Sea level changes: the data available at the PSMSL and SONEL and the results of satellite altimetry

Maria Assunção Araújo

mariassuncaoaraujo@gmail.com

Porto University

Research Article

Keywords: Relative sea level changes, absolute sea level changes, vertical movements, satellite altimetry, global mean sea level

Posted Date: December 20th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-2383126/v1

Additional Declarations: No competing interests reported.

Abstract

Sea level changes are a complex and quite discussed topic in the media, mostly because of their relationship with “climate change”. The first instruments to evaluate sea level changes are the Tide Gauges (TG) that began to register data in 1700, at Amsterdam. The TG registrations are validated and homogenized, to be comparable, by PSMSL (Permanent Service for Mean Sea Level). The longest record is the one in Brest (France) that begins in 1807. They register the *Relative* Sea Level (RSL). In fact, the data show that the vertical movements on the continent strongly affect the RSL curves.

The recent implementation of GPS near the TG allows to evaluate the “absolute” sea level changes and calculate the respective trends. The average values, including some “suspect” outliers, is about 2 mm/yr.

However, due to the lack of existence of GPS near all the TG and the completeness/duration of TG curves, only 164 stations are registered as defining a probable eustatic, “absolute” sea level trend.

Since 1993 it is implemented a satellite altimetry system that used several satellites and is improving the techniques and models to allow the definition of a global sea level change. However, their results (3,55 mm/yr) are much different from the painstaking TG trends, constructed through more than 2 centuries and complemented by the recent GPS information. It is a good technique to show the marine currents, their development, and the influence of warm water in the middle of the oceans, affecting local sea level. But it seems inappropriate, right now, to give the “absolute” sea level trend near the coastline, where this data is most needed.

1 – Introduction

Sea level changes, frequently associated with “climate change” (Cazenave, 2022), are one of the major concerns of people right now.

As climate change is being over talked, sea level changes are also becoming a great concern for people all around the world.

Sea level is always changing in different scales and time scales, so, many specialties deal with this subject – most of the times in a very technical way, generally difficult to understand to non-specialists.

Our main goal is to use documents and data available in the WWW to understand a puzzling fact: the TGs and their corrections with vertical movements of the land measured by nearby GPS give results that are quite different from the satellite altimetry data.

The first thing to consider is what sea level really is. It is always changing but its changes appear in different timings. The most conspicuous are the tides that can have amplitudes that go till 18m (Mörner, 2013)

That’s why the only possible way to deal with all these changes is to look for an average: mean sea level. This one is particularly important because it is also the base level for topographic maps. So, many entities deal with that from early times. However, as it is necessary to make some investment on technical hardware (TG) and their registering, it is understandable that the TG stations are not equally distributed on a world basis (Fig. 1).

2 - Permanent Service For Mean Sea Level (Psmsl) And Relative Sea Level (Rsl)

The Fig. 1 represents a dot for each TG whose data are available on PSMSL The dots almost design the coastline we know in some areas (Northern America, Western coast of South America, Europe, Southeastern and Eastern Asia and even Australia). There is a strong concentration on the medium latitudes of the northern hemisphere. As we will see, this data has some peculiarities that make the comparation with other areas a bit difficult.

Each dot, 1548 in total, represents a TG station defined by its latitude and longitude. https://www.psmsl.org/data/obtaining/, accessed on 12 October 2022)

PSMSL is the best source for sea level date. First, the monthly and annual means was reduced to a common datum, to make the sea level curves comparable.

Each TG in the database is available as a folder in a Zip file https://psmsl.org/data/obtaining/complete.php with all the monthly data. This allows anyone to plot the data and to find the respective trends.

There is also a web page in which the station ID works as a link to more information about the data and monthly data plots of every station

The position of all registered TGs can be found in a Google Earth file.

This Google Earth file (.kml) also allows to see the sea level curves of all the points, classified by the last year of the reported data.

The calculation of trends obeys to several restrictions. The results can be found in a .txt file.

The consulted file is from 3 January 2022. It is important that the date of the download is known because the number of stations and their data are frequently actualized.

The sea level trends at PSMSL are calculated only for 792 TGs filtered by several conditions (duration of the series, completeness, last data available). These filters reduce the number of available TGs. For instance, in Portugal, only 3 TGs, of the available 14, have their trends published. However, In Spain, including the islands and Ceuta, the number gets much higher: 25 TGs.

It is this database (792 TGs) that was used to produce Fig. 2, selecting only the European TGs.

The trends calculated by PSMSL represent the tendencies of sea level in each station. The positive number signify that sea level is going up. The negative figures represent points where the sea level is going down.

Also, at the NOAA site (https://tidesandcurrents.noaa.gov/sltrends/sltrends.html), a nice graphic presentation of the sea level trends can be found, and the link to a .kml file representing 366 trends

3 - The Movements From Earth And “absolute” Sea Level Trends

Relative Sea Level (RSL) trends can go from + 10.25 (ascendant) till – 18,1 mm/yr (descendent sea level). These figures can be puzzling for people living in areas where it is said that sea level is rising.

How can they be explained?

To simplify our analysis, we choose only the European TGs represented by their RSL trends to produce Fig. 2: the data is organized by decrescent latitudes. The data were extracted from the .txt file referred above.

It is easy to see that there is a strong opposition between northern and southern Europe. In the northern areas, above 57º of latitude, the sea level is going down (black lines). At lower latitudes the sea level is generally going up (blue lines).

What is the main cause for this?

