Is Sea Level Rise Due to CO_2?

Rick Bradford, 7/1/20

Contents

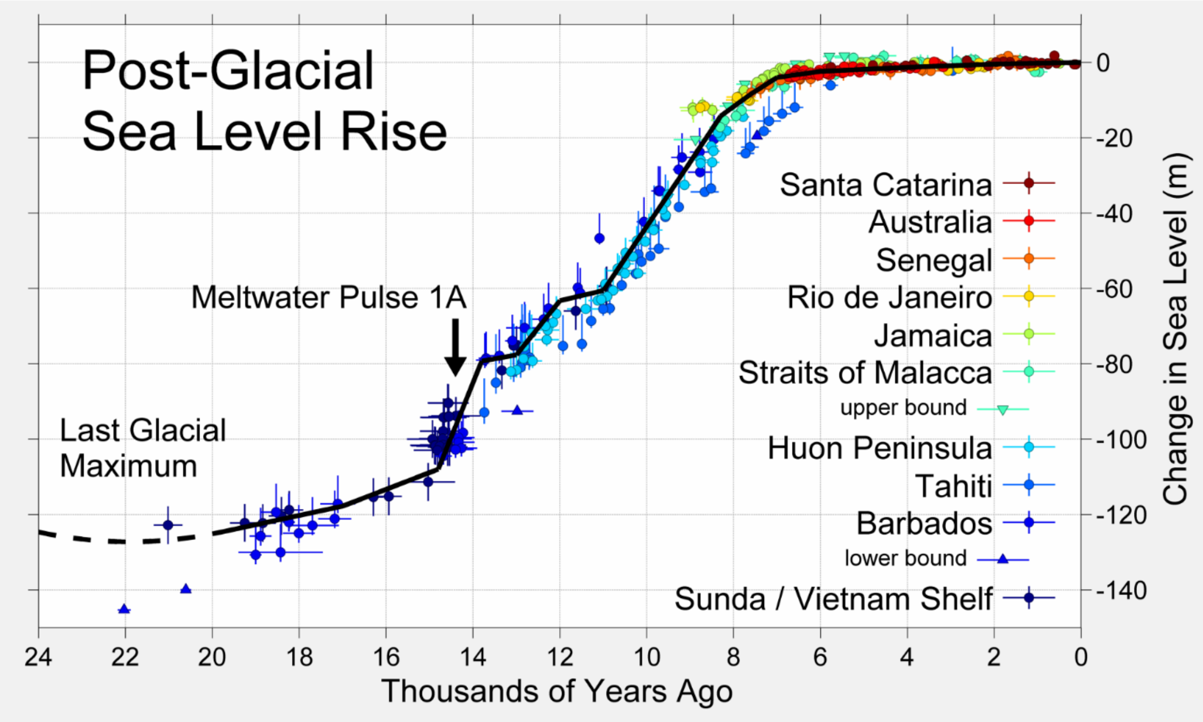
- The main text critiques the standard picture of sea level rise but without independent examination of the raw data.
- The Appendix independently examines the raw sea level data from 70 tidal stations worldwide.
- Section 5 summarises the conclusions from both studies.

1. Global Average Sea Level is Rising

This section summarises the standard picture of sea level changes over very long time periods. I shall not examine it closely as I shall concentrate on the period since about 1850 when routine and reliable tidal records began. Nevertheless, the longer timescale provides crucial background as it puts current sea level rises in context.

On average over the globe, mean sea level has been rising for about 20,000 years, since the end of the last glacial episode, like this…

Figure 1: Sea level rise over the last 20,000 years, from Refs.[1-3]



Note that the scale of this graph is in ***metres***. Over the last 20,000 years, global mean sea level (GMSL) has risen by about 125 metres (over 400 feet, or getting on for twice the height of the Avon Gorge). This is bound to have had dramatic effects on land geography. One of them was making Britain an island when the North Sea drowned Doggerland which had previously connected Britain to continental Europe.

On the scale of Figure 1 recent sea level rise (i.e., over a century or two) would be imperceptible. Current GMSL rise rates are around 3mm per year (or perhaps less, as we shall see), so even three centuries at that rate would see a rise of less than a metre, which would not be noticeable on the scale of Figure 2. This is what I mean by "putting in context".

The last 20,000 years is not unique – far from it. The sea level has been going up and down by the order of 125 metres repeatedly over the last million years or so (Figure 2), and probably for far longer. Even over the last thousand years the sea level has gone up and down, albeit by only about 10 cm until the last 130 years over which time there has been a rise of about 21 cm (Figure 3). It is this latter period on which I shall focus here.

Figure 2: Sea level over the last 800,000 years (from Ref.[4]), scale: metres

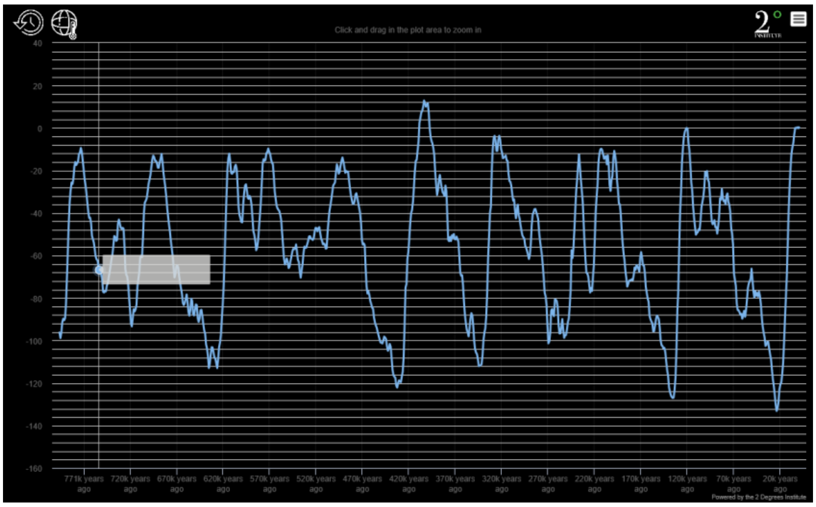
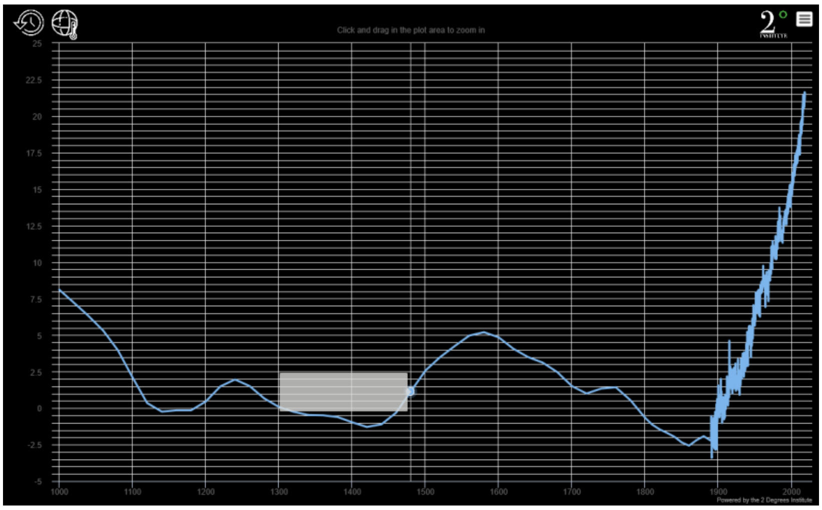


Figure 3: Sea level over the last 1,000 years (from Ref.[4]), scale: centimetres



2. Church & White, 2011 (Ref.[5])

An independent estimate of the GMSL change would be prohibitively time consuming. There are roughly 1,000 stations around the world which gather tidal data (see the map here). Moreover, even if it were feasible for an amateur to get to grips with all this disparate data, there would remain the problem of how to calculate a global average from these measurements – most of which are on the costal peripheries of the great oceans. Consequently I start by quoting from the paper by Church & White, Ref.[5], and follow that (in an Appendix) with a look at the data from 70 tidal stations, the aim being to check that the conclusions of Church & White appear born out. Their result in the form of GMSL versus year is shown in Figure 4 (and Figure 5 after certain corrections). Note that their data starts in year 1860.

Figure 4: GMSL since 1860 from Church & White, Ref.[5]

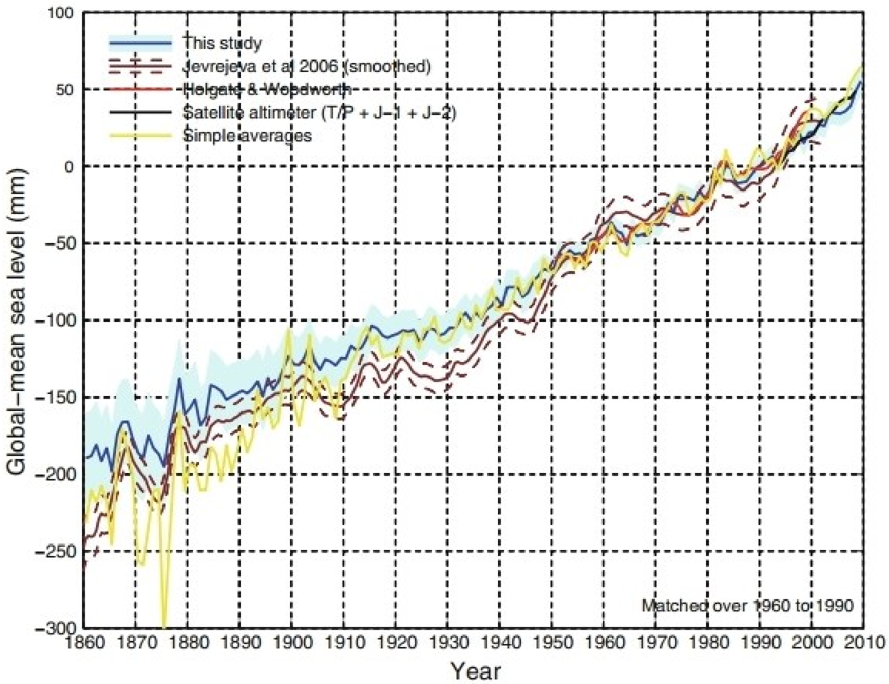
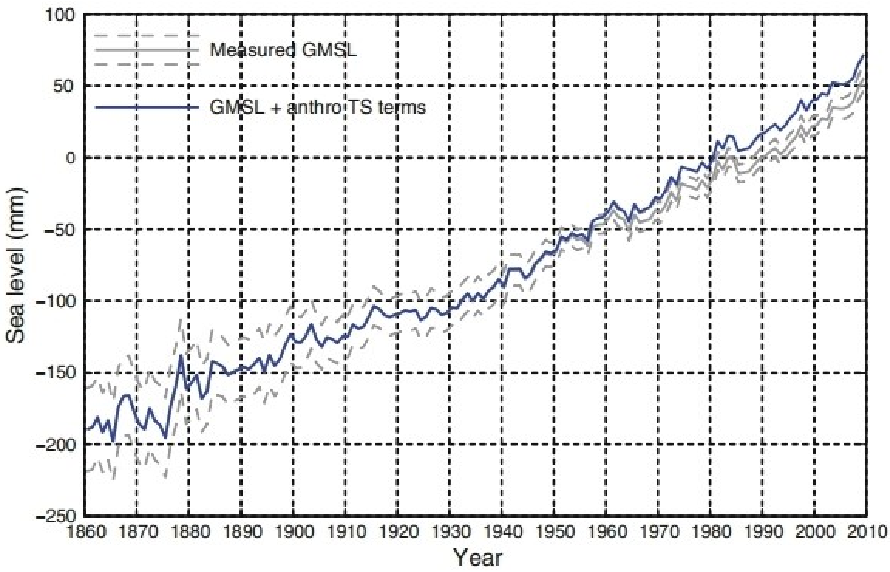
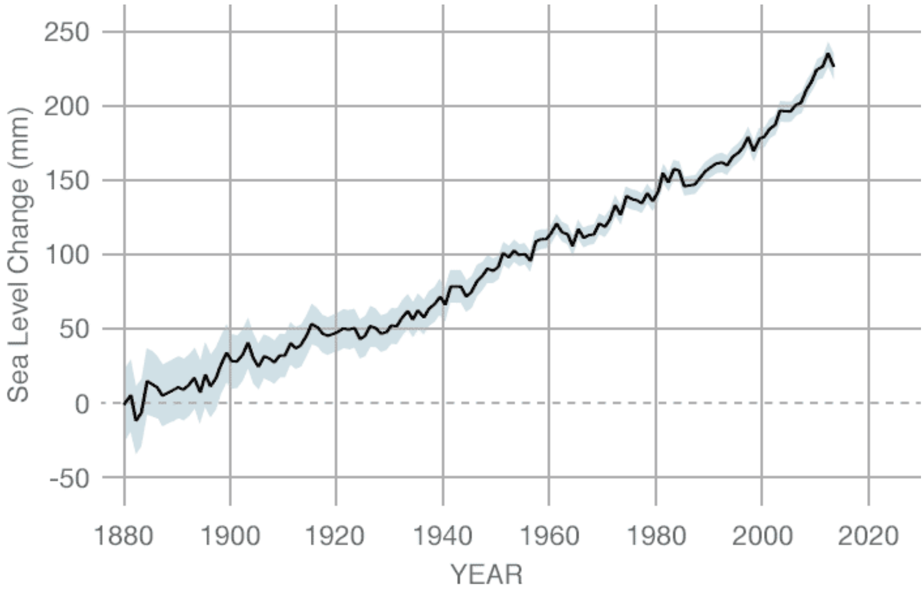


Figure 5: GMSL since 1860 from Church & White, Ref.[5], after corrections



For comparison, Figure 6 shows the GMSL versus year, from 1880, from a NASA site, Ref.[6]. The starting datum is arbitrary, apart from that the graphs of Figures 4,5 are broadly similar to Figure 6 although the latter exhibits slightly greater acceleration (upward curvature). The significance of this is discussed below.

Figure 6: GMSL over the last ~140 years (from Ref.[6]).



From Church & White's Abstract,

"*We estimate the rise in global average sea level from satellite altimeter data for 1993–2009 and from coastal and island sea-level measurements from 1880 to 2009. For 1993–2009 and after correcting for glacial isostatic adjustment, the estimated rate of rise is 3.2 ± 0.4 mm per year from the satellite data and 2.8 ± 0.8 mm per year from the in-situ data. The global average sea-level rise from 1880 to 2009 is about 210 mm. The linear trend from 1900 to 2009 is 1.7 ± 0.2 mm per year and since 1961 is 1.9 ± 0.4 mm per year. There is considerable variability in the rate of rise during the twentieth century but there has been a statistically significant acceleration since 1880 and 1900 of 0.009 ± 0.003 mm year*$^{-2}$ *and 0.009 ± 0.004 mm year*$^{-2}$*, respectively*."

3. What is the Relevance of GMSL Acceleration?

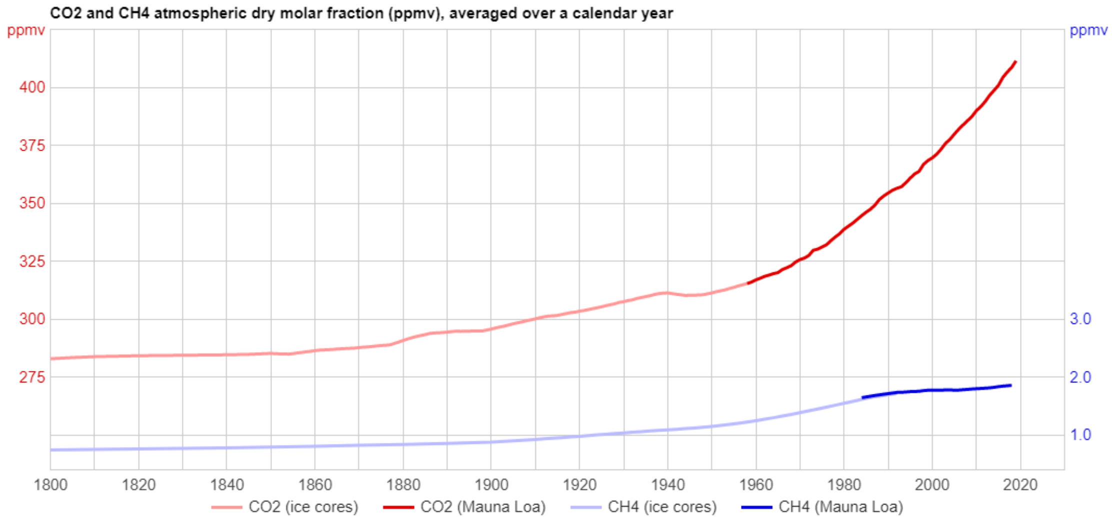
Why do Church & White focus on the ***acceleration*** of GMSL? There are two reasons, and both cast doubt on the alarmist interpretation of the data.

