.4 ± 0.1	0.4 (0.3)	ICE-5G
14.	”	”	1.5 ± 0.1	0.4 (0.3)	ANU05
15.	SG01	22	1.5 ± 0.1	0.4 (0.3)	Any of the three above ^a

rotational FB
ON

^a Accounts for the effect of the rotational feedback on sea level change according to the theory outlined by Milne & Mitrovica (1998).

GIA-corrected, global mean rate of sea level rise
(1880-2010)

$$\mu' = 1.5 \pm 0.1 \text{ mm/yr}$$

$$rms = 0.4 \text{ mm/yr}, wrms = 0.3 \text{ mm/yr},$$

(first Italian estimate)

Contents:

- 1). Motivations, previous work, relevance
- 2). Data: RLR tide gauge (TG) observations since 1880
- 3). Obtaining sea level trends from TG time series
- 4). Corrections in general and GIA corrections
- 5). Some new estimates of the secular sea level rise
- 6). Outlook (a couple of points)

Are EQs affecting the sea level trends at TGs?

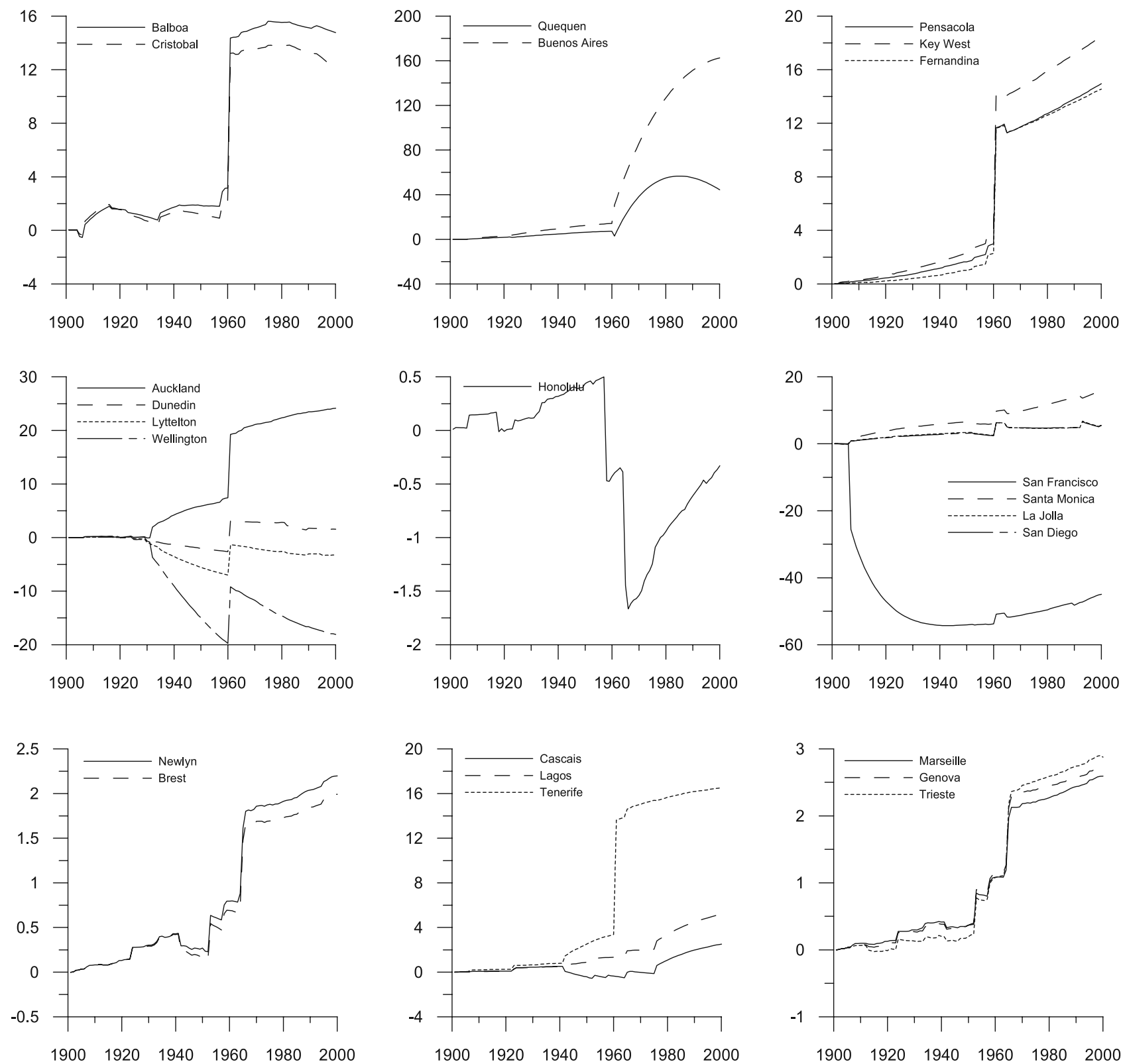
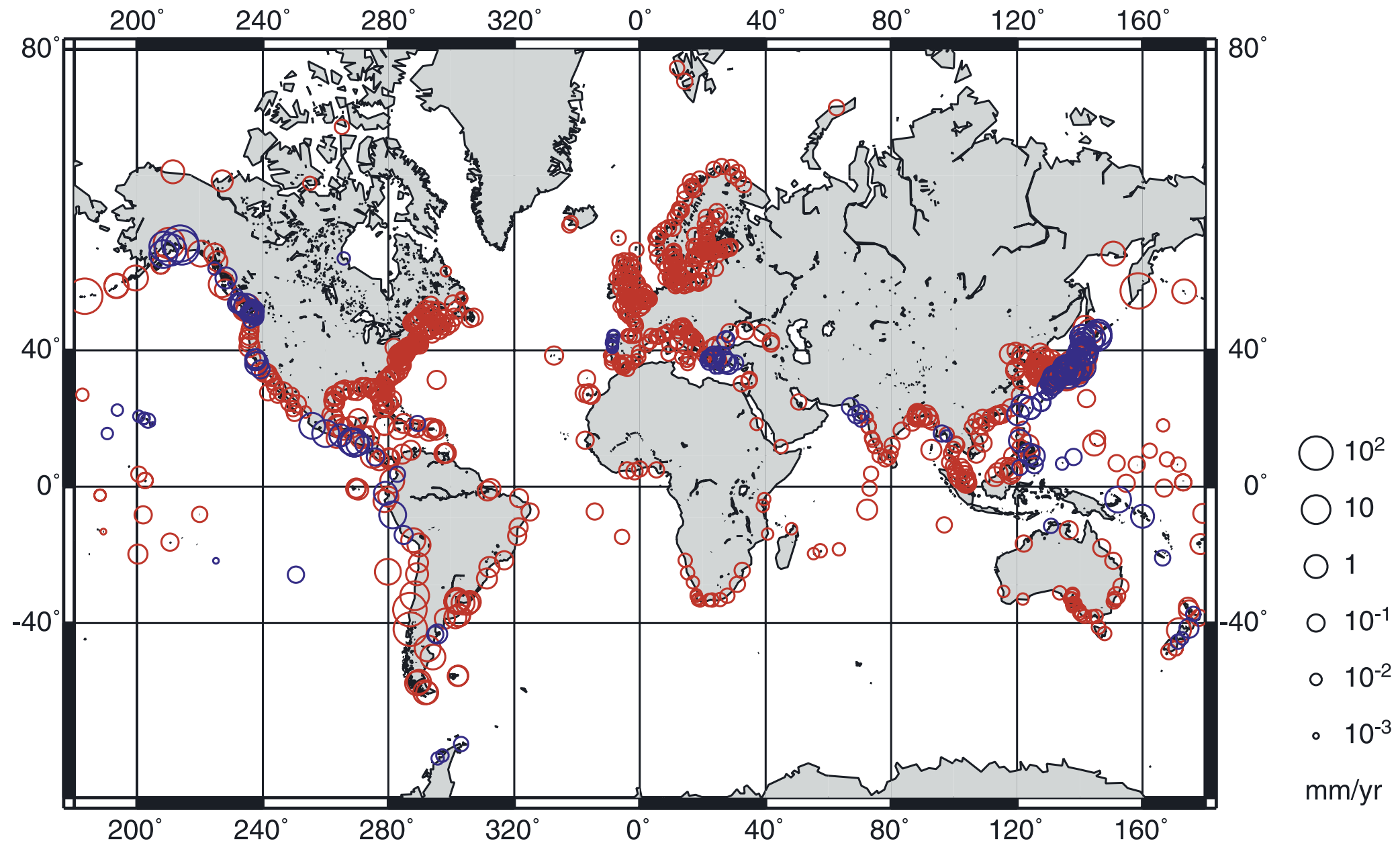