During last glaciation a great and thick inlandsis was covering an important part of Scandinavia and Scotland performing an enormous pression upon the asthenosphere.

Because the viscoelastic relaxation of the mantle (Wouter, 2017), after the deglaciation, the recovering of the lithosphere from all this pression created an uplifting area that can move upwards till 1cm/year at Bothnia Gulf in the center of the glaciated area (Mörner, 2004; Simon at al., 2018).

The uplifting movement slows down to the periphery of the previous inlandsis area and gives origin to a subsiding movement to compensate the displacement of mass inside the mantle. This subsiding situation originates an almost general trend for a raising sea level (blue lines).

This figure shows the importance of knowing the comportment of the land to fully understand sea level changes, their consequences and future prognosis.

The recent development of GPS stations all over the world gives us an opportunity to evaluate the movements of the land.

The SONEL site is the best we know to deal with this issue. « SONEL » Is the acronyme to « Système d’Observation du Niveau des Eaux Littorales » (https://www.sonel.org/?lang=en).

It is a very complete site with several links to PSMSL and it also presents sea level trends (Fig. 3). The sea level trends are divided into 2 sectors: relative to the land and absolute (geocentric, corrected with nearby GPS).

The inferior part of the figure shows the links to consult land movements, provided by GPS at selected points.

RSL sea level trends available at SONEL are retrieved and processed in real-time from PSMSL. As TGs are implanted upon a continental place, the eventual movements of the TG spot (from tectonic, isostatic, or anthropic causes) can be relevant. However, knowing the vertical movement of the place where the TG is positioned, we can deduce the real, “absolute”, eustatic sea level change.

The presentation of relative and “absolute” sea level trends in SONEL site are subjected to several conditions:

The trends are available only for the RSL times series with at least 70% of valid data and limited to a minimum time span of 30 years. This is important because of the lunar cycle of 18,6 years that influences tide amplitudes and, as consequence, sea level changes.

The number of TGs that fill all these conditions is quite variable. From 1900 till 1980 the number oscillates between 30 and 40. As 30 years is the minimum time span to give acceptable data results, the TGs usable in different time intervals are almost never coincident. This makes the comparation quite difficult.

Only TGs with a nearby robust GPS velocity should be displayed

(even for relative trends). Indeed, the variability of RSL trends can only be understood if we consider the existence of land movements augmenting or diminishing the RSL curves (Fig. 2).

At the bottom of the figure there are links to the GPS results about land movements. (https://www.sonel.org/-Sea-level-trends-.html).

We know that GPS data are only available for the last 21 years. The site presents data for 546 active GPS stations. Only 21% of them (116) have at least 20 years of data. The results of “absolute” sea level trends are published for 164 points. A .txt file can be downloaded at:

https://www.sonel.org/-Sea-level-trends-.html?lang=en

In an appendix, more GPS stations are referred: exactly 1254 in 2 de December 2022.

This list is intended to be corrected and updated by the users.

At Fig. 4 we can get a better understanding of the reason for the development of RSL trends in Europe (Fig. 2):

In the northern stations the GPS indicates an uplift of the continent. In the south there is some variability, but mostly a trend for subsidence in the littoral areas. This fact will contribute to an augmentation of rising sea level trends.

So, it is obvious that these results of “absolute” sea level trends are very important to understand the RSL changes.

Using the text file referred above and converting it into a .xlsx file it is possible to make a further analysis of the data. The results are as follows:

Absolute sea level trends (SONEL, mm/yr, 156 stations, 1980–2018):

Average: 2,07 mm/yr,

Maximum: 6,08 mm/yr,

Minimum: -1,38 mm/yr.

Table 1
RSL trends (PSMSL, 2022), GPS vertical velocities and calculated “absolute” sea level trends (SONEL): the outliers, their latitude and the distance between GPS and TG.

TG	TG_lat	CGPS	TG_CGPS_Dist	RSL Trend (PSMSL)	V_CGPS	ABS_SLT	V_CGPS_U
HONNINGSVAG	70,9803	HONS	456	1,58	2,79	4,1958	0,49
ARGENTINE ISLANDS	-65,2462	VNAD	152	1,26	4,82	6,0839	0,29
CORDOVA	60,5583	EYAC	1076	3,26	2,34	6,0038	0,4
GOTEBORG - TORSHAMNEN	57,6847	0BIS	7518	0,6	3,64	4,0286	0,24
CADIZ III	36,5401	SFER	11100	3,57	0,8	4,3681	0,57
CADIZ III	36,5401	ROAP	11059	3,57	0,1	3,6681	0,22
GALVESTON II, PIER 21, TX	29,31	TXGA	2831	6,57	-4,11	2,7597	0,32
FREEPORT	28,9483	DWI1	11791	8,59	-2,45	5,9336	0,74
ROCKPORT	28,0217	TXRP	4495	6,22	-2,88	4,3496	0,3

V_GPS_U: Vertical Velocity of GPS Uncertainty.

Adapted from SONEL (1960–2018); RSL trends from PSMSL (2022).

Table 1 pretends to show most of the cases of absolute sea level trends greater than 4 mm/yr and some nearby stations for comparation. The stations are ranged by their latitude. The first 4 cases correspond to areas of more than 57° latitude, where quaternary glaciations are responsible for an important uplift. RSL trends are generally small because of the land uplift.

Nevertheless the “absolute” sea level trend seems quite high (more than 4 mm/yr).

This happens probably because the intensity of land movement is not well identified by the GPS stations. So, perhaps the GPS compensation is lower than it should be.