3.1 The Sea was Already Rising in the 1800s

Based on my examination of the data, below, I believe (with caveats) that Figures 4, 5 and 6 are reasonable representations of how GMSL has changed since the mid-to-late 1800s. But note that, although the GMSL may have accelerated to some extent, the rise rate was of a similar order in 1860 as currently. And yet in 1860 the concentrations of CO_2 and CH_4 in the atmosphere had hardly shifted from their pre-industrial levels (Figure 7).

Clearly the rising sea level in 1860 cannot be attributed to greenhouse gases. In popular accounts of sea level rise this is rarely made clear to the public. Worse: some sources make explicitly false statements. For example, CSIRO (Commonwealth Scientific and Industrial Research Organisation) describes itself as "an independent Australian federal government agency", though how it can be both independent and a government agency escapes me. On CSIRO's sea level web page, Ref.[8], they state unequivocally that, "*sea-level rise is a response to increasing concentrations of greenhouse gases in the atmosphere and the* *consequent changes in the global climate*". Yet a simple comparison of Figures 4-6 with Figure 7 shows that this cannot be true.

Figure 7: Greenhouse gas concentrations since 1800 (from Ref.[7])



Given that the effect of greenhouse gases was negligible in 1860, the most one could claim is that the ***increase*** in the rate of rise of GMSL since 1860 ***might*** be due to the effect of greenhouse gases via their presumed effect on global warming. This is why Church & White quote the ***acceleration*** of the GMSL, because – at worst - it is only the acceleration since ~1860 which could be a result of greenhouse gas induced global warming. Note how small is Church & White's central estimate of the acceleration: 0.009 mm/year^2. If this acceleration were sustained for 100 years, it would cause an increase in the GMSL rise rate of only 0.9 mm/year. But the rise rate is currently ~3 mm/year. Since the effect of greenhouse gases was negligible 100 years ago, it follows that about 2.1 mm/year of the current 3 mm/year rise rate is not due to greenhouse gases. I conclude that…

- The majority of the current rate of sea level rise is not due to greenhouse gases.
- Assuming the quadratic fit to historic data (Figures 4,5) could justifiably be used to extrapolate a hundred years into the future, the current rise rate of ~3 mm/year would only increase to ~3.9 mm/year, and the maximum effect that could possibly be attributed to ongoing greenhouse effects is the ~0.9 mm/year increase in rise rate.
- Assuming the quadratic fit to historic data could justifiably be used to extrapolate into the future, the GMSL would increase by 269 mm between 2020 and 2100.
- If all (presumed) effects of greenhouse gases could be magically vanished away instantly today, so that the sea level rise rate reverted to its rate 100 years ago, i.e., about 2.1 mm/year, the sea would still rise by 168 mm between 2020 and 2100.
- Hence, most of the predicted sea level rise this century cannot be attributed to greenhouse gases even if one assumes their effects are at the maximum possible consistent with historic data.

The message to take away from the above conclusions is that the far higher predictions of sea level rise by 2100 within the IPCC reports are entirely dependent on theoretical models which predict that, not only is the sea level rise rate accelerating, but that *the rate of acceleration is itself increasing*. These predictions cannot be validated on the basis of historic data. They are purely theoretical predictions without current empirical validation. This is discussed further in the next section.

It is worth emphasising in passing that the principal mechanisms of sea level rise are the melting of land ice and the thermal expansion of ocean waters, both of which require increasing temperatures. (Melting sea ice does not significantly affect sea level: floating ice displaces its own mass of water. There may be very small effects due to differences in salinity). Whilst global average temperatures have been increasing since the mid-twentieth century, the claim that greenhouse gases are the cause of this global warming is less well established than the public have been led to believe. Doubt about this presumed causality is scientifically reasonable, not irrational denial - for example see this. Moreover, global average temperature was not increasing in 1860 (in fact it decreased between 1880 and 1920) which does not fit well with the sea level rise which was already underway in 1860.

3.2 The Extrapolation and Its Importance

As noted above, without making any hypotheses about the physical cause of GMSL rise, an estimate of its further rise over the rest of this century can be made by assuming the quadratic fits to the existing data can be extrapolated by 80 years (including the modest acceleration identified by Church & White). This results in additional GMSL rise between 2020 and 2100 of 269mm. And yet claims from IPCC and their referenced sources recognise this prediction only as the lower bound of models assuming "*a stringent mitigation scenario*" to "*keep global warming likely below 2°C above pre-industrial temperatures*". The IPCC and NOAA also present more worrying predictions of additional sea level rise by 2100.

The predictions published in the 2014 IPCC report, Ref.[9], are shown in Figure 8. These predictions range between my 269mm (lower bound) to ~1 metre (though based on an earlier start date). The four modelled scenarios (referred to as RCPs) used by IPCC are defined as follows,

"*The RCPs include a stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0) and one scenario with very high GHG emissions (RCP8.5). Scenarios without additional efforts to constrain emissions ('baseline scenarios') lead to pathways ranging between RCP6.0 and RCP8.5 (Figure SPM.5a). RCP2.6 is representative of a scenario that aims to keep global warming likely below 2°C above pre-industrial temperatures*."

So IPCC refer to the higher, red-shaded, models in Figure 8 as "baseline scenarios", which range up to 1 metre. In the 2014 report, IPCC state,

"*For sea level, based on current understanding (from observations, physical understanding and modelling), only the collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause global mean sea level to rise substantially above the likely range during the 21st century*."

By "likely range" here, IPCC mean the range shown in Figure 8. In other words predictions even greater 1 metre would require hypothesising some Antarctic ice melt. By 2017, work coming out of NOAA (the US National Oceanic and Atmospheric Administration) was already pushing predictions upwards, including the hypothesis of Antarctic ice melt contributing to the sea rise, as shown in Figure 9 from Ref.[10]. On this basis the prediction is up to 2.4 metres. But even without Antarctic melt, this NOAA report pushes the upper bound IPCC RCP8.5 scenario to 1.3 metres.

Figure 8: GMSL Rise Predictions from IPCC 2014, Ref.[9]

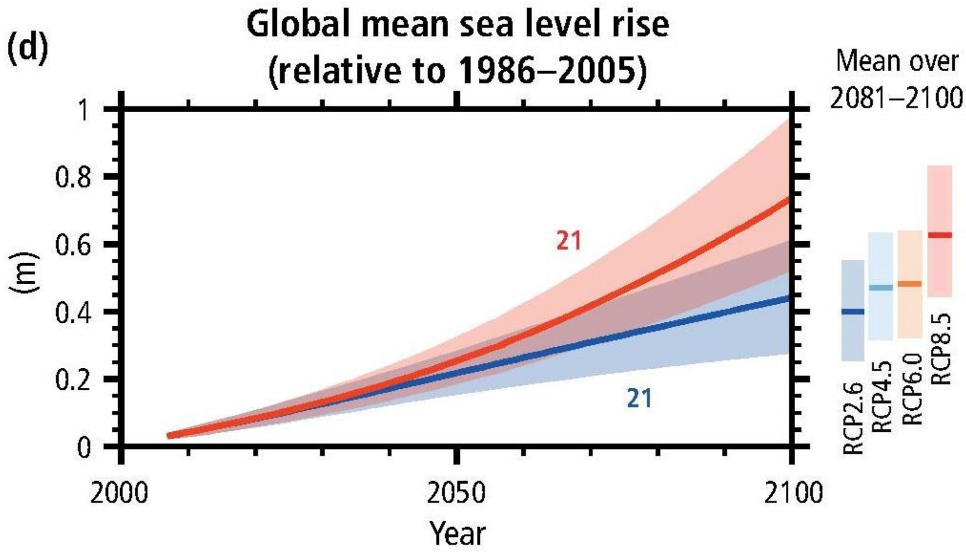
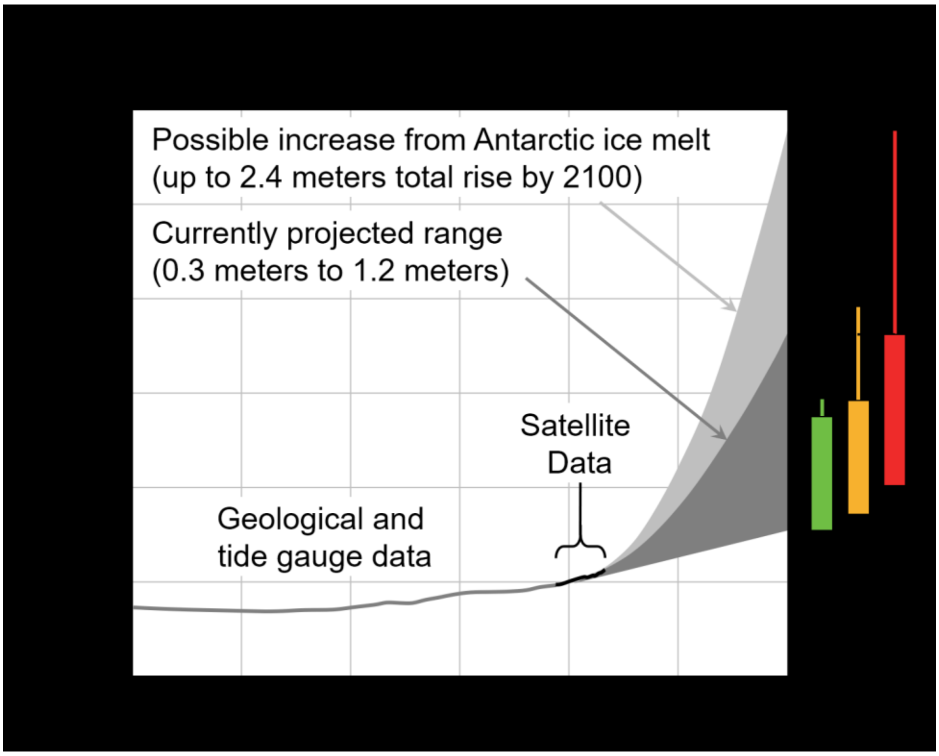


Figure 9: GMSL Rise Predictions from NOAA, Ref.[10]



My conclusions in respect of IPCC/NOAA projections of sea level rise are,

- Extrapolation of observational data to-date produces the ***lower bound*** predictions of Figures 8 and 9.
- All higher predictions in Figures 8 and 9 are based on theoretical models. The further these models depart from the lower bound, the less the physical assumptions upon which these models are based are constrained by observational data.
- Predictions higher than the lower bound are predicated upon an ***increasing acceleration*** in the GMSL whose basis is entirely theoretical.
- This postulated increasing acceleration is based on an assumed link with ongoing increases in atmospheric CO_2, but this hypothesis is unproved and in some tension with the fact that greenhouse gases are certainly not the cause of most of the current rate of sea level rise.

4. Independent Data Analysis

My examination of the raw data upon which Figures 4-6 are based is included in the Appendix. Inevitably it is beyond a few days' work to get to grips with all such data, which is extremely voluminous. In particular I have not examined satellite data, preferring to concentrate on ground-based tidal station data. I have looked at data from 70 such stations, but this is a tiny fraction (~7%) of the total worldwide number of tidal stations. I have concentrated on stations with the longest historical records. The conclusions from my (limited) data analysis are combined with my conclusions drawn from the above text in the following section.

5. Overall Conclusions

Without conducting independent examination of the data:-

[1] Most of the current rate of sea level rise is not due to greenhouse gases.

[2] Assuming the quadratic fit to historic data (Figures 4,5), as given by Church & White, Ref.[5], could justifiably be used to extrapolate a hundred years into the future, the current rise rate of ~3 mm/year would only increase to ~3.9 mm/year, and the maximum effect that could possibly be attributed to ongoing greenhouse effects is the ~0.9 mm/year increase in rise rate.

[3] Assuming the quadratic fit to historic data could justifiably be used to extrapolate into the future, the GMSL would increase by 269 mm between 2020 and 2100.

[4] If all (presumed) effects of greenhouse gases could be magically vanished away instantly today, so that the sea level rise rate reverted to its rate 100 years ago, i.e., about 2.1 mm/year, the sea would still rise by 168 mm between 2020 and 2100.

[5] Using extrapolation of existing empirical data as the basis of projection, including current rates of acceleration, most of the predicted sea level rise by 2100 cannot be

attributed to greenhouse gases even if one assumes their effects are at the maximum possible consistent with historic data.

[6] Extrapolation of observational data to-date produces the ***lower bound*** predictions of sea level rise by IPCC/NOAA (Figures 8 and 9).

[7] All higher predictions of sea level rise by IPCC and their referenced authors (Figures 8 and 9) are based on theoretical models. The further these models depart from the lower bound, the less the physical assumptions upon which these models are based are constrained by observational data.

[8] Predictions higher than the lower bound are predicated upon an ***increasing acceleration*** in the GMSL whose basis is entirely theoretical.

[9] This postulated increasing acceleration is based on an assumed link with ongoing increases in atmospheric CO_2, but this hypothesis is unproved and in some tension with the fact that greenhouse gases are certainly not the cause of most of the current rate of sea level rise

After conducting an independent examination of the data my conclusions harden further:-

[10] Of the 70 stations selected on the basis of length of record, but otherwise random, 34 stations showed sea level changes which were qualitatively different from the standard picture, i.e., showing no trend or a downward trend, or no consistent trend (Figures A2).

[11] The remaining 36 stations (Figures A.1), which show upward trends, all display sea levels which were rising significantly at the earliest date for which data is available. For ten stations the earliest data starts in the nineteenth century (1843, 1856, 1864, 1865, 1874, 1889, 1896, 1897, 1897, 1899). A further 14 stations' earliest data starts between 1900 and 1927.

[12] Comparing with the history of CO_2 (Figure 7), these observations imply that most of the current rate of sea level rise is not due to CO_2.

[13] Of the 36 stations which have consistent upwards trends, 20 show positive accelerations, and 16 show negative accelerations. Of the 20 positive accelerations, only 5 were statistically significantly different from zero at the 90% confidence level, on an individual station basis. (It is acknowledged that pooling global data might enhance statistical significance).

[14] The above findings can crudely be characterised thus: ~50% of stations do not show consistent upward trend; only slightly more than 25% show a consistent upward trend with positive acceleration; only slightly less than 25% show a consistent upward trend but with negative acceleration.

[15] Whilst the cursory examination conducted here cannot provide a properly weighted global average, the implication of these observations is that the current GMSL trend in rise rate appears slower than Church & White's ~3 mm/year, and the global mean acceleration lower than their 0.009 mm/year^2, perhaps a great deal lower.

[16] The evaluation of GMSL trend and acceleration will be very sensitive to how stations' data is weighted in the attempt to correctly represent the entirety of the world's aqueous volume. Possibly satellite data may be beneficial in this respect, but satellite data has not been examined here.

6. References

[1] Fleming, Kevin, Paul Johnston, Dan Zwartz, Yusuke Yokoyama, Kurt Lambeck, and John Chappell (1998). "Refining the eustatic sea-level curve since the Last Glacial Maximum using far- and intermediate-field sites". *Earth and Planetary Science Letters* **163** (1-4): 327-342. doi:10.1016/S0012-821X(98)00198-8

[2] Fleming, Kevin Michael (2000) *Glacial Rebound and Sea-level Change Constraints on the Greenland Ice Sheet*, Australian National University PhD Thesis

[3] Milne, Glenn A., Antony J. Long and Sophie E. Bassett (2005). "Modelling Holocene relative sea-level observations from the Caribbean and South America". *Quaternary Science Reviews* **24** (10-11): 1183-1202. doi:10.1016/j.quascirev.2004.10.005

[4] https://www.sealevels.org/

[5] John A. Church and Neil J. White, "Sea-Level Rise from the Late 19th to the Early 21st Century", Surv Geophys (2011) 32:585–602 DOI 10.1007/s10712-011-9119-1

[6] https://climate.nasa.gov/climate_resources/133/sea-level-historic-data/

[7] https://www.sealevel.info/CO2_and_CH4_from_1800.png

[8] https://research.csiro.au/slrwavescoast/sea-level/

[9] IPCC Climate Change Synthesis Report 2014, https://www.ipcc.ch/report/ar5/syr/

[10] U.S. Global Change Research Program for the Fourth National Climate Assessment, NOAA Technical Report NOS CO-OPS 083, "Global and Regional Sea Level Rise Scenarios for the United States"

[11] Permanent Service for Mean Sea Level (PSMSL), web site https://www.psmsl.org/

[12] PSMSL Interactive Tidal Station Map

Appendix: Examination of Tidal Station Historic Data & Trends

A.1 Methodology

The purpose of this exercise is to examine whether Figures 4-6 appear to be a reasonable representation of data obtained from long time-base records of sea level from tidal stations around the world. For this purpose I have used the Permanent Service for Mean Sea Level (PSMSL), a service within the Global Sea Level Observing System (GLOSS), which is a programme coordinated by the Intergovernmental Oceanographic Commission. Specifically I have used an interactive world map provided by PSMSL which shows all tidal stations with relevant data (either current or historic). I estimate there are about 1,000 such stations.