Figure 2. Contribution of global seismicity to the long-term relative sealevel variations considered by *Douglas* [1997].

Are EQs affecting the TG sea level trends?



Ocean - averaged effect is ZERO

but the EQs have a cumulatively NEGATIVE tendency at TGs

(~ -0.2 mm/yr)

Melini et al. GRL 2004

GMSLC is the first term of a more general expression

$$SLC(\theta, \lambda) = \mu + c_1\mu_1(\theta, \lambda) + c_2\mu_2(\theta, \lambda) + \dots$$

μ is Global Mean Sea Level Change
includes steric effects and eustatic variations
associated with glacial melting

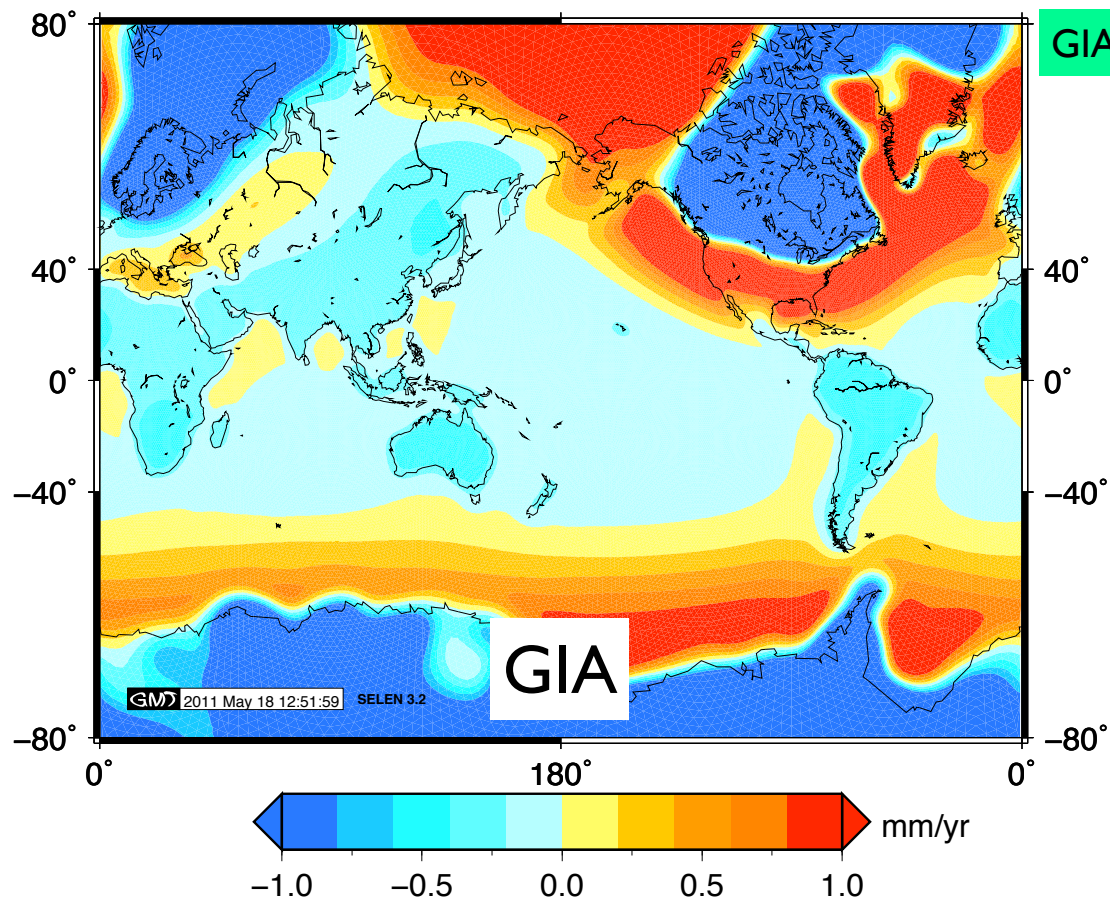
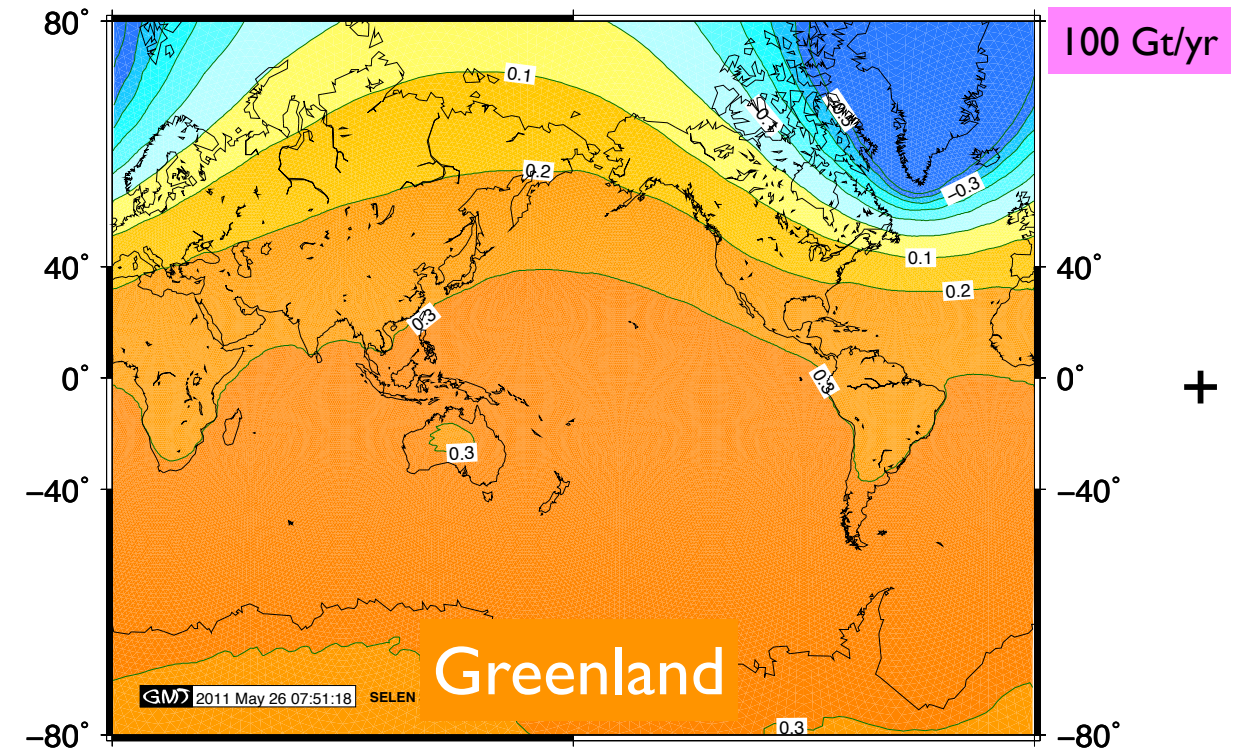
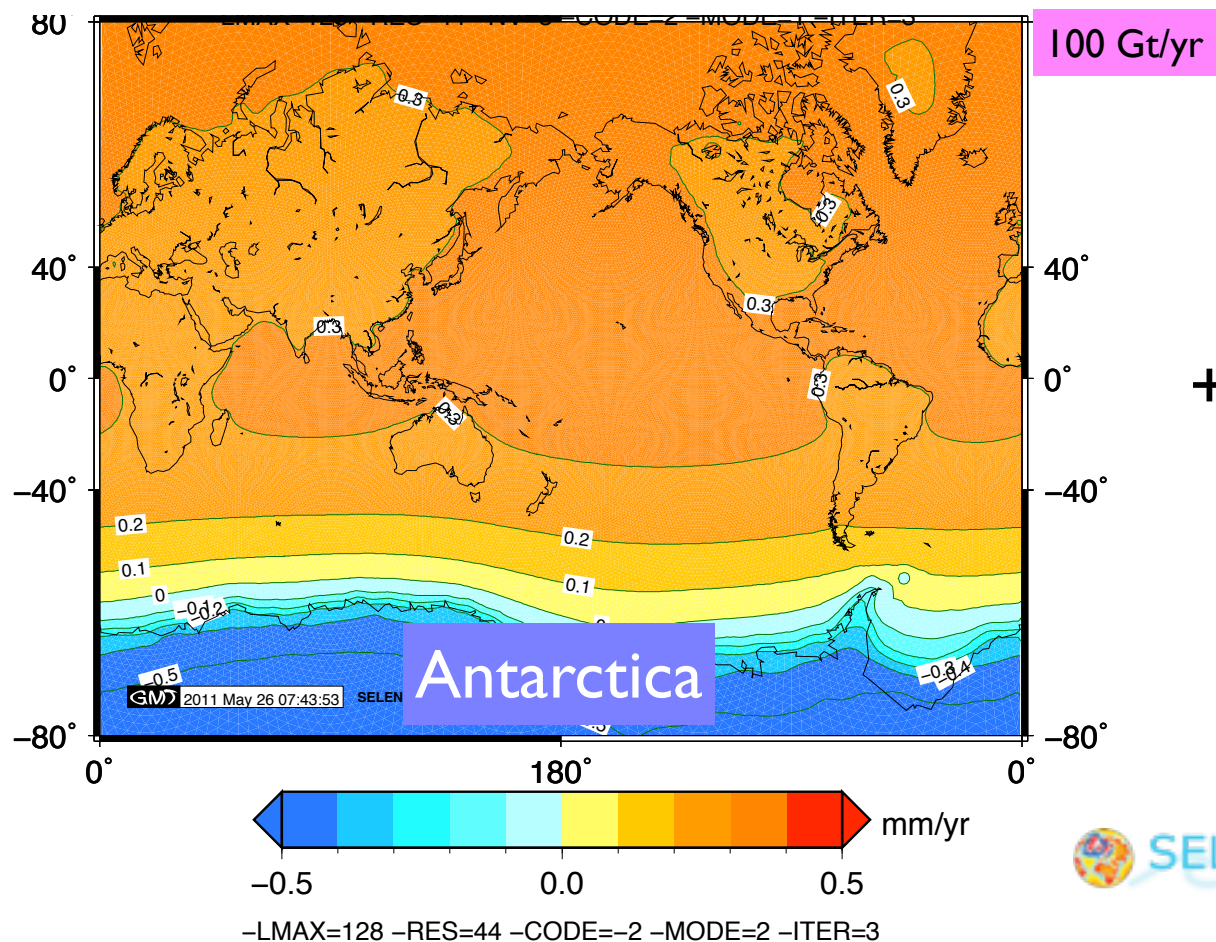
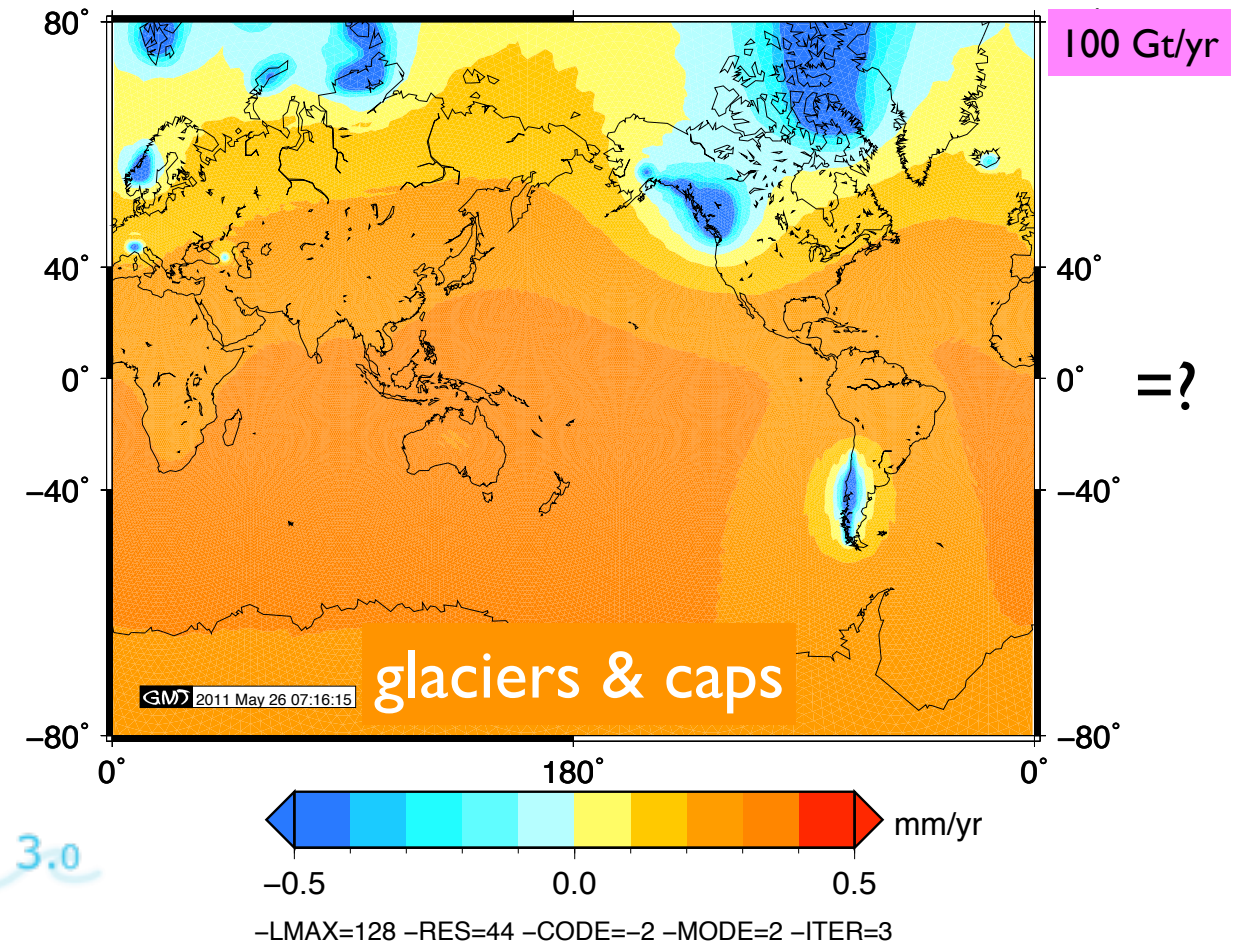
$\mu_i(\theta, \lambda)$ are the Sea Level Fingerprints - spatial dependent
patterns - of major continental
ice sheets and mountain glaciers (see next slide)

c_i are unknown constants

Simultaneous inversion of TG observations for:

1) the mass balances and 2) the GMSLC

GIA, Greenland, Antarctica, & Glaciers fingerprints



SELEN 3.0