Nevertheless, the problem of sea invasion doesn’t exist. For example, at Argentine Islands (Antarctica) a 1,25mm/yr of RSL rise doesn’t seem dangerous for anyone.

The cases of Cadiz III, Freeport and Rockport deserve a further analysis. The GPS used to calculate the “absolute” sea level change is respectively 11,1, 11,8 and 4,5 km far away from the TGs (see the bold numbers in table I).

For example, for Cadiz III, the TG is located on a small pier at the North of the port. The GPS is inland, at 11,7 km to the SE. If we use another GPS (ROAP, decommissioned in March 2018), the “absolute” sea level trend would be smaller: 3,67 mm/yr.

Galveston TG has a RSL trend quite high, but it is compensated by a high subsiding movement measured by the GPS. So, the “absolute” sea level trend (2,76) is only a little above the average (2 mm/yr). Rockport and Freeport have GPS quite distant from the TG (ca 4,5 and 11,8km). So, it is very probable that the GPS measured subsidence is under evaluated, giving an “absolute” sea level trend higher than the average value (5,93, 4,35 mm/yr).

If we exclude these outliers of table I, the average of the absolute sea level changes goes down to 1,92 mm/yr.

The TGs present in Fig. 6 have RSL trends comprised between 1 mm/yr (Brest) and 3,3 (Sines). The correction from the GPS (Brest, Santander I, La Coruña I and Vigo results on “absolute” sea level trends lower than the average. The uncertainties (V_CGPS_U) of these results are quite low, which gives some assurance on the rightfulness of the absolute sea level trends. Only Vigo TG is quite far away from the used GPS.

Table 2
” Absolute” sea level trends of some Atlantic stations.

TG	CGPS	TG_CGPS_Dist	ABS_SLT	V_CGPS_U
BREST	BRST	292	1,5811	0,17
SANTANDER I	CANT	1329	1,702	0,25
LA CORUNA I	ACOR	476	0,304	0,22
VIGO	VIGO	9053	1,0335	0,16

Unfortunately, we can’t calculate the “absolute” sea level trend for Leixões because the nearest GPS (Gaia) stays too far away from Leixões TG: exactly 13km.

At Cascais the PSMSL data are only registered till 1993. Indeed, they are not contemporaneous with the GPS data, so the “absolute” sea level of Cascais is not in SONEL database.

At Sines there is no GPS available.

However, the presented examples from Iberia Atlantic coastline, show that “absolute” sea level trends are lower than the 2 mm/yr average.

To evaluate “absolute” sea level trends a long TG series (more than 18,6 years, at least 30 years) and precise GPS data, near TG, are needed.

As we saw at the later paragraphs about Portugal, many times, these conditions are not available together.

4 – Is There An Acceleration Of Sea Level Rise?

The google earth file (dataCatalog.kml) is very useful to find the TGs that have actualized data and are suitable for analyzing the possible “acceleration of sea level rise”.

Brest has the longest RSL curve in the database: because of this and because it is also an Atlantic TG, we show it for comparation.

At continental Portugal, unfortunately, only Leixões (near Porto) and Sines have data patronized by PSMSL that goes till 2020. So, we choose Spanish PSMSL TG in the Atlantic coast of Iberia with the longer data series. The different RSL curves show that there is no acceleration on sea level rise at recent years. There is a maximum around 2015 and the last part of the curve doesn't show a sea level rise: on the contrary: there seems to be some decline.

The data of Cascais and Lagos are not suitable for sea level rise "acceleration" analysis because the last points of their series in PSML database are respectively from 1993 and 1999.

Admitting that sea level rise is one of the consequences of climate warming, the data from western Iberia doesn't seem to provide a confirmation of it.

5 - Satellite Altimetry

Since 1993, there is another way of measuring the sea level changes: satellite altimetry. It has advantages over the laborious and expensive monitoring of TG and GPS. It pretends to find the "absolute" sea level changes.

Our analysis will be based on AVISO (Archiving, Validation, and Interpretation of

Satellite Oceanographic data: https://www.aviso.altimetry.fr/en/home.html)

At Fig. 7, we can see that since 1993, most of the seas of world seem to be affected by a sea level rise (warm colors). The higher trends follow very closely the warm ocean currents. However, these strong values dissipate when the warm currents arrive near the coastline. "The differences between the estimated rates of sea level change from

in-situ TG and satellite measurements vary, in absolute value, from 0.49 to 5.57 mm/a with an average of 1.94 mm/a. One of the reasons for these differences can be attributed to the fact that the altimetry measurements are not accurate near the coasts" (Tahib, 2019).

So, satellite altimetry doesn't seem the best way of measuring sea level changes near the coastline. There is some literature about these difficulties. (Simon, 2018, Ablain, 2019). The effort the researchers are making on this subject shows very well how practical should be to have precise data on "absolute" sea level changes all over the world without the difficulties of having to correlate TG and GPS, with very different time spans.

AVISO site presents a global sea level rise of 3,55 mm/yr (Fig. 8), evaluated at 2022/10/29.

AVISO also presents regional sea level curves and the respective trends (Table 3)

Table 3
regional sea level trends published in AVISO site (https://www.aviso.altimetry.fr/en/data/products/ocean-indicators-products/mean-sea-level/data-acces.html#c12195). Regional data marked * are dated 9 Feb. 2022.