It is not feasible to attempt, in a few days, a global average such as done by Church & White, Ref.[5]. I am content to examine whether data from individual tidal stations is typically similar to Figures 4-6, whilst accepting that a global averaging process may arrive at these Figures from individual station data with a wide range of different behaviours.

I am most interested in stations with records starting at the earliest dates, preferably in the 1800s. The reason is the crucial importance of the sea level rise rate in the 1800s to the logic of my critique in the main text. Usefully, the stations marked on the interactive map are colour coded according to the time-span of the data available, as follows.

- White = over 100 years: I used all these;
- Yellow = over 75 years: I used a random sample of these from around the world;
- Orange = over 50 years: I used some of these when a region would otherwise be unrepresented (Africa is very poorly served);
- Brown (>30 yrs) and Black (<30 yrs): I did not use these.

The key questions to be addressed are,

- Does the raw data bear out the implication of Figures 4-6 that sea level was already rising, and at rates not too far different from today's, in the 1800s?
- What are the accelerations in rise rate for each Station, and do these support Church & White's estimated global average?
- How common are stations which indicate sea level behaviours radically different from Figures 4-6, e.g., no significant rise or decreasing levels?

I am concerned here with ***mean*** sea level, not high and low levels (which, of course, vary twice daily). I exclusively use yearly-average data. These are obtained by averaging 12 monthly averages, which in turn are obtained from daily averages, which in turn are obtained from typically either 4 (high/low) tide readings, or hourly readings. The use of yearly averages eliminates tidal and seasonal effects.

A.2 Data Selection

I have looked at the data from 70 stations around the world. They are by no means uniformly spread around the oceans. For a start, they are strongly biased to the ocean peripheries at the coast of major land masses (continents). There are relatively few in mid-ocean, excepting a few randomly scattered island stations. The southern hemisphere is poorly served compared with the northern hemisphere. In particular, North America and Europe are well covered, and, to a somewhat lesser extent, the arctic, and near-arctic, seas also. Records back to the nineteenth century are scarce elsewhere. India and the Far East are reasonably well covered, but generally with records back only 50 to 75 years. Africa is very poorly served, and South America and Australia/NZ are not well covered by the longest time-base datasets.

The 70 stations I looked at were deliberately biased to stations with longer time-base records. Of these 70 stations, 36 had sea level graphs reasonably qualitatively similar to the "standard picture" of Figures 4-6, although many of these 36 displayed negative accelerations (i.e., decelerations) in level change. The sea level graphs for these 36 stations are shown in Figures A.1.

The remaining 34 stations were not even qualitatively like the standard picture, indicating no trend, or a downward trend, or being irregular in behaviour. The sea level graphs for these 34 stations are shown for comparison (or, rather, for contrast) in Figures A.2.

My analysis has focussed on the 36 stations with behaviour conforming to the standard picture (i.e., Figures A.1). But it should be born in mind that many stations will be more like those of Figures A.2. Hence, any judgment about global average sea level behaviour based only upon the 36 stations of Figures A.1 will tend to over-estimate the rate of GMSL rise and hence also to over-estimate its acceleration.

A.3 Analysis

Quadratic regression was applied to each of the 36 stations' data and the coefficients are given on Figures A.1. The sea level, y mm, wrt some arbitrary datum, is given in terms of the calendar year, x, by $y = ax^2 + bx + c$ so that the rate of rise is $2ax + b$ (mm/year) and the acceleration is 2a (mm/year^2).

Regression was used to find the 95%CL upper and lower bounds to the coefficients, and specifically the coefficient a which determines the acceleration. If the range between the lower and upper 95%CL values for a encompasses zero then the acceleration in the sea level for that station is not statistically significantly different from zero at the 90% confidence level.

Of the 36 stations in Figures A.1, 20 were found to have positive accelerations and 16 to have negative accelerations. Table A.1 lists the 20 stations with positive accelerations together with their best fit acceleration and whether it is statistically significant. For only 5 out of the 20 station datasets with positive best-fit acceleration is this acceleration statistically significant (i.e., different from zero at 90% confidence) for that station taken in isolation.

Table A.1 also lists the fitted rate of rise of sea level, i.e., $2ax + b$, at year x = 2020. The Black Sea appears to have a particularly rapid rise rate but will contribute negligibly to the global average due to its comparatively small size. Nevertheless, even including the Black Sea the simple average rise rate over the 20 stations with positive accelerations is 2.99 mm/year, and their average best-fit acceleration is 0.0175 mm/year^2. The latter is roughly double Church & White's global average acceleration. This is hardly surprising as we have here selected 20 stations out of 70 on the basis of their positive gradients and positive accelerations (i.e., it's a biased sample). The global average would involve including the other 50 stations in the averaging (and, of course, a great many more).

Table A.2 is the equivalent of Table A.1 for the 16 stations with negative accelerations (except I have not checked statistical significance in this case). Two stations turned out to have negative fitted gradients at year 2020. Setting these to zero, the average rise rate for the 16 stations is 1.53 mm/year. The average of the best-fit accelerations in Table A.2 is -0.0140 mm/year^2.

Putting the data from Tables A.1 and A.2 together, the average rise rate at present (2020) for the 34 stations conforming qualitatively to "standard behaviour" is 2.34 mm/year and the average acceleration is 0.0040 mm/year^2.

Both the rise rate and the acceleration derived in this manner are smaller than given by Church & White. This is despite the fact that we have not yet accounted for the 34 stations of Figures A.2 which do not conform to "standard behaviour". These have reducing, or constant, sea levels – or are just anomalous. Their contribution to the global average will therefore be to reduce further the magnitudes of the current rise rate and accelerations, which I would therefore expect to be less than 2.34 mm/year and 0.0040 mm/year^2 respectively, and perhaps a lot less.

I must emphasise at this point that I did not set out to estimate these quantities, and the simplistic averaging of a random, and very small, subset of the world's tidal stations is not a proper basis for such an estimate. The challenge to an analyst attempting to perform this calculation sensibly is to use all the reliable data and to weight them suitably so that all the world's oceans and seas are represented appropriately for their size. The falling level of the Baltic, for example, is of little consequence in view of its relatively small size.

Consequently, I make no extravagant claims for my very crude investigation. However, what it does serve to illustrate quite forcibly is that the weighting given to different stations' data will be crucial to the outcome for the global mean. I noted a number of cases where stations not far distant on the same coast appeared to have directly opposite behaviour, one with rising sea levels and one falling. The details of the weighting process are likely to determine the outcome of any estimate of GMSL change. The naïve perspective promulgated to the public that "scientists measure sea level and it's rising" disguises the difficulties in forming a true global average.

On the other hand, it is not the global average which determines the human impact: it is the local behaviour of the sea.

However, of greatest concern to those investigating climate change is the resulting uncertainty in global average acceleration and its postulated increase, as this is what drives IPCC predictions above their lower bound.

Conclusions for Appendix A

[1] Of the 70 stations selected on the basis of length of record, but otherwise random, 34 stations showed sea level changes which were qualitatively different from the standard picture, i.e., showing no trend or a downward trend, or no consistent trend (Figures A2).

[2] The remaining 36 stations (Figures A.1), which show upward trends, all display sea levels which were rising significantly at the earliest date for which data is available. For ten stations the earliest data starts in the nineteenth century (1843, 1856, 1864, 1865, 1874, 1889, 1896, 1897, 1897, 1899). A further 14 stations' earliest data starts between 1900 and 1927.

[3] Comparing with the history of CO_2 (Figure 7), these observations imply that most of the current rate of sea level rise is not due to CO_2.

[4] Of the 36 stations which have consistent upwards trends, 20 show positive accelerations, and 16 show negative accelerations. Of the 20 positive accelerations, only 5 were statistically significantly different from zero at the 90% confidence level, on an individual station basis. (It is acknowledged that pooling global data might enhance statistical significance).

[5] The above findings can crudely be characterised thus: ~50% of stations do not show consistent upward trend; only slightly more than 25% show a consistent upward trend with positive acceleration; only slightly less than 25% show a consistent upward trend but with negative acceleration.

[6] Whilst the cursory examination conducted here cannot provide a properly weighted global average, the implication of these observations is that the current GMSL trend in rise rate appears slower than Church & White's ~3 mm/year, and the global mean acceleration lower than their 0.009 mm/year^2, perhaps a great deal lower.

[7] The evaluation of GMSL trend and acceleration will be very sensitive to how stations' data is weighted in the attempt to correctly represent the entirety of the world's aqueous volume. Possibly satellite data may be beneficial in this respect, but satellite data has not been examined here.

Table A.1: Stations with "standard behaviour" and positive accelerations. The "statistical significance" refers to the acceleration, not the rate of rise.

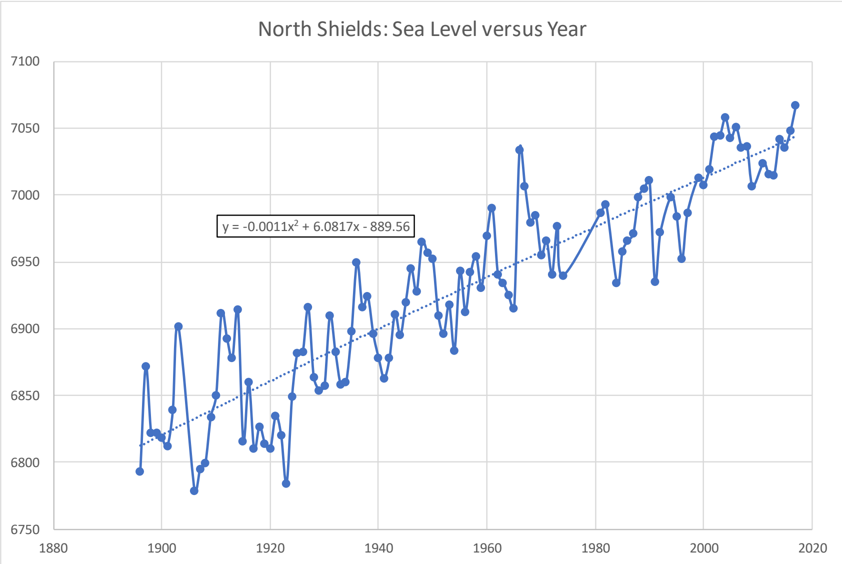
Station	Statistically Significant?	Acceleration (mm/year^2)	Fitted Rate of Rise 2020 (mm/year)
Newlyn, UK	No	0.0081	2.30
Seattle, USA	No*	0.0100	2.67
Prince Rupert, Gulf of Alaska	No	0.0101	1.69
Den Helder, Netherlands	No	0.0036	1.76
Esbjerg, Denmark	No	0.0106	1.95
Korsor, Denmark	No*	0.0082	1.36
Warnemunde, Germany	Yes	0.0066	1.81
Tuapse, Black Sea	No	0.0174	3.36
Poti, Black Sea	Yes	0.0221	8.33
La Jolla, California	No	0.0039	2.24
Key West, Gulf of Mexico	Yes	0.0140	3.18
Pensacola, Gulf of Mexico	No	0.0114	2.96
Atlantic City, USA	No	0.0106	4.68
Charlotte, Canada	No	0.0043	3.34
Wellington (NZ)	Yes	0.0586	4.93
Bluff (NZ)	Yes	0.0206	2.82
Adelaide. Australia	No	0.0111	1.89
Cebu, Philippines	No	0.0450	3.27
Visak, Bay of Bengal	No	0.0221	1.99
Bunbury, Australia	No	0.0511	3.34
Average	**-**	**0.0175**	**2.99**

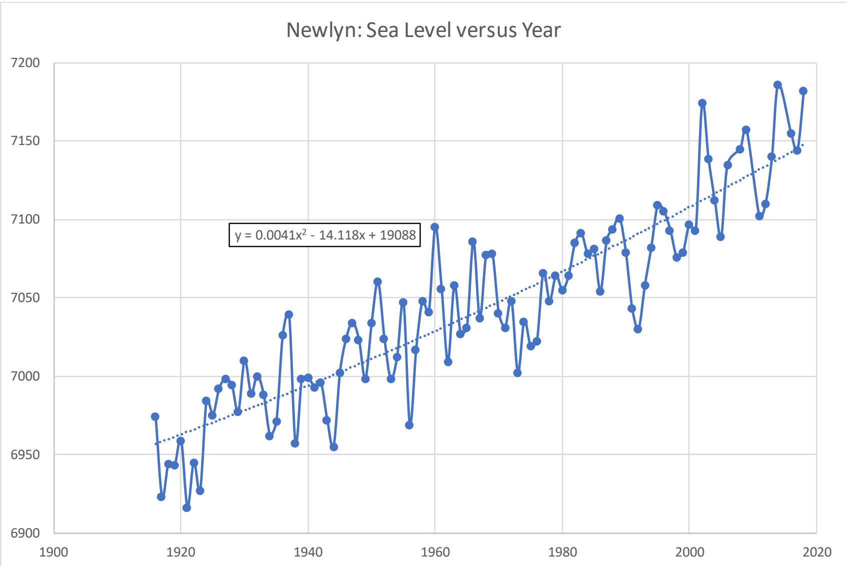
**close miss*

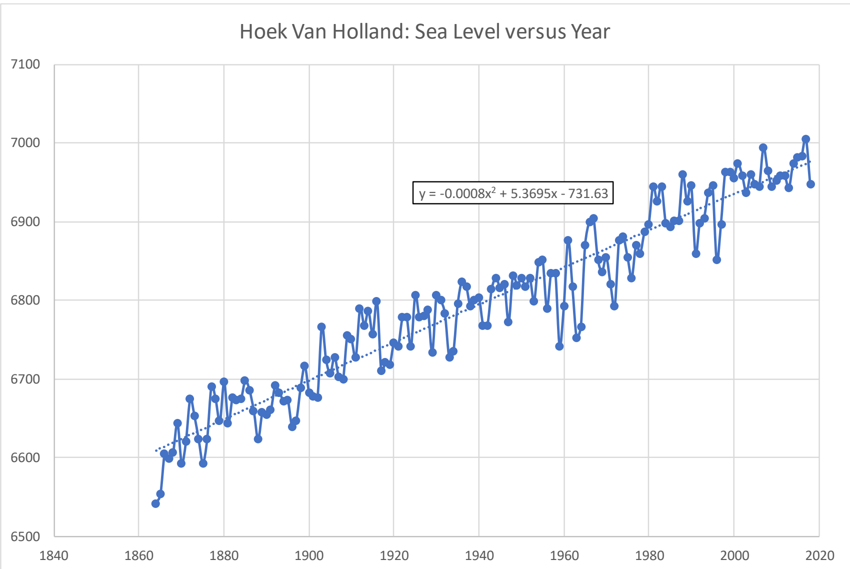
Table A.2: Stations with "standard behaviour" but negative accelerations

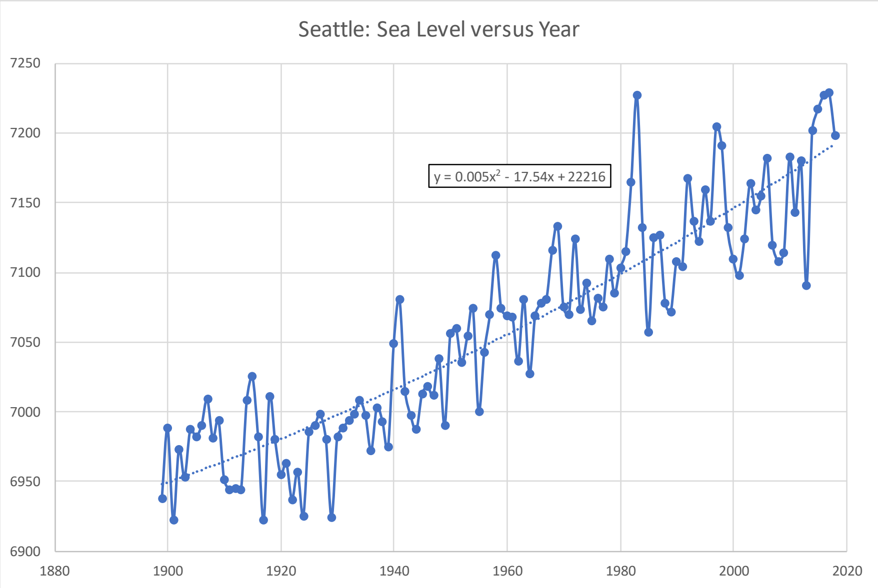
Station	Acceleration (mm/year^2)	Fitted Rate of Rise 2020 (mm/year)
North Shields, UK	-0.0022	1.64
Hoek Van Holland	-0.0016	2.14
Cuxhaven, Germany	-0.0080	1.16
Reykjavic, Iceland	-0.0306	1.12
Kotelnyi, Russia (Laptev Sea)	-0.0464	2.84
Hilo, Hawaii	-0.0178	2.36
Portland, Maine, USA	-0.0058	1.57
Boston, USA	-0.0058	2.69
St.John, Canada	-0.0058	1.75
Auckland (NZ)	-0.0160	0.25
Phrachula, Thailand		Negative
Lagos, Portugal	-0.0360	Negative
Alexandria, Egypt	-0.0088	1.42
Argentine Islands, Antarctica	-0.0112	0.84
Montevideo, Uruguay	-0.0006	0.83
Cananeia, Brazil	-0.0140	3.91
Average	**-0.0140**	**1.53**

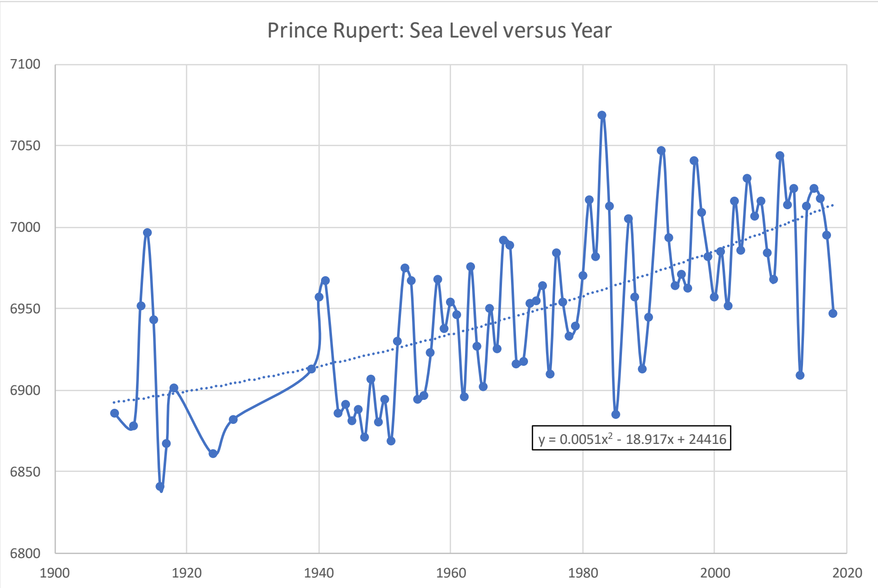
Figures A.1: Data from the 36 tidal stations illustrated here are qualitatively similar to the "standard picture" exemplified by Figures 4-6 (i.e., continuously rising sea levels)

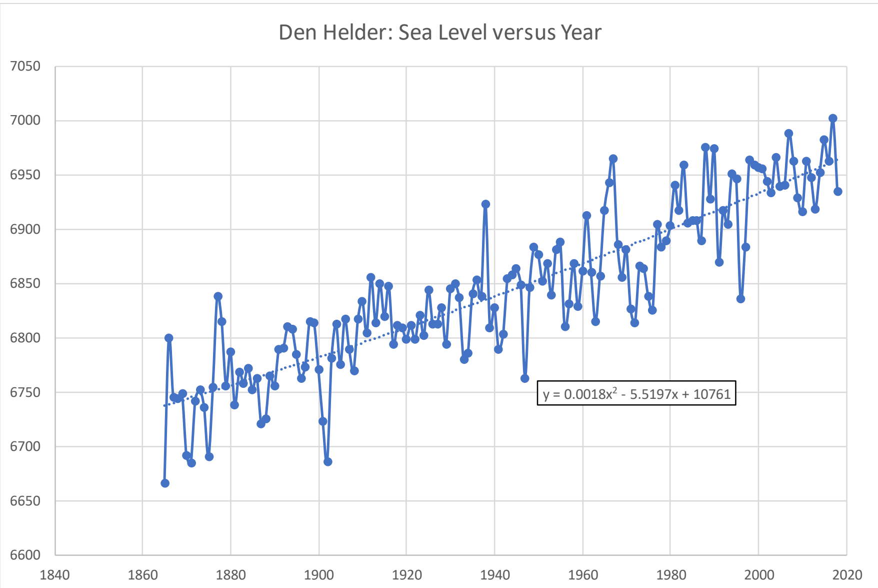


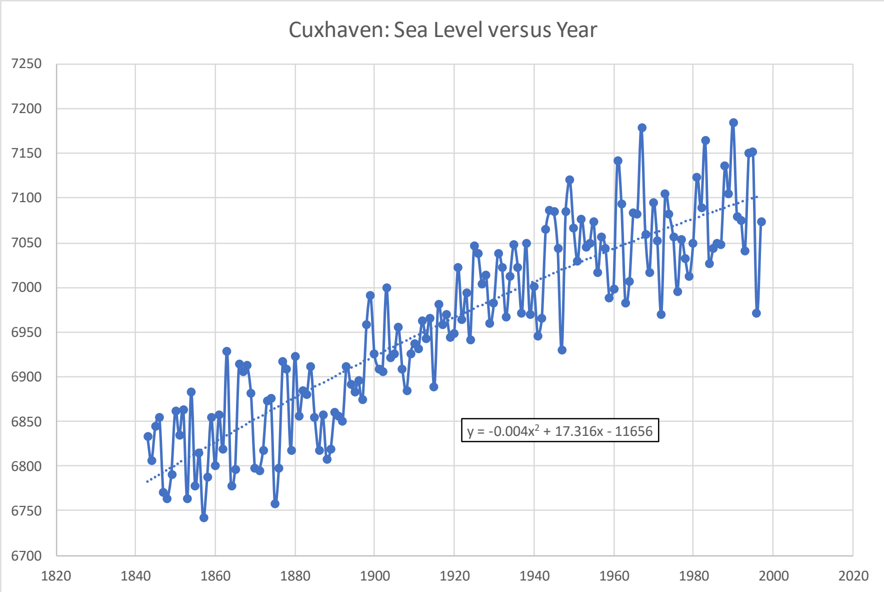




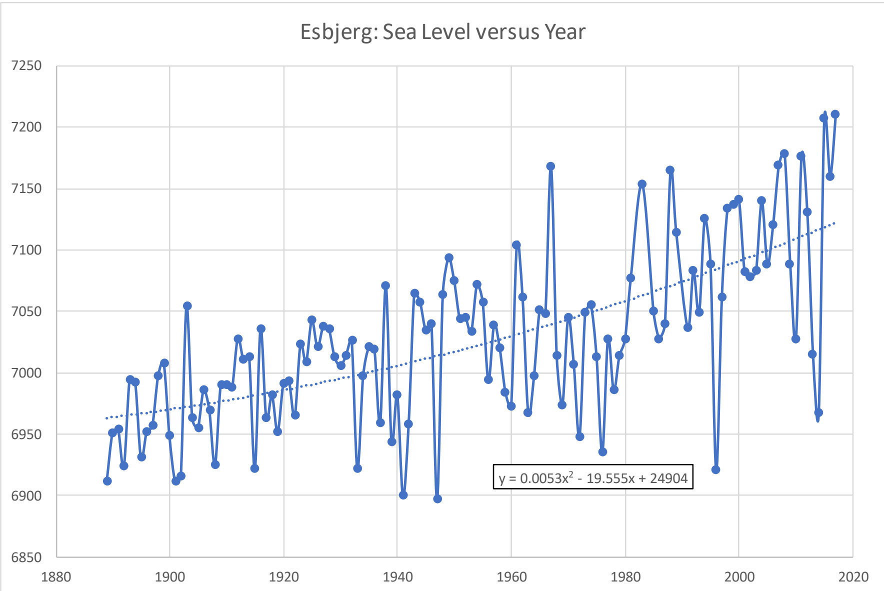

Seattle: Sea Level versus Year
y = 0.005x² - 17.54x + 22216
7250
7200
7150
7100
7050
7000
6950
6900
1880
1900
1920
1940
1960
1980
2000
2020


Prince Rupert: Sea Level versus Year
y = 0.0051x² - 18.917x + 24416
7100
7050
7000
6950
6900
6850
6800
1900
1920
1940
1960
1980
2000
2020

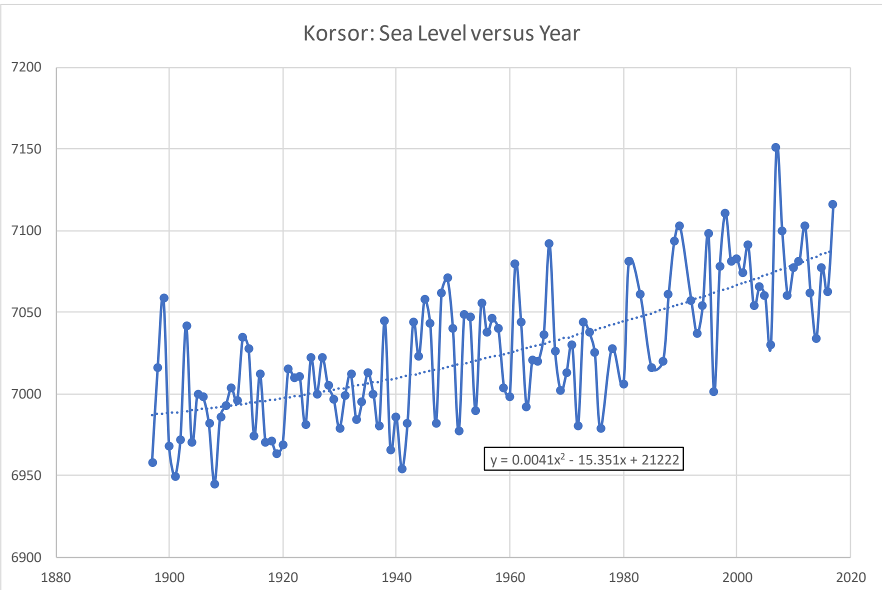

Den Helder: Sea Level versus Year
y = 0.0018x² - 5.5197x + 10761
7050
7000
6950
6900
6850
6800
6750
6700
6650
6600
1840
1860
1880
1900
1920
1940
1960
1980
2000
2020



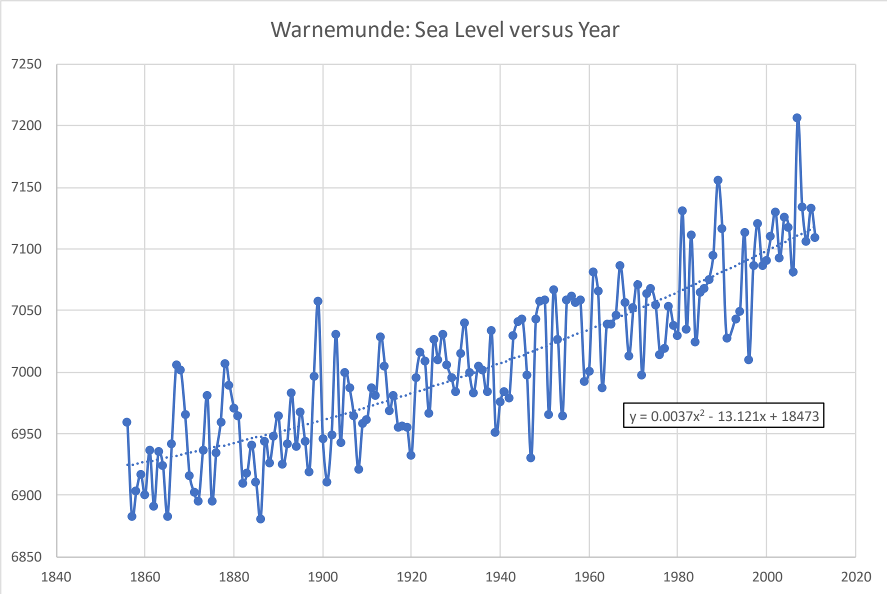
Cuxhaven: Sea Level versus Year
7250
7200
7150
7100
7050
7000
6950
6900
6850
6800
6750
6700
1820
1840
1860
1880
1900
1920
1940
1960
1980
2000
2020
y = -0.004x² + 17.316x - 11656

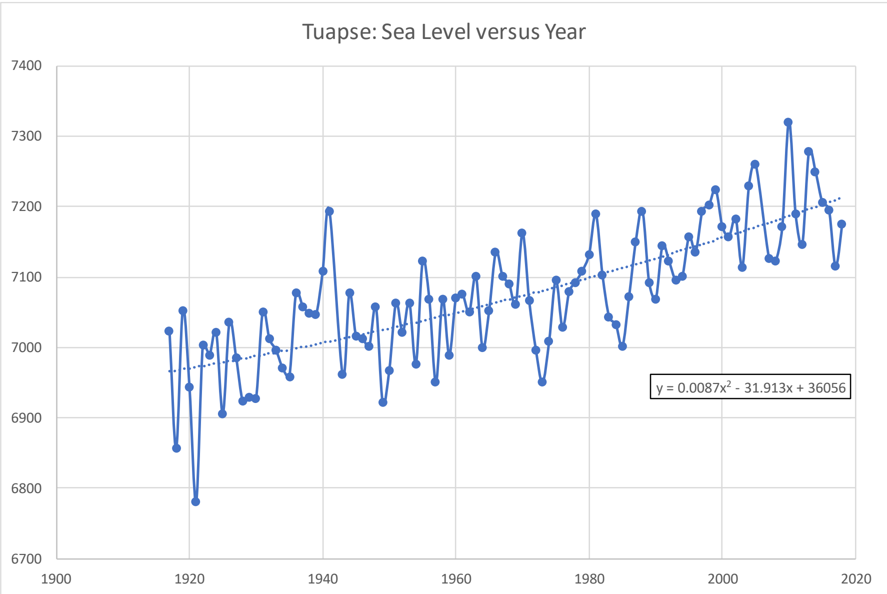


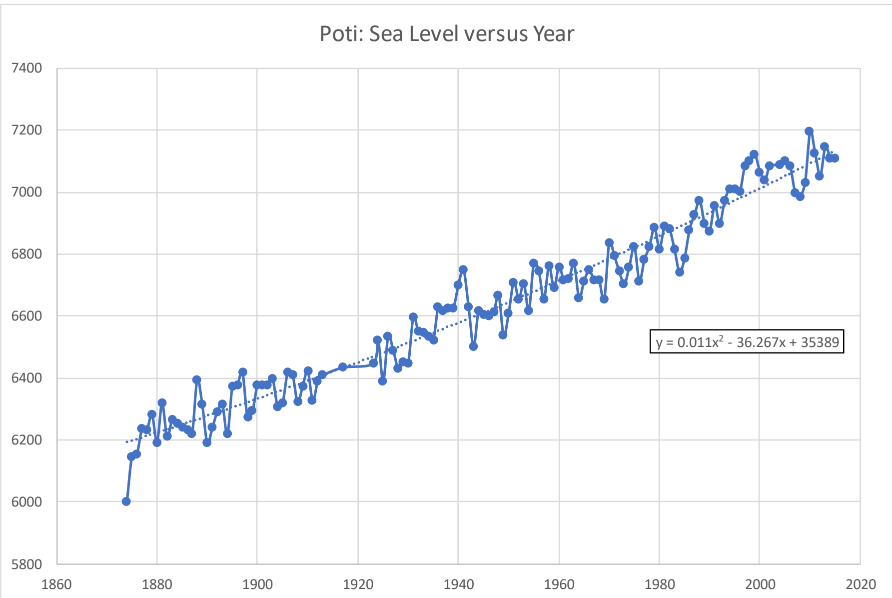
Esbjerg: Sea Level versus Year
7250
7200
7150
7100
7050
7000
6950
6900
6850
1880
1900
1920
1940
1960
1980
2000
2020
y = 0.0053x² - 19.555x + 24904