MSL (AVISO)	
North Atlantic*	3,19
South Atlantic*	3,47
Mediterranean*	2,51
Black Sea*	1,57
Indian Ocean*	3,42
North Pacific*	3,09
South Pacific*	2,94
Northern Hemisp.*	3,18
Southern Hemisp.*	3,2
Global (Feb, 4, 2022)	**3,53**
Global (Oct, 29, 2022)	**3,55**

All the regional/partial trends were calculated for 9 Feb. 2022. However, none of the presented regional values attains at least the "global" value of mean sea level calculated 4 Feb. 2022 (3,53).

How is it possible to get a "global" MSL trend that is greater than all the partial trends, when this global date is only 5 days older than the regional values calculated the 9 Feb. 2022?

We can also ask how it is possible that the sum of Southern and Northern hemisphere can give a trend bigger than each hemisphere individually considered.

The last value (Oct 29, 2022) suggests a bigger figure (3,55 mm/yr). We don't have the regional data for this date. Nevertheless, the first global value is dated Feb 4, 2022, so it is very close to the data of the regional MSL presented in the table III.

Conclusion

The values of RSL trends are very much dependent on the length of the series. PSMSL recommends series of at least 30 years.

The obvious influence of vertical movements from the land underlines the need of existing GPS with reliable and at least 20 years data situated very near the TGs. These conditions are relatively rare. So, only 164 stations have their "absolute" sea level calculated by SONEL. Some of these calculations are disputable and give origin to exaggerated “absolute” sea level trends. This value is very important because it is the only one that has an eustatic origin and mays be associated with climate change.

We can say for sure that the average “absolute” sea level trends without the outliers (1,9 mm/yr) could be even lower if there is an improvement in the number of GPS near TG and the TG series get longer and more robust.

The satellite altimetry could be a response for these problems. But the maps show very well that is very difficult to consider a “global mean sea level”, when the differences from area to area are so great. What is interesting for Humankind is to know what happens near the coastlines. And satellite altimetry is simply unable to give reliable results on this issue.

On the other hand, the values obtained for this global mean sea level trend (3,55mm/yr) are almost the double of the “absolute” sea level trends calculated locally. They are not as a faithful as they should be when littoral management needs reliable data.

Declarations

Websites

(Organized by main site)

AVISO
https://www.aviso.altimetry.fr/en/home.html)

https://www.aviso.altimetry.fr/en/data/products/ocean-indicators-products/mean-sea-level/data-acces.html#c12195

NOAA
https://tidesandcurrents.noaa.gov/sltrends/coops-slt.kml

https://tidesandcurrents.noaa.gov/sltrends/sltrends.html

PSMSL
https://www.psmsl.org/data/obtaining/

https://psmsl.org/data/obtaining/metric.php

https://psmsl.org/data/obtaining/
https://psmsl.org/data/obtaining/complete.php

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https://www.psmsl.org/products/trends/trends.txt

SONEL
https://www.sonel.org/?lang=en).

https://www.sonel.org/-Sea-level-trends-.html?lang=en

https://www.sonel.org/-Sea-level-trends-.html.

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Figures

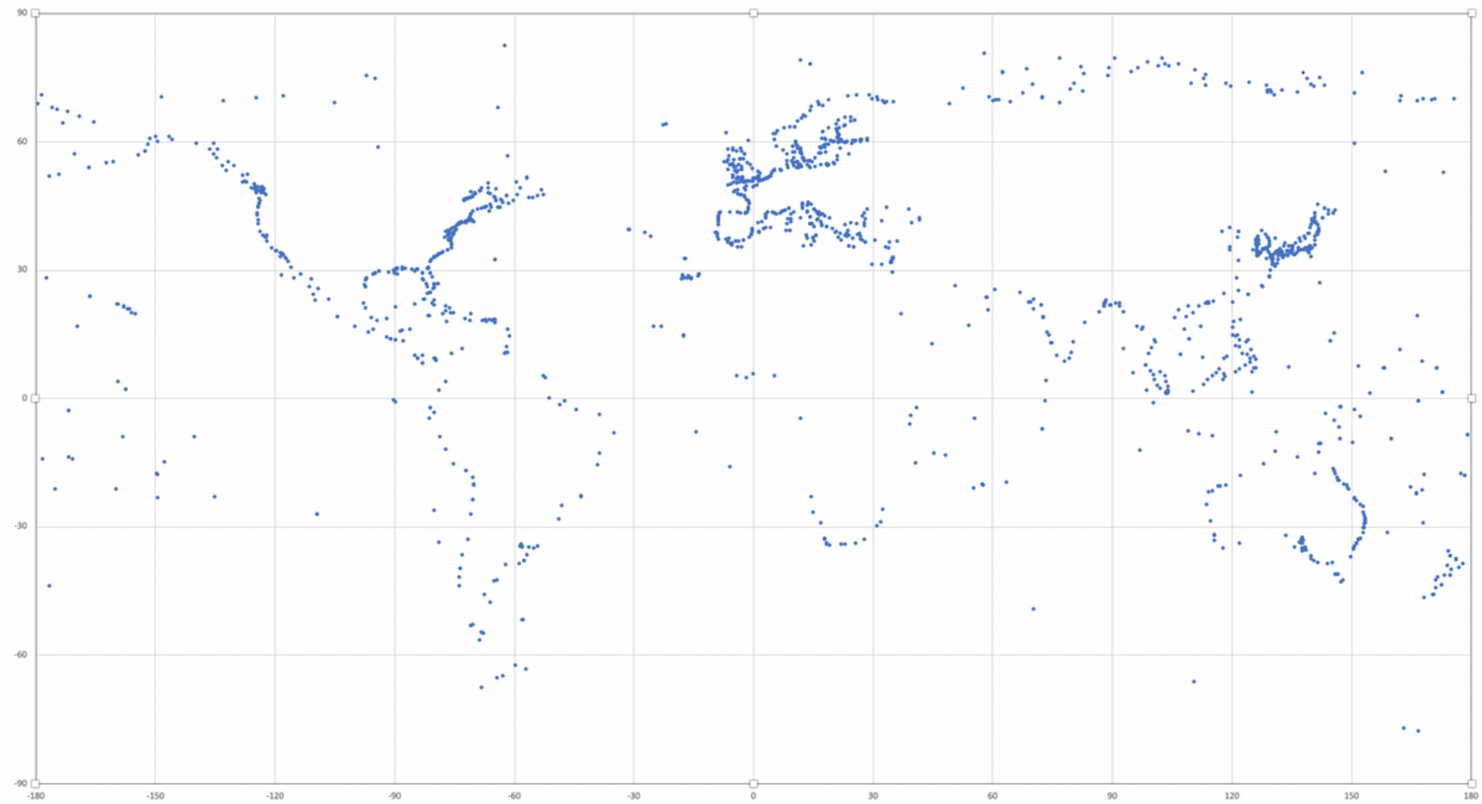

Figure 1

The situation of PSMSL data stations.

Each dot, 1548 in total, represents a TG station defined by its latitude and longitude. https://www.psmsl.org/data/obtaining/, accessed on 12 October 2022)

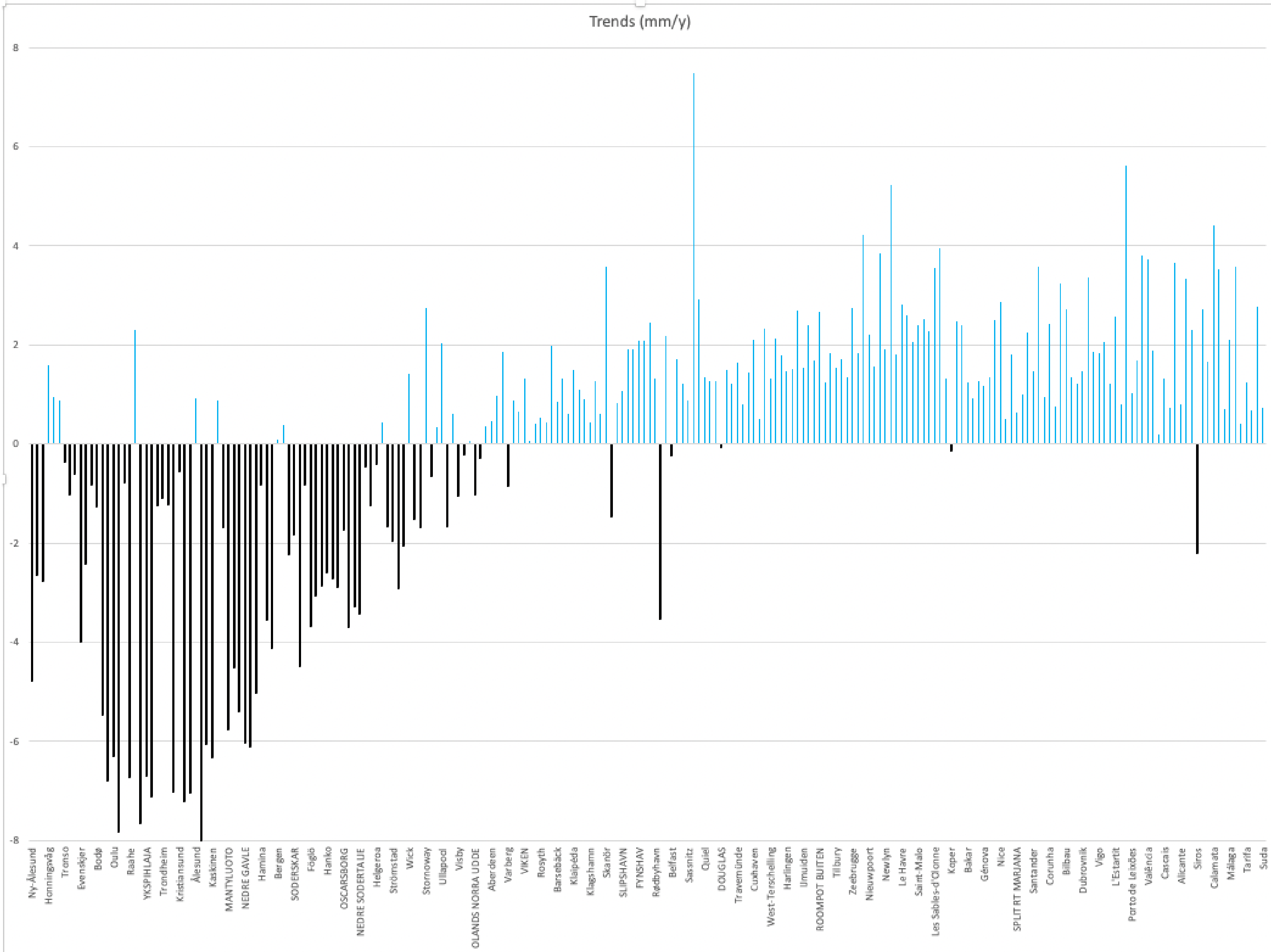

Figure 2

Figure legend not available with this version.

Figure 3

Partial view of SONEL homepage showing the possibility of choosing relative or absolute sea level trends.