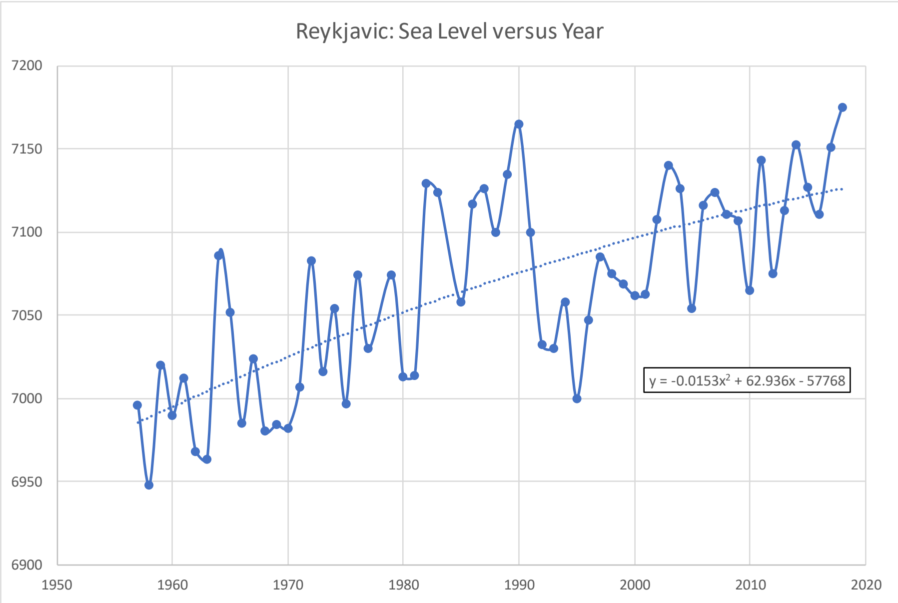


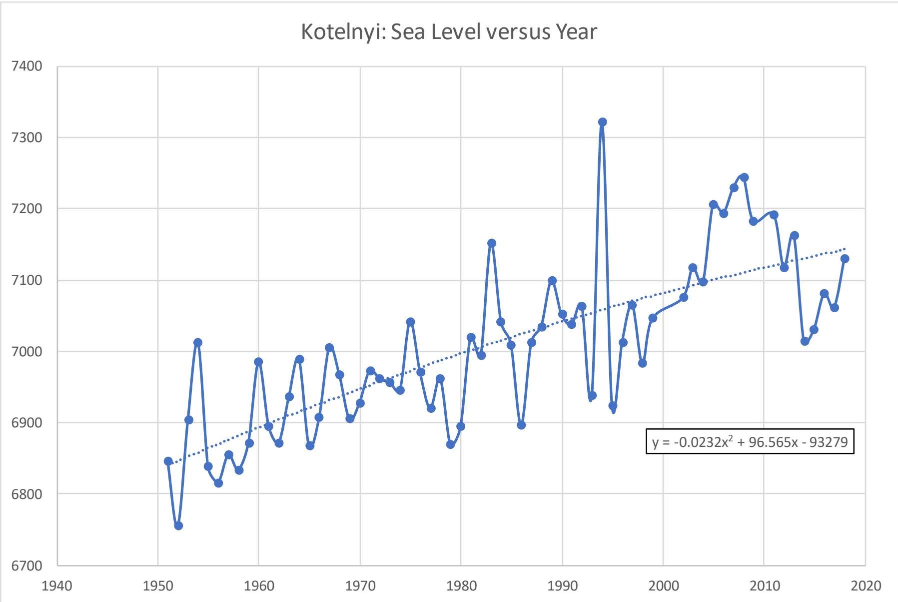
Korsor: Sea Level versus Year
7200
7150
7100
7050
7000
6950
6900
1880
1900
1920
1940
1960
1980
2000
2020
y = 0.0041x² - 15.351x + 21222

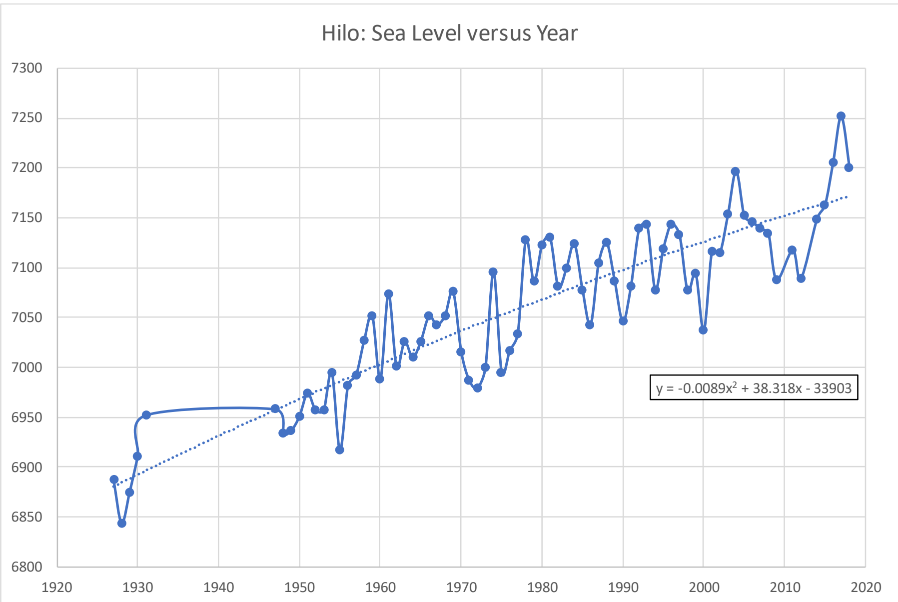

Warnemunde: Sea Level versus Year
7250
7200
7150
7100
7050
7000
6950
6900
6850
1840
1860
1880
1900
1920
1940
1960
1980
2000
2020
y = 0.0037x² - 13.121x + 18473

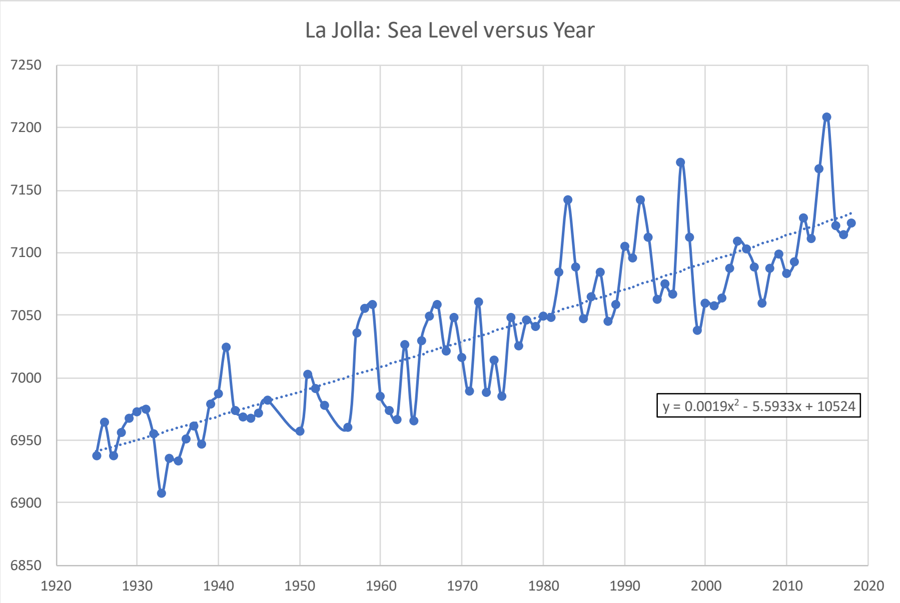

Tuapse: Sea Level versus Year
7400
7300
7200
7100
7000
6900
6800
6700
1900
1920
1940
1960
1980
2000
2020
y = 0.0087x² - 31.913x + 36056

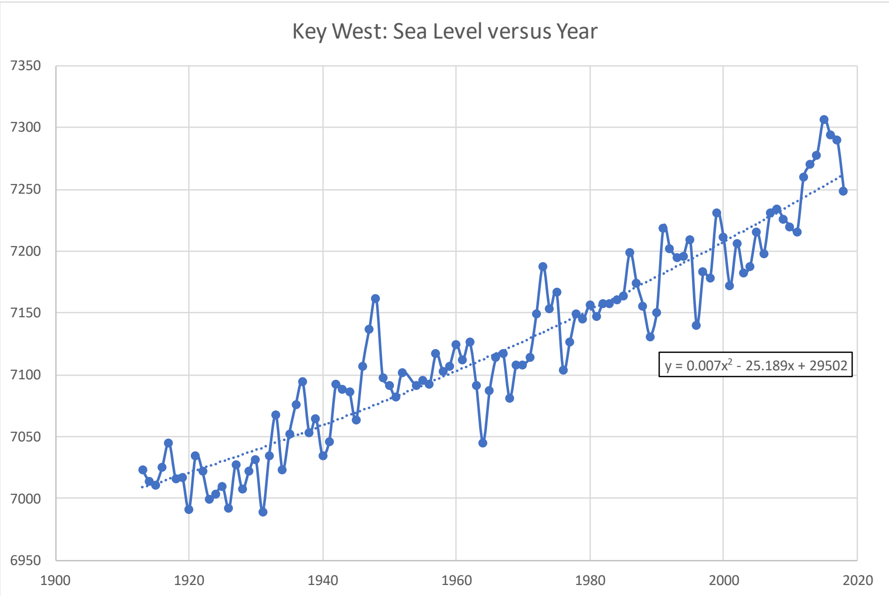

Poti: Sea Level versus Year
7400
7200
7000
6800
6600
6400
6200
6000
5800
1860
1880
1900
1920
1940
1960
1980
2000
2020
y = 0.011x² - 36.267x + 35389

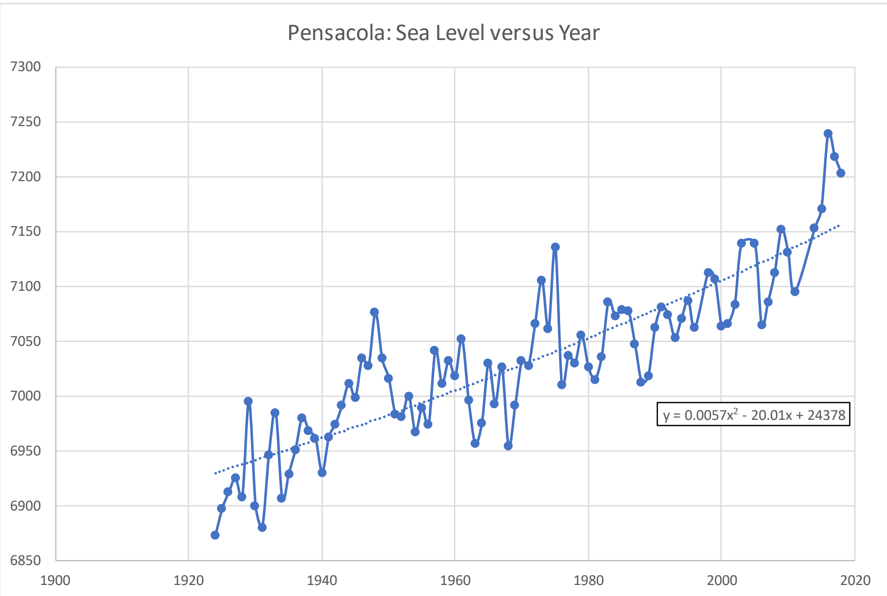

Reykjavic: Sea Level versus Year
y = -0.0153x² + 62.936x - 57768
7200
7150
7100
7050
7000
6950
6900
1950
1960
1970
1980
1990
2000
2010
2020

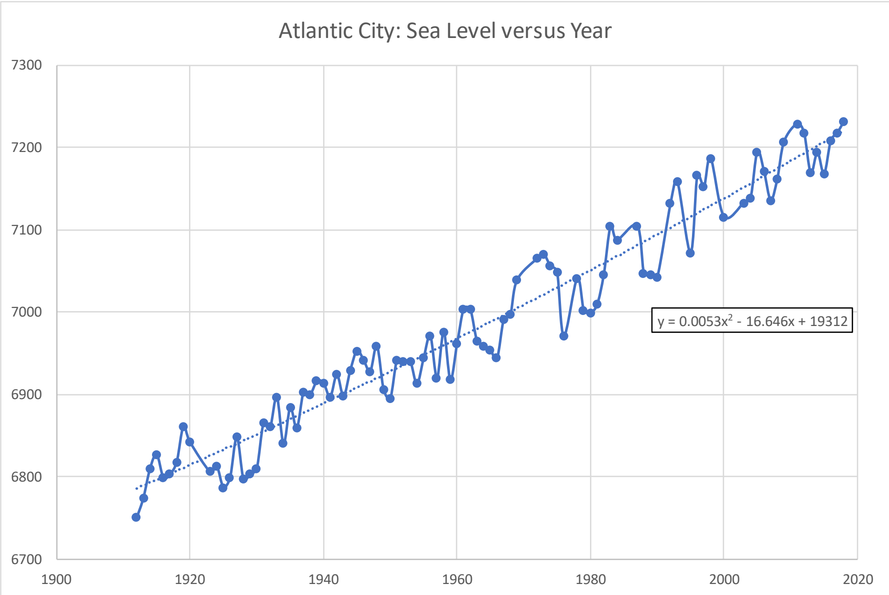

Kotelnyi: Sea Level versus Year
y = -0.0232x² + 96.565x - 93279
7400
7300
7200
7100
7000
6900
6800
6700
1940
1950
1960
1970
1980
1990
2000
2010
2020

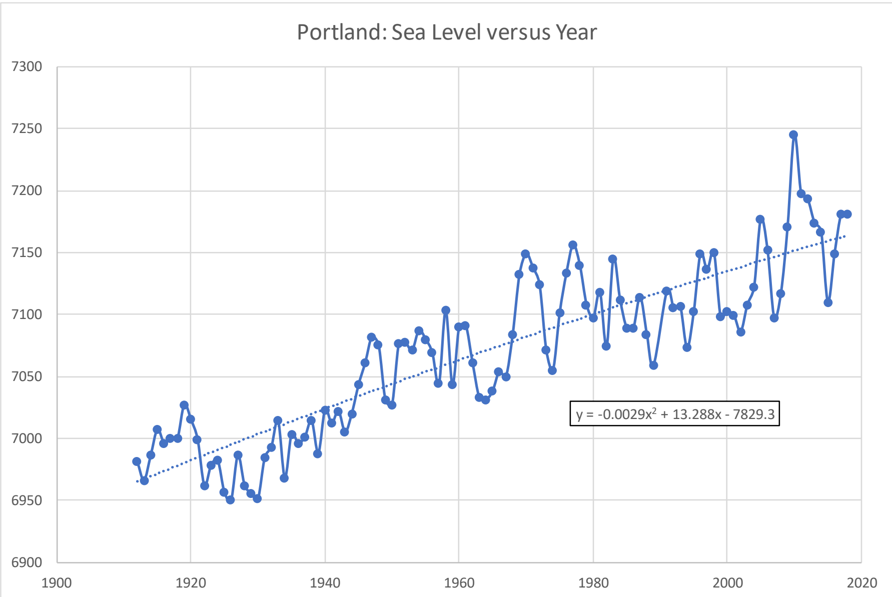

Hilo: Sea Level versus Year
y = -0.0089x² + 38.318x - 33903
7300
7250
7200
7150
7100
7050
7000
6950
6900
6850
6800
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

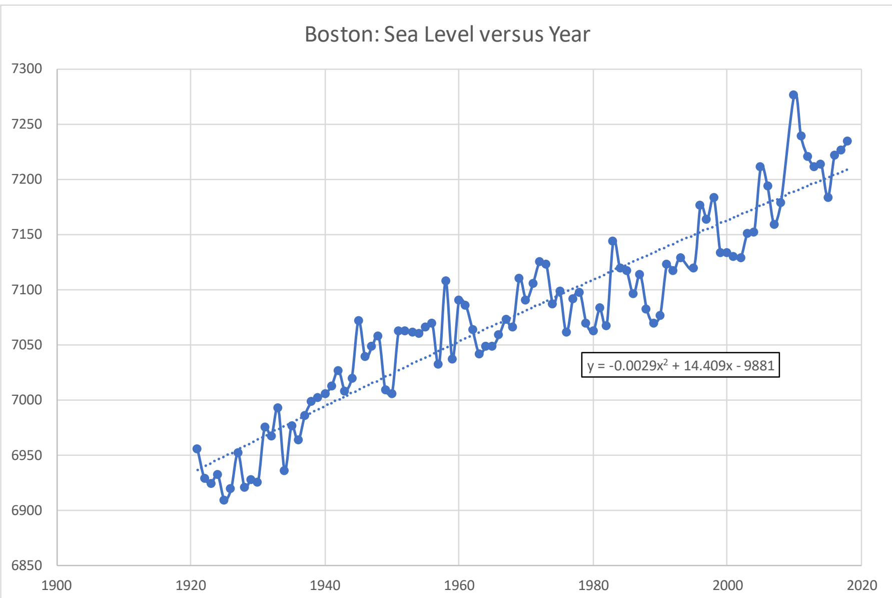

La Jolla: Sea Level versus Year
7250
7200
7150
7100
7050
7000
6950
6900
6850
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
y = 0.0019x² - 5.5933x + 10524