At the bottom of the figure there are links to the GPS results about land movements. (https://www.sonel.org/-Sea-level-trends-.html).

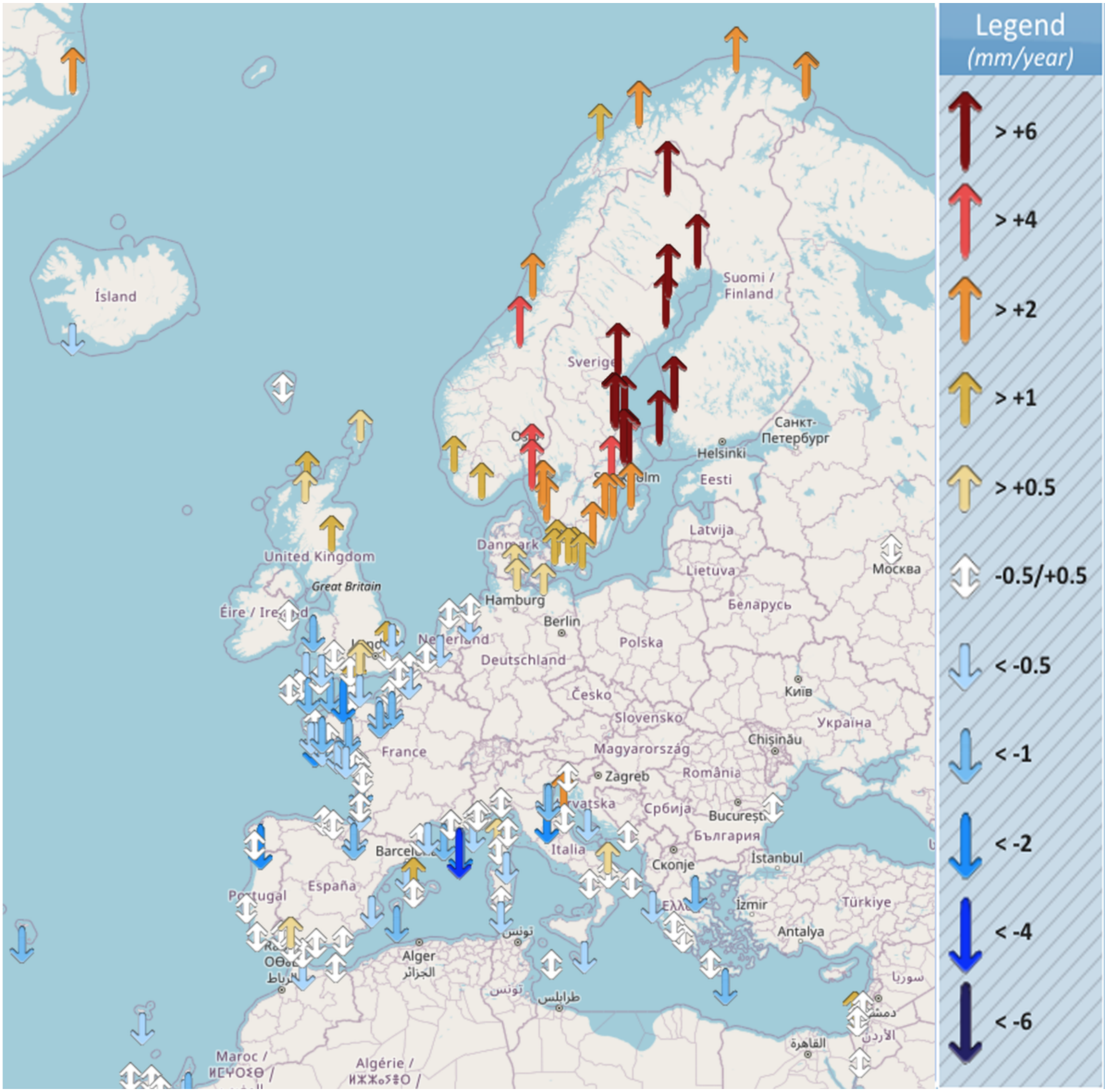

Figure 4

GPS calculated movements for Europe and some adjacent areas. The white arrows mean stability/slow movements form the land (-0,5/+0,5 mm/yr). The yellow-red-brown arrows mean a land uplift. The blue arrows mean that the place where the GPS is settled is suffering some subsidence. Adapted from https://www.sonel.org/-Vertical-land-movements-.html?lang=en

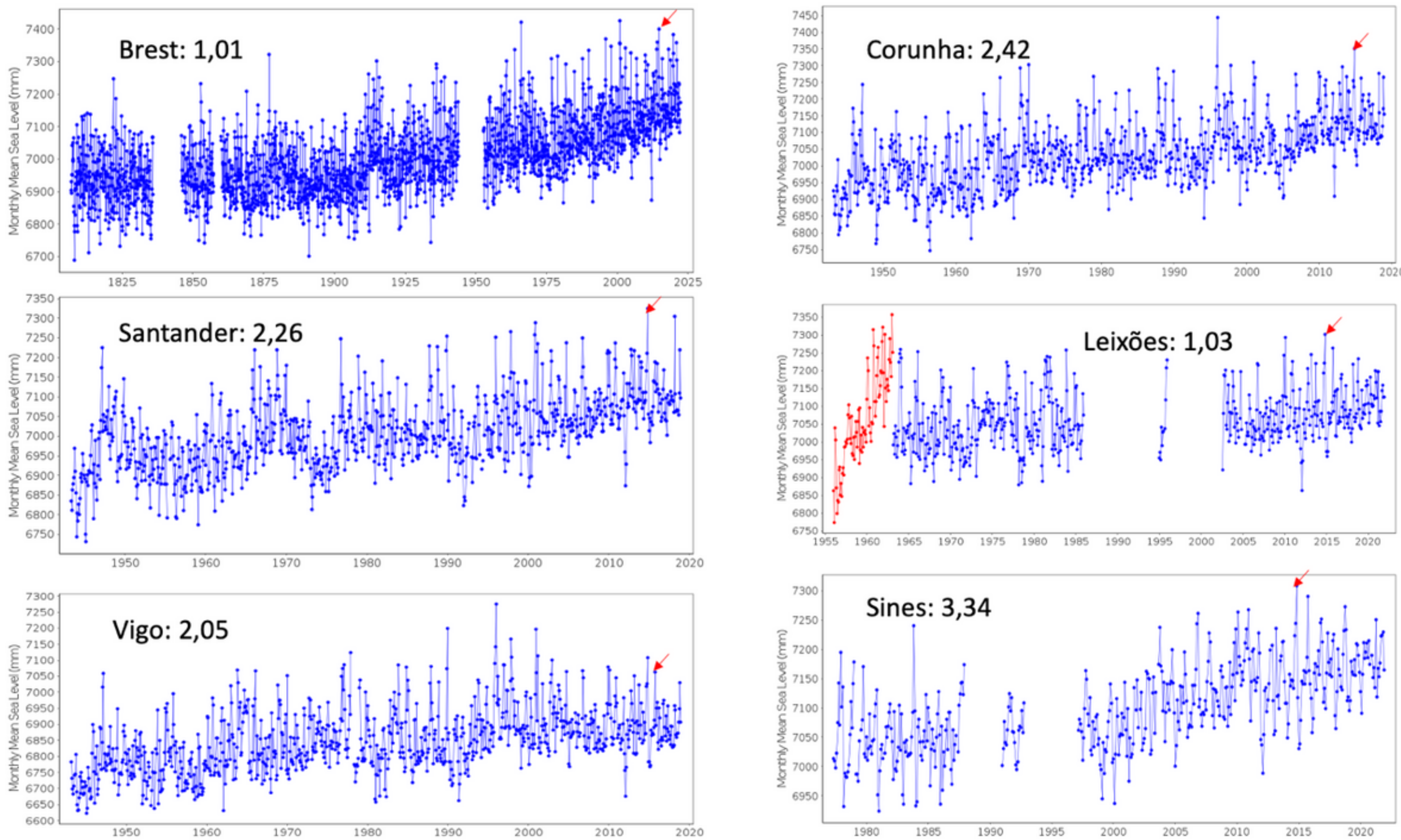

Figure 5

The “absolute” sea level trends for 156 stations (from 1960 till 2018): The stations are classified by their latitude: the northern latitudes to the left and the southern latitudes to the right. The average of the “absolute” sea level trend is 2 mm/yr. There are some outliers, with more than 4 mm/yr. Some of them are highlighted and their results will be briefly analyzed.