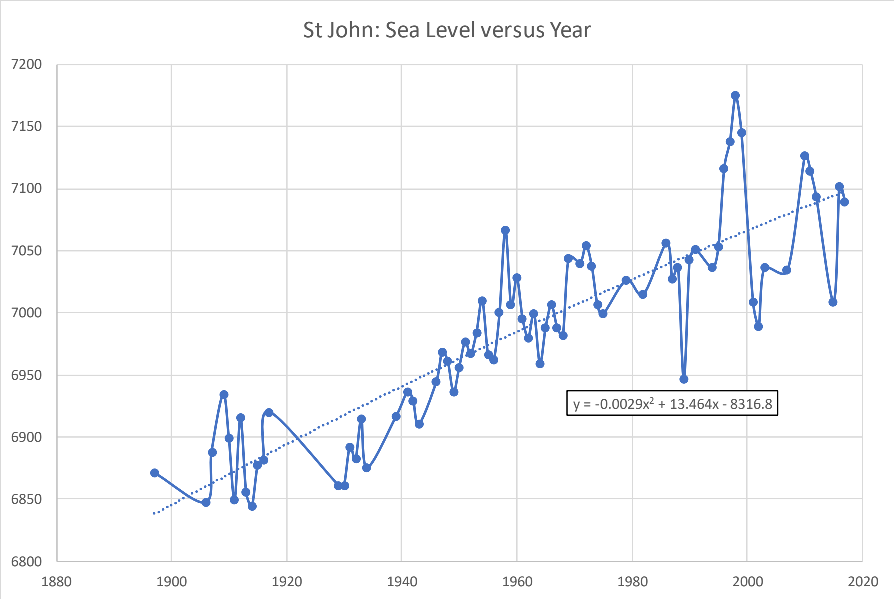

Key West: Sea Level versus Year
7350
7300
7250
7200
7150
7100
7050
7000
6950
1900
1920
1940
1960
1980
2000
2020
y = 0.007x² - 25.189x + 29502


Pensacola: Sea Level versus Year
7300
7250
7200
7150
7100
7050
7000
6950
6900
6850
1900
1920
1940
1960
1980
2000
2020
y = 0.0057x² - 20.01x + 24378

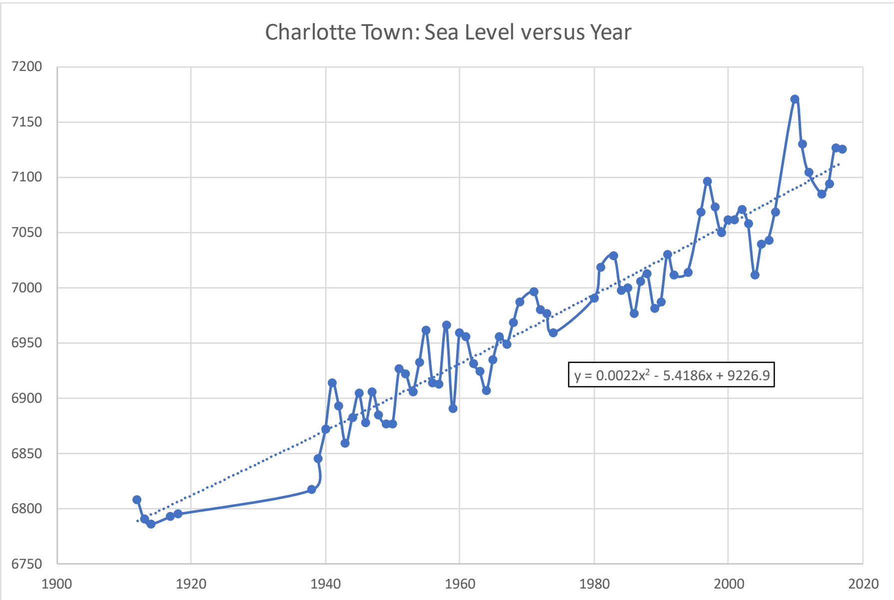

Atlantic City: Sea Level versus Year
y = 0.0053x² - 16.646x + 19312
7300
7200
7100
7000
6900
6800
6700
1900
1920
1940
1960
1980
2000
2020


Portland: Sea Level versus Year
y = -0.0029x² + 13.288x - 7829.3
7300
7250
7200
7150
7100
7050
7000
6950
6900
1900
1920
1940
1960
1980
2000
2020

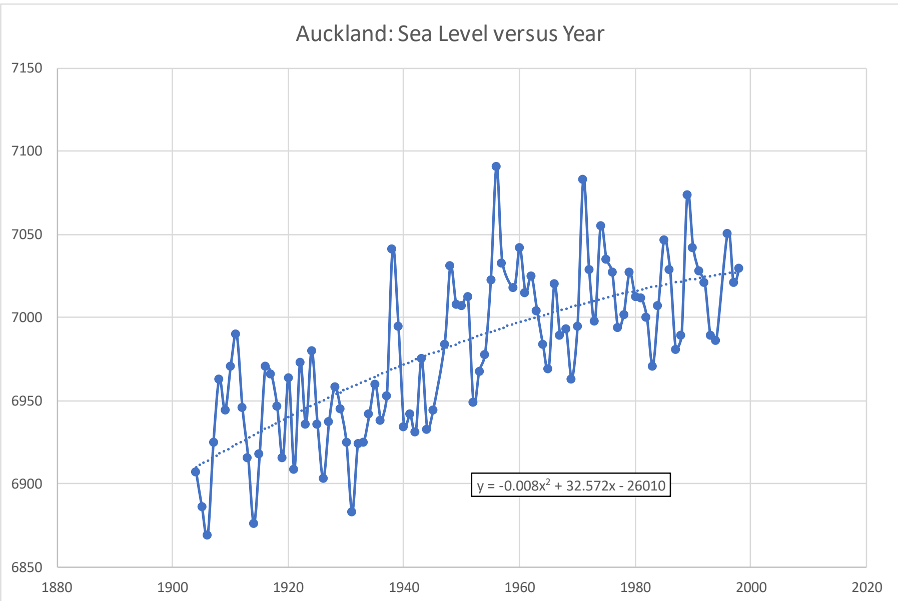

Boston: Sea Level versus Year
y = -0.0029x² + 14.409x - 9881
7300
7250
7200
7150
7100
7050
7000
6950
6900
6850
1900
1920
1940
1960
1980
2000
2020



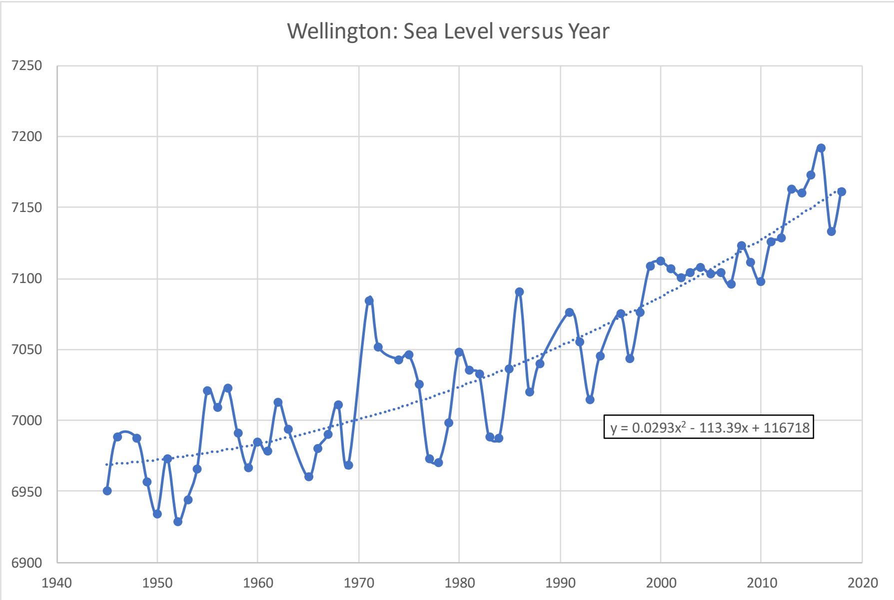
St John: Sea Level versus Year
y = -0.0029x² + 13.464x - 8316.8
7200
7150
7100
7050
7000
6950
6900
6850
6800
1880
1900
1920
1940
1960
1980
2000
2020

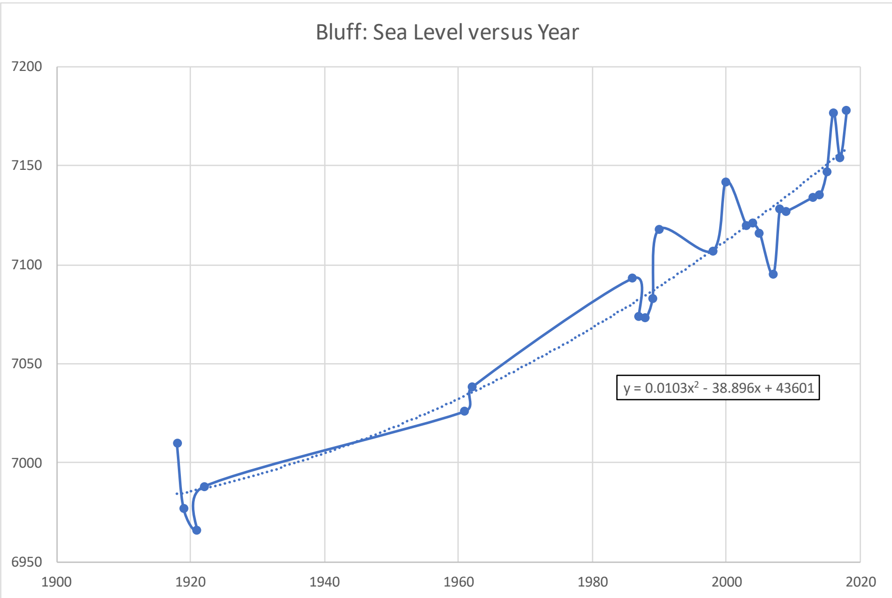


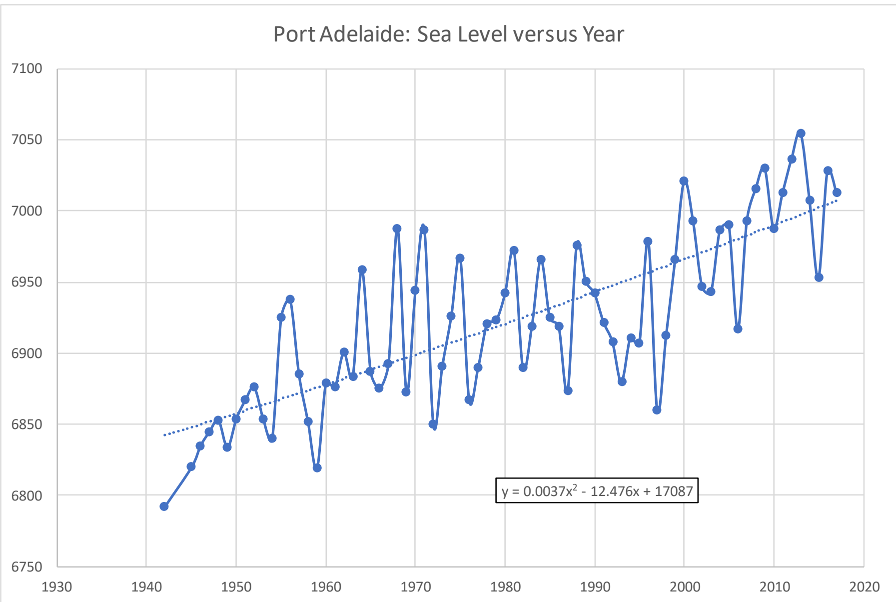
Charlotte Town: Sea Level versus Year
y = 0.0022x² - 5.4186x + 9226.9
7200
7150
7100
7050
7000
6950
6900
6850
6800
6750
1900
1920
1940
1960
1980
2000
2020

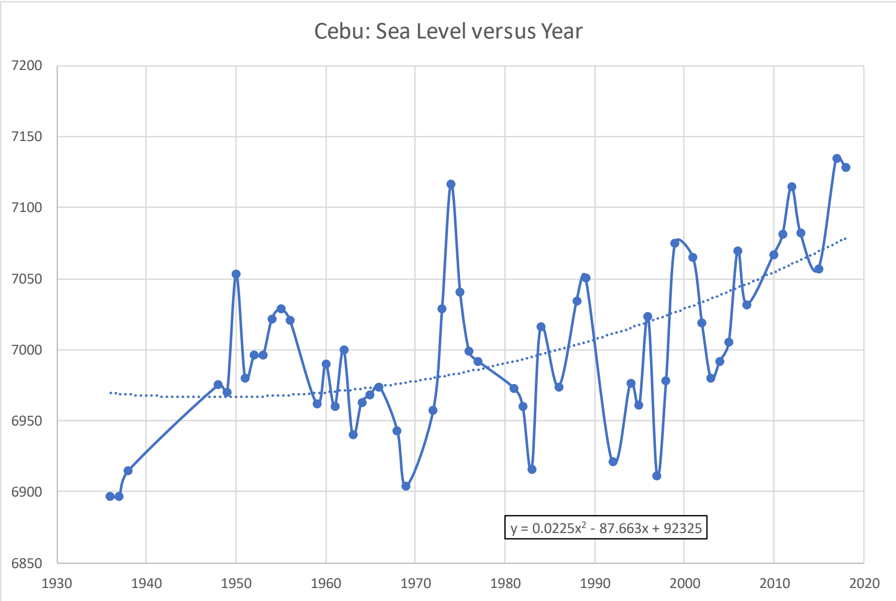


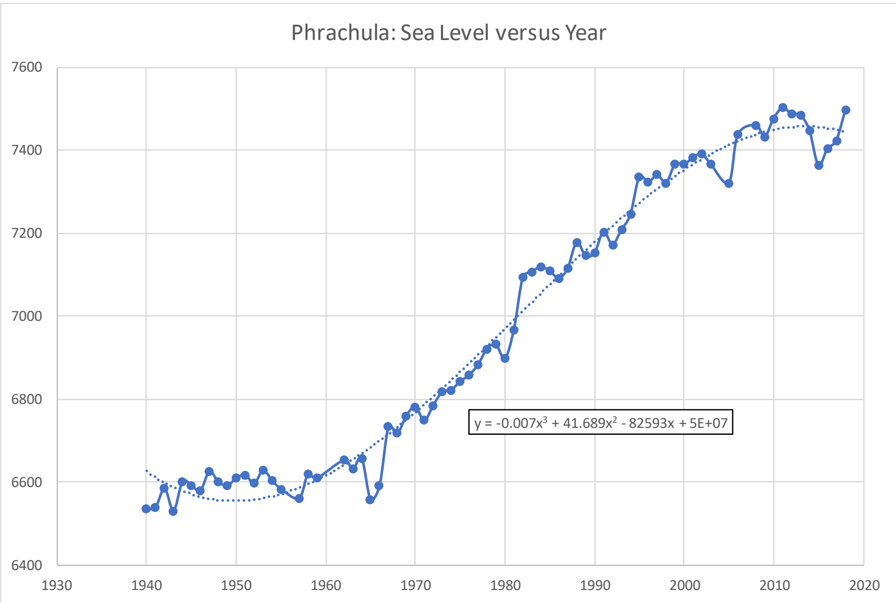
Auckland: Sea Level versus Year
y = -0.008x² + 32.572x - 26010
7150
7100
7050
7000
6950
6900
6850
1880
1900
1920
1940
1960
1980
2000
2020

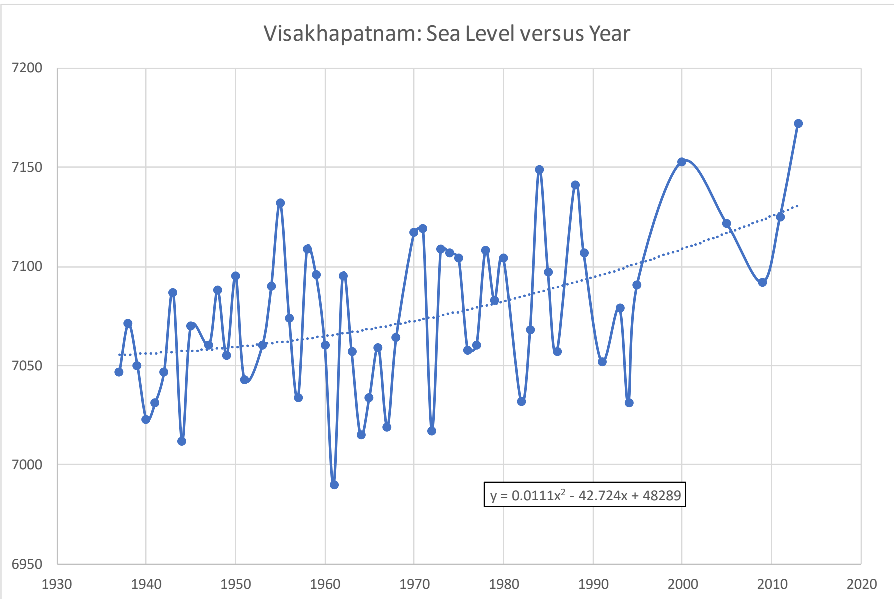

Wellington: Sea Level versus Year
7250
7200
7150
7100
7050
7000
6950
6900
1940
1950
1960
1970
1980
1990
2000
2010
2020
y = 0.0293x² - 113.39x + 116718

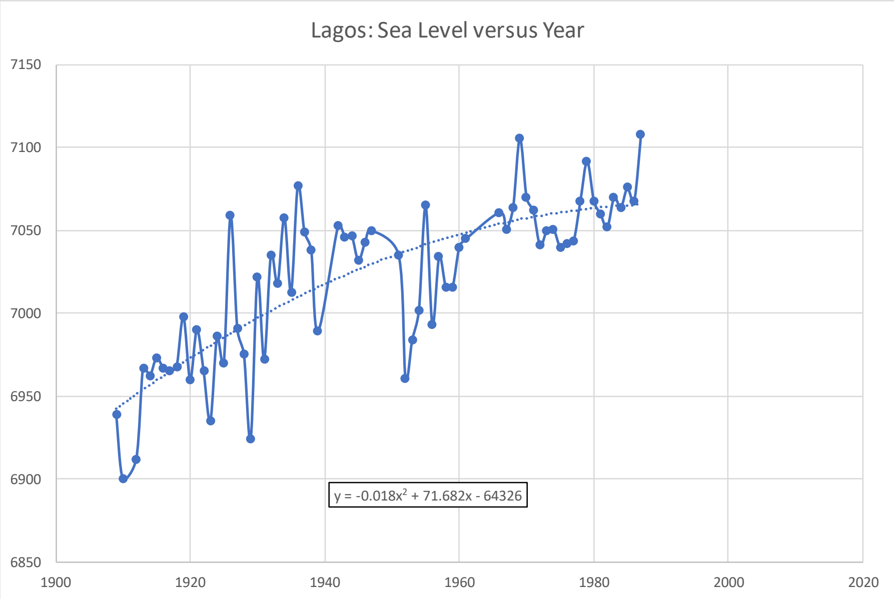

Bluff: Sea Level versus Year
7200
7150
7100
7050
7000
6950
1900
1920
1940
1960
1980
2000
2020
y = 0.0103x² - 38.896x + 43601


Port Adelaide: Sea Level versus Year
7100
7050
7000
6950
6900
6850
6800
6750
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
y = 0.0037x² - 12.476x + 17087

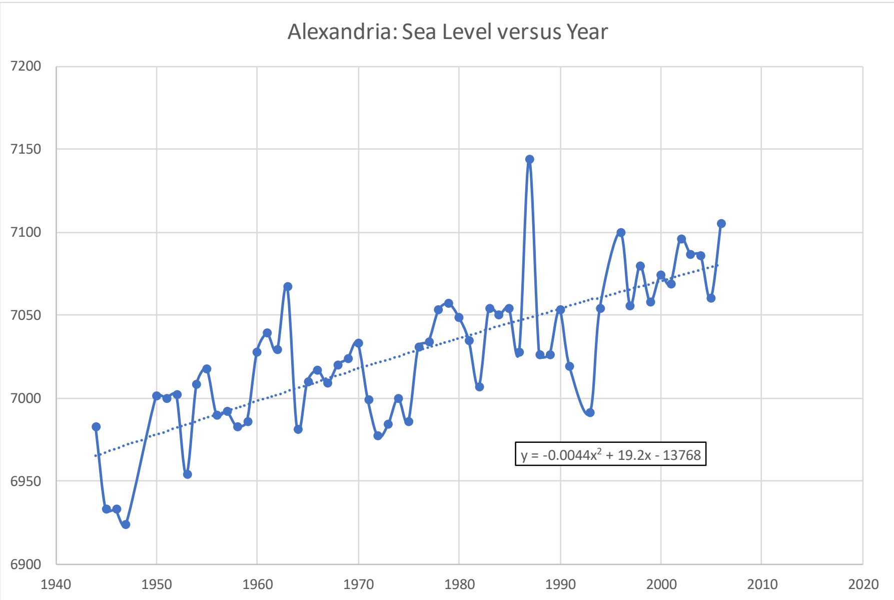

Cebu: Sea Level versus Year
7200
7150
7100
7050
7000
6950
6900
6850
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
y = 0.0225x² - 87.663x + 92325


Phrachula: Sea Level versus Year
7600
7400
7200
7000
6800
6600
6400
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
y = -0.007x³ + 41.689x² - 82593x + 5E+07

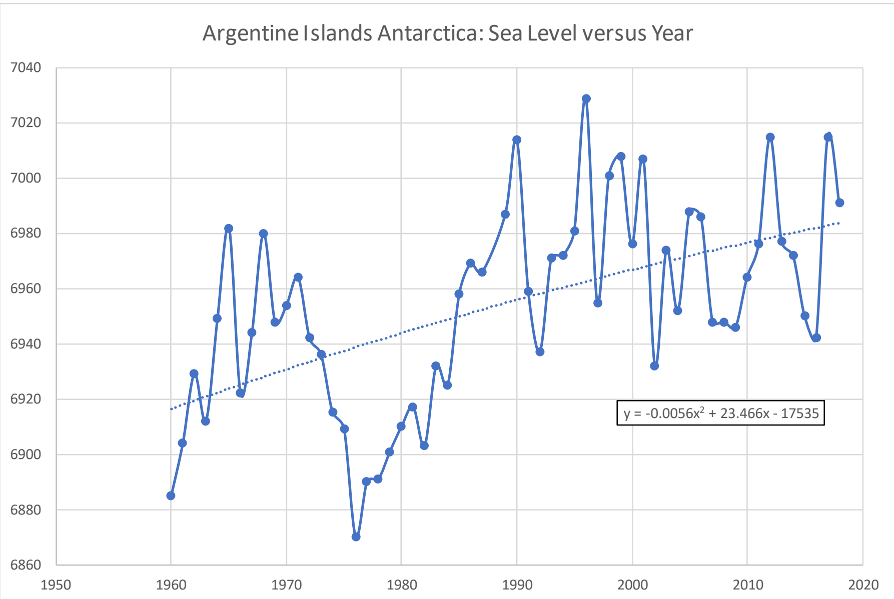

Visakhapatnam: Sea Level versus Year
7200
7150
7100
7050
7000
6950
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
y = 0.0111x² - 42.724x + 48289



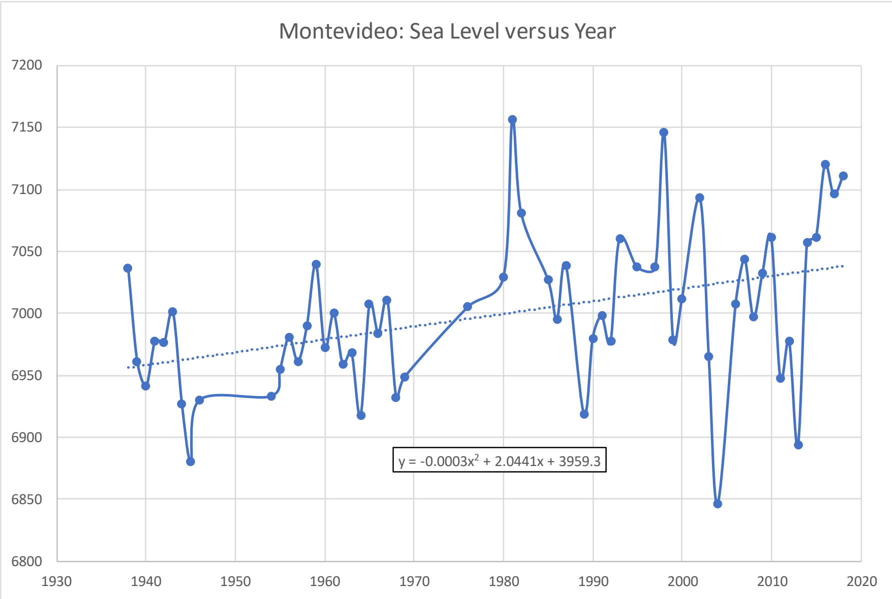
Lagos: Sea Level versus Year
7150
7100
7050
7000
6950
6900
6850
1900
1920
1940
1960
1980
2000
2020
y = -0.018x² + 71.682x - 64326

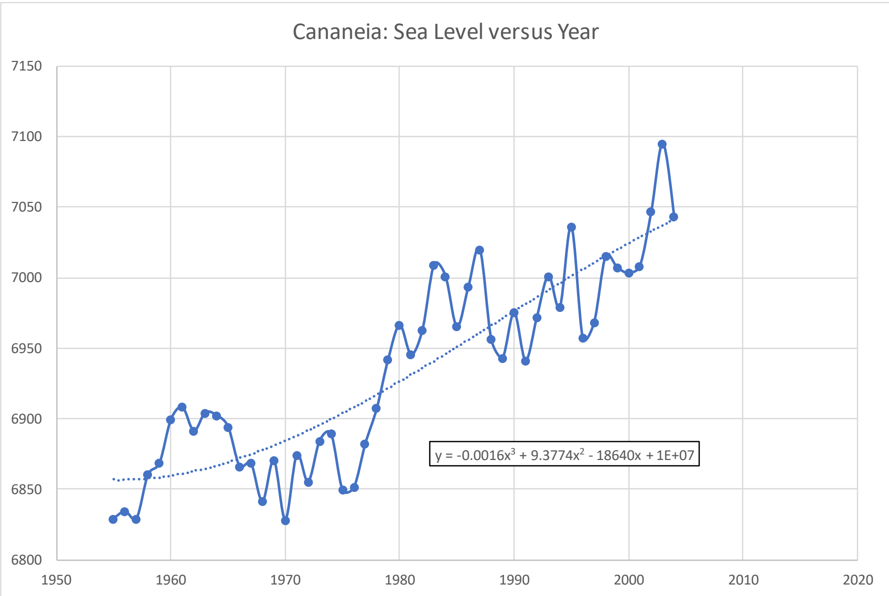


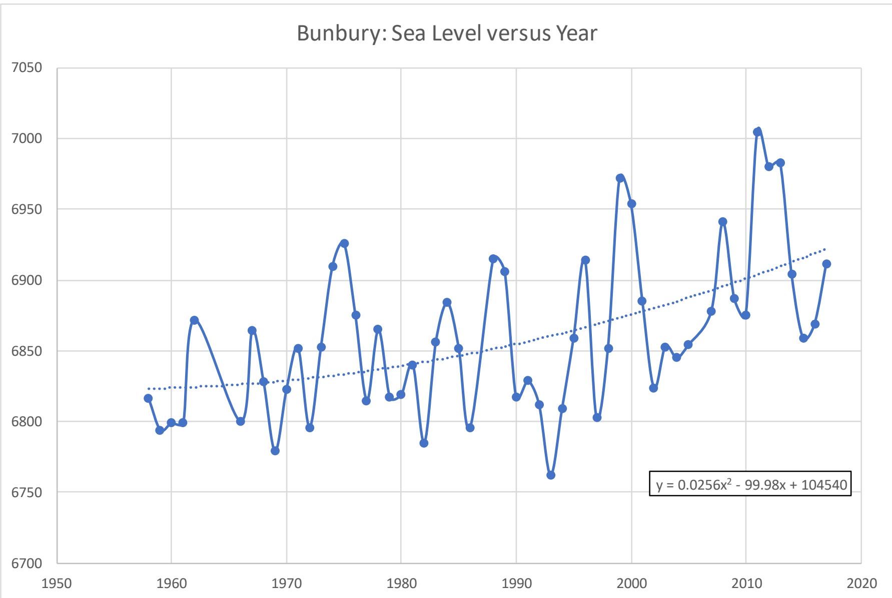
Alexandria: Sea Level versus Year
7200
7150
7100
7050
7000
6950
6900
1940
1950
1960
1970
1980
1990
2000
2010
2020
y = -0.0044x² + 19.2x - 13768



Argentine Islands Antarctica: Sea Level versus Year
7040
7020
7000
6980
6960
6940
6920
6900
6880
6860
1950
1960
1970
1980
1990
2000
2010
2020
y = -0.0056x² + 23.466x - 17535

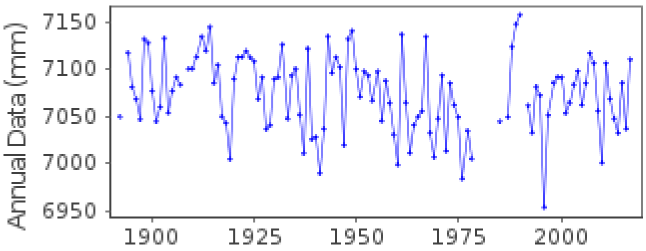

Montevideo: Sea Level versus Year
y = -0.0003x² + 2.0441x + 3959.3
7200
7150
7100
7050
7000
6950
6900
6850
6800
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020


Cananeia: Sea Level versus Year
y = -0.0016x³ + 9.3774x² - 18640x + 1E+07
7150
7100
7050
7000
6950
6900
6850
6800
1950
1960
1970
1980
1990
2000
2010
2020

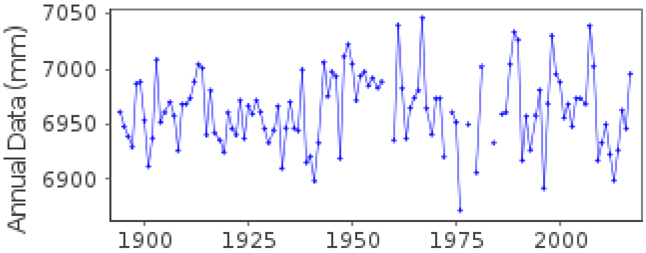

Bunbury: Sea Level versus Year
y = 0.0256x² - 99.98x + 104540
7050
7000
6950
6900
6850
6800
6750
6700
1950
1960
1970
1980
1990
2000
2010
2020

Figures A.2: The data from the 34 tidal stations illustrated here are qualitatively different from the "standard picture" exemplified by Figures 4-6

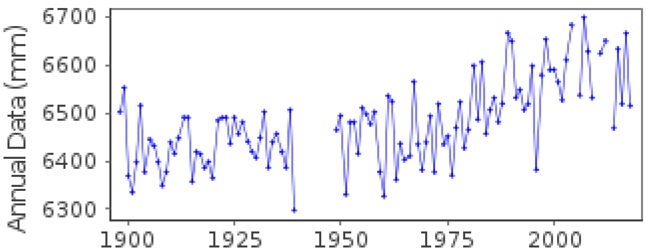
(a) Hirtshals (Denmark) – no trend



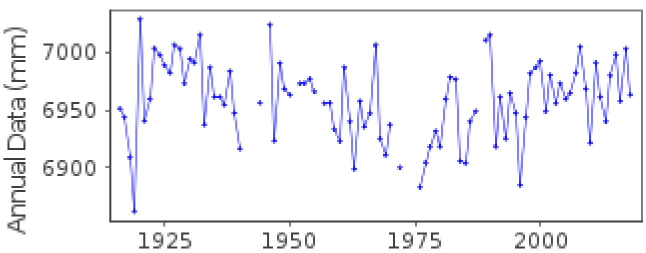
(b) Frederikshavn (Denmark) – no trend



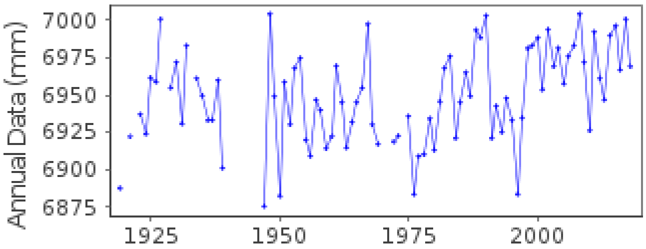
(c) Klaipeda (Lithuania)- irregular



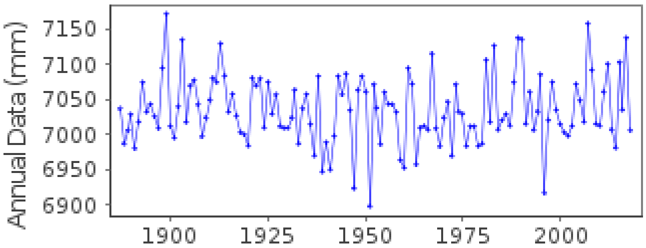
(d) Bergen (Norway) – no increase



(e) Stavanger (Norway) - little change

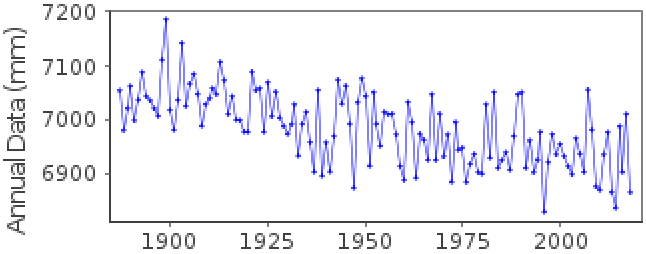


(f) Kungsholmsfort (Sweden) – no trend

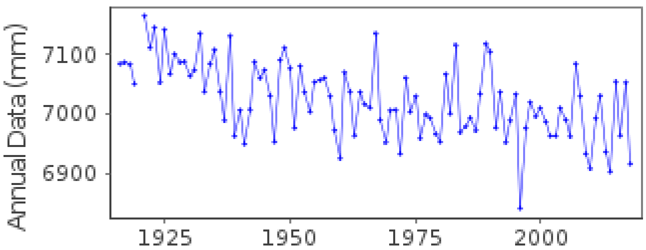


The next six are all on the Baltic and indicate a consistent downward trend. The Baltic is dropping.

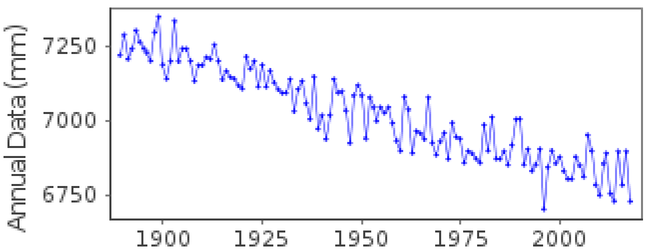
(g) Orlands Norra Udde (Sweden) – Baltic – Trends downwards



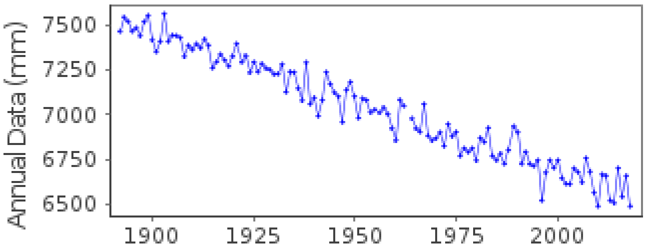
(h) Visby (Sweden) – Island in Baltic, opposite Orlands Norra Udde – also trends down



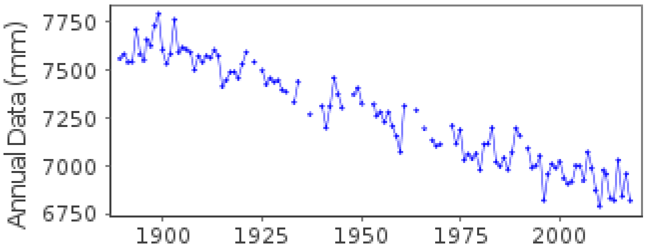
(i) Stockholm (Sweden) – also trends down



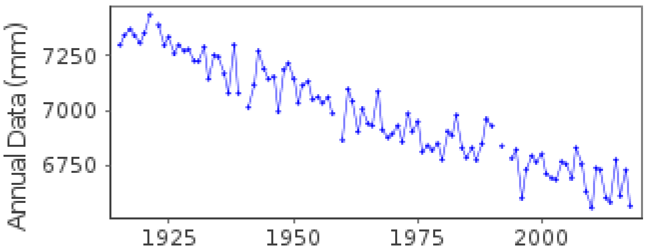
(j) Ratan (Sweden) – northern end of Baltic – also trends down



(k) Oulu / Uleaborg (Finland, Baltic) – again trends down – clearly real

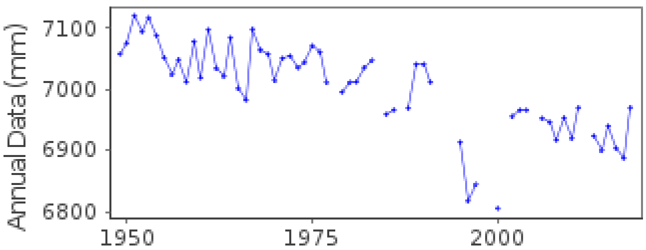


(l) Pietarsaari / Jakobstad (Finland) – and again

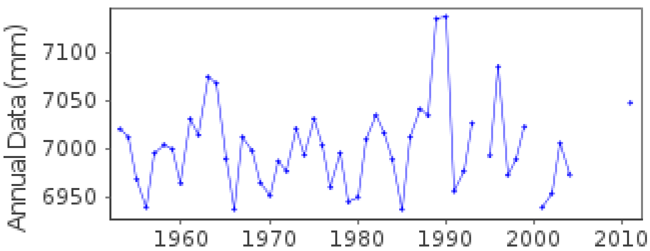


The next 8 are in cold northern seas and most indicate downward trends or no trend…

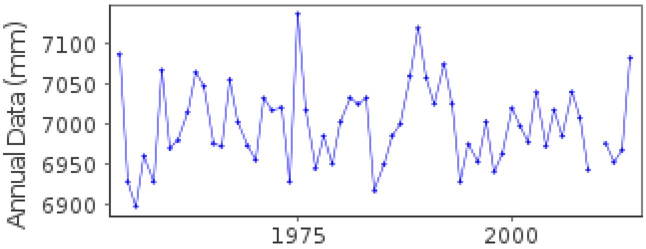
(m) Barentsburg (Svalbard) – Greenland Sea - trend downwards



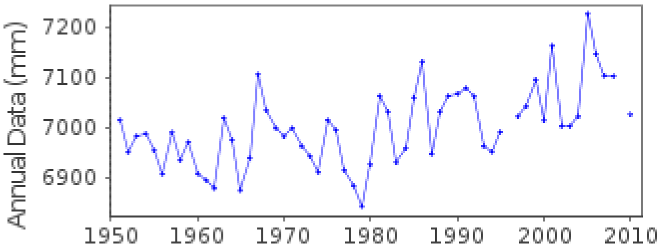
(n) Vise Ostrov (Island North of Russia in Kara Sea) – no trend



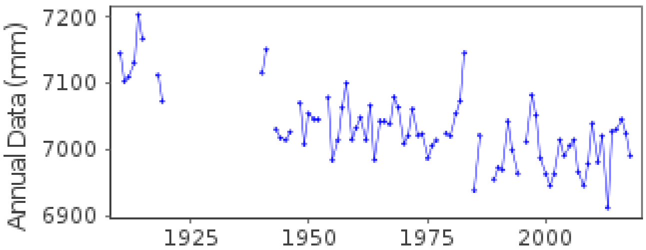
(o) Izvestia Tsik Ostrov (Russian Fed) Island in Kara Sea – no trend



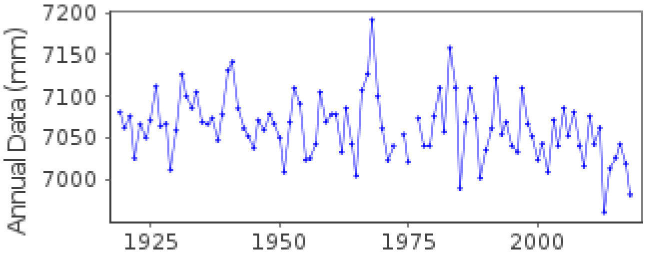
(p) Dunai Ostrov (Russian Fed) , Laptev Sea coast



(q) Tofino (north of Vancouver) – downward trend

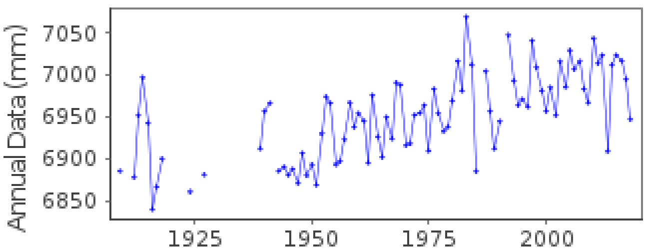


(r) Ketchikan (Gulf of Alaska) – downward trend

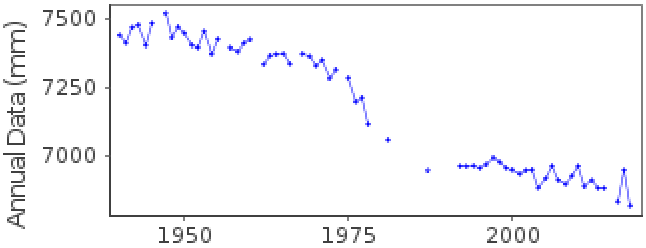


Ketchikan goes down, whilst nearby Prince Rupert goes up…

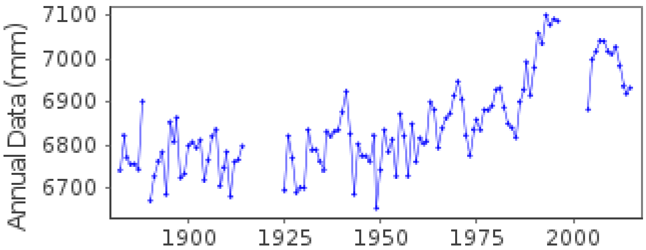
(s) Prince Rupert (Gulf of Alaska)



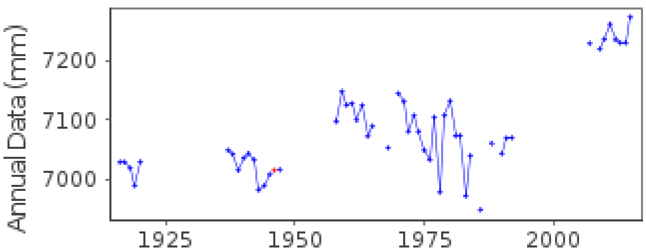
(t) Churchill (Canada) Hudson Bay – downward trend



(u) Batumi (Georgia) – Black Sea – Does not show such a clear trend as Poti, despite being close by

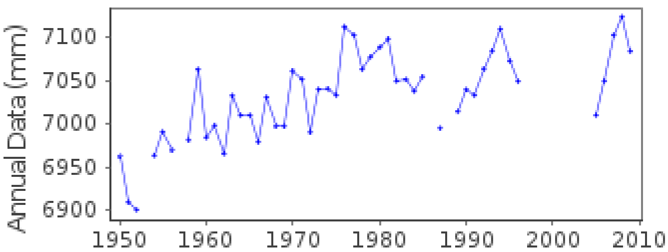


(v) Karachi – upward trend, but too intermittent to fit

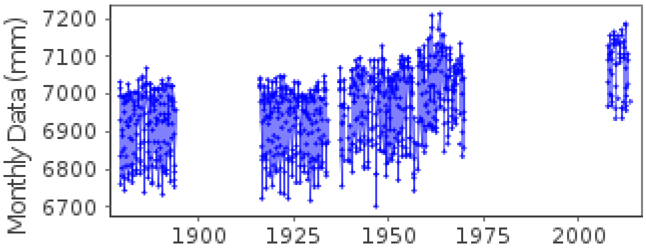


The credibility of the most recent Karachi data is challenged by the data a little further south down the Arabian Sea at Kandala…

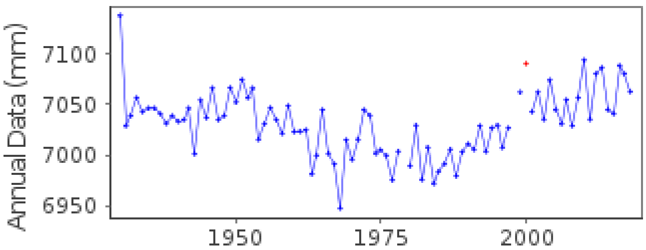
(w) Kandala – trend flat recently



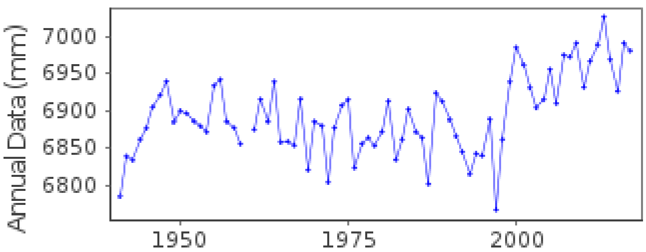
(x) Aden (monthly data) Arabian Sea near mouth of Red Sea – irregular



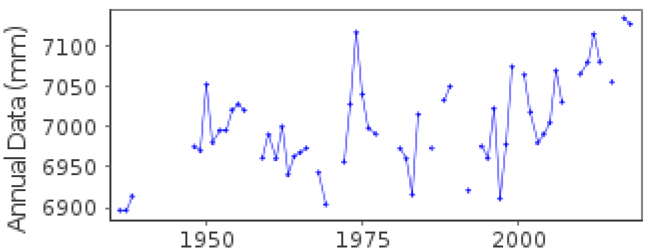
(y) Wajima (Japan) – no clear trend



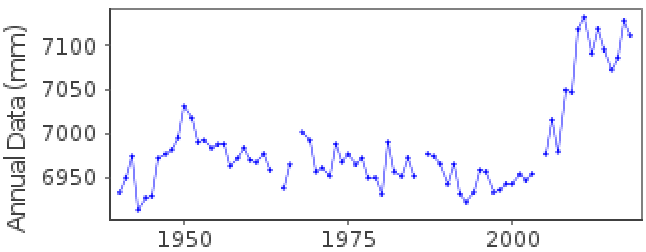
(z) Port Pirie (Australia, south coast)



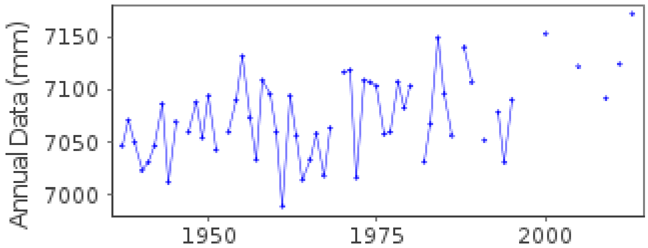
(ab) Cebu (Philippines)



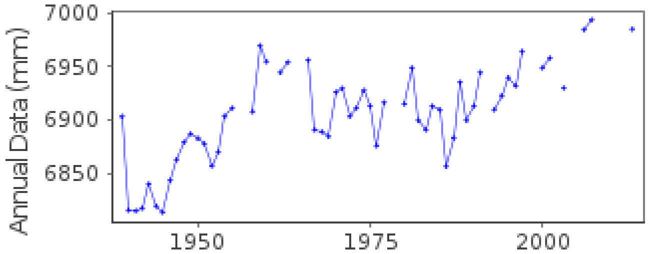
(bb) Kolak (Thailand)



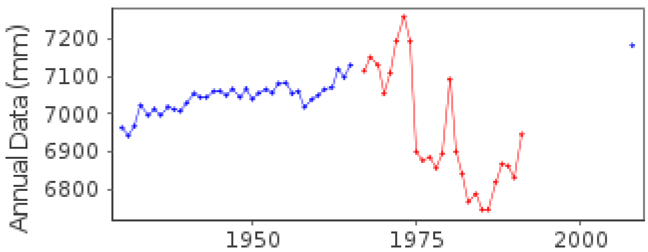
(cb) Visakhapatnam (India, Bay of Bengal)



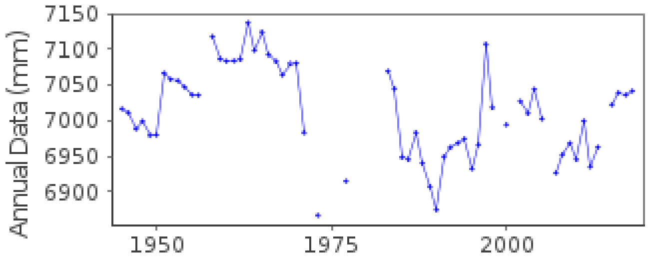
(db) Cochin (Willingdon Island) South India



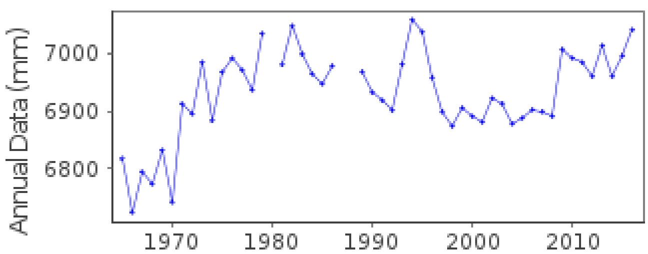
(eb) Takoradi, Ghana



(fb) Valparaiso (Chile)



(gb) Ilha Fiscal (Brazil)



(hb) Cananeia (Brazil)