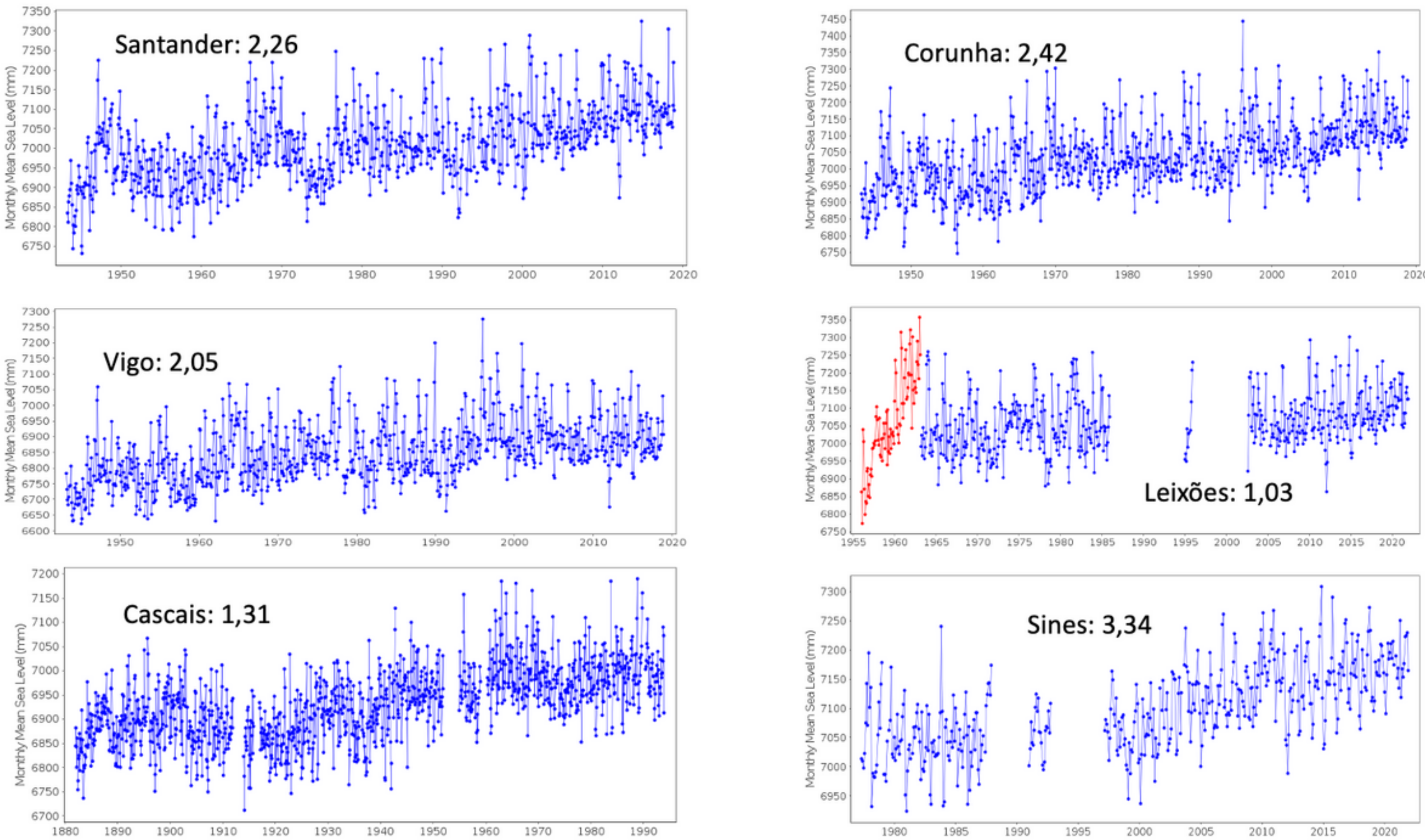

Figure 6

Brest, northern and western Iberia RSL changes. The trends, according to PSMSL are represented in mm/yr. A small arrow points the maximum RSL from the beginning of XXI century.

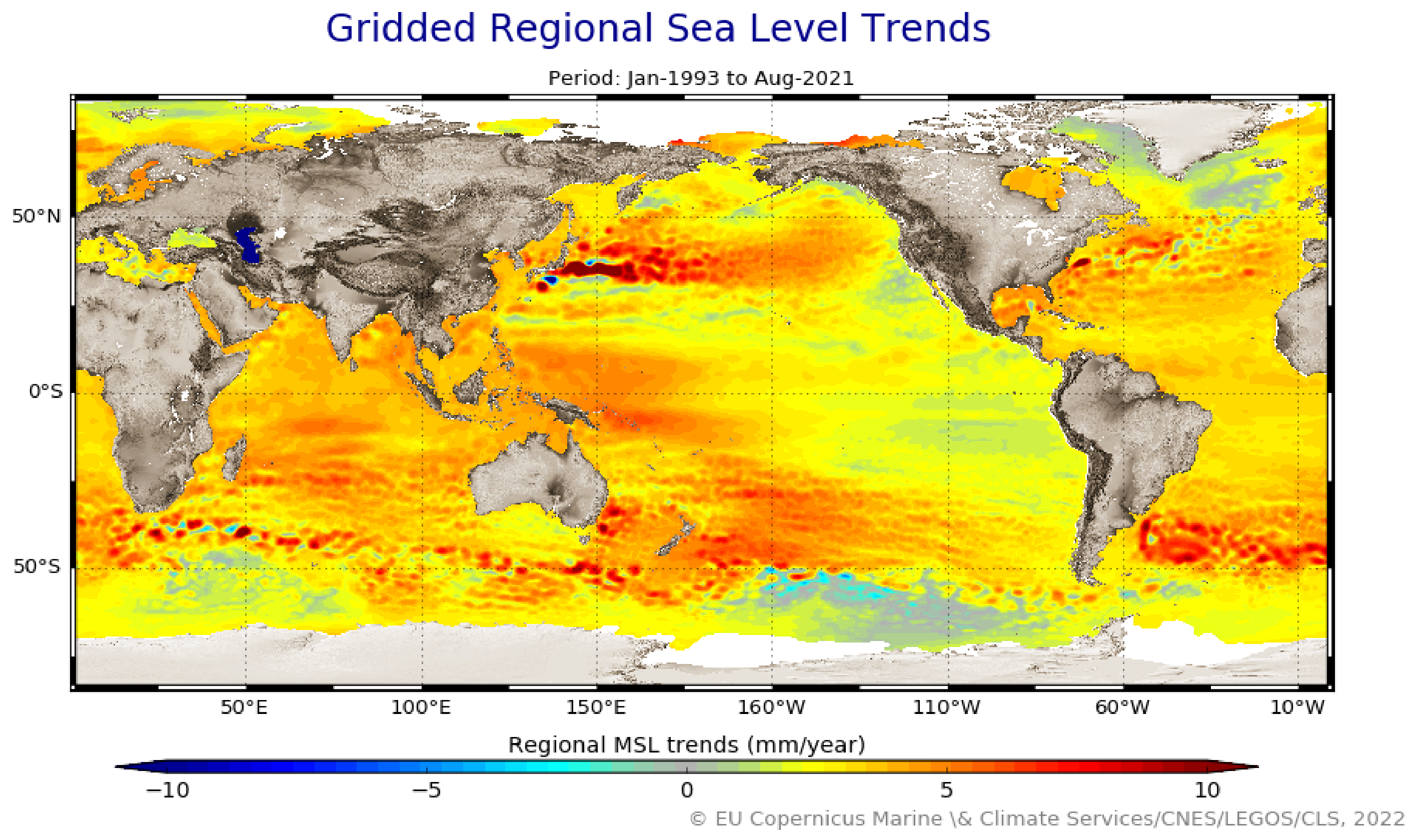

Figure 7

The last map of satellite altimetry from AVISO (13 December 2022)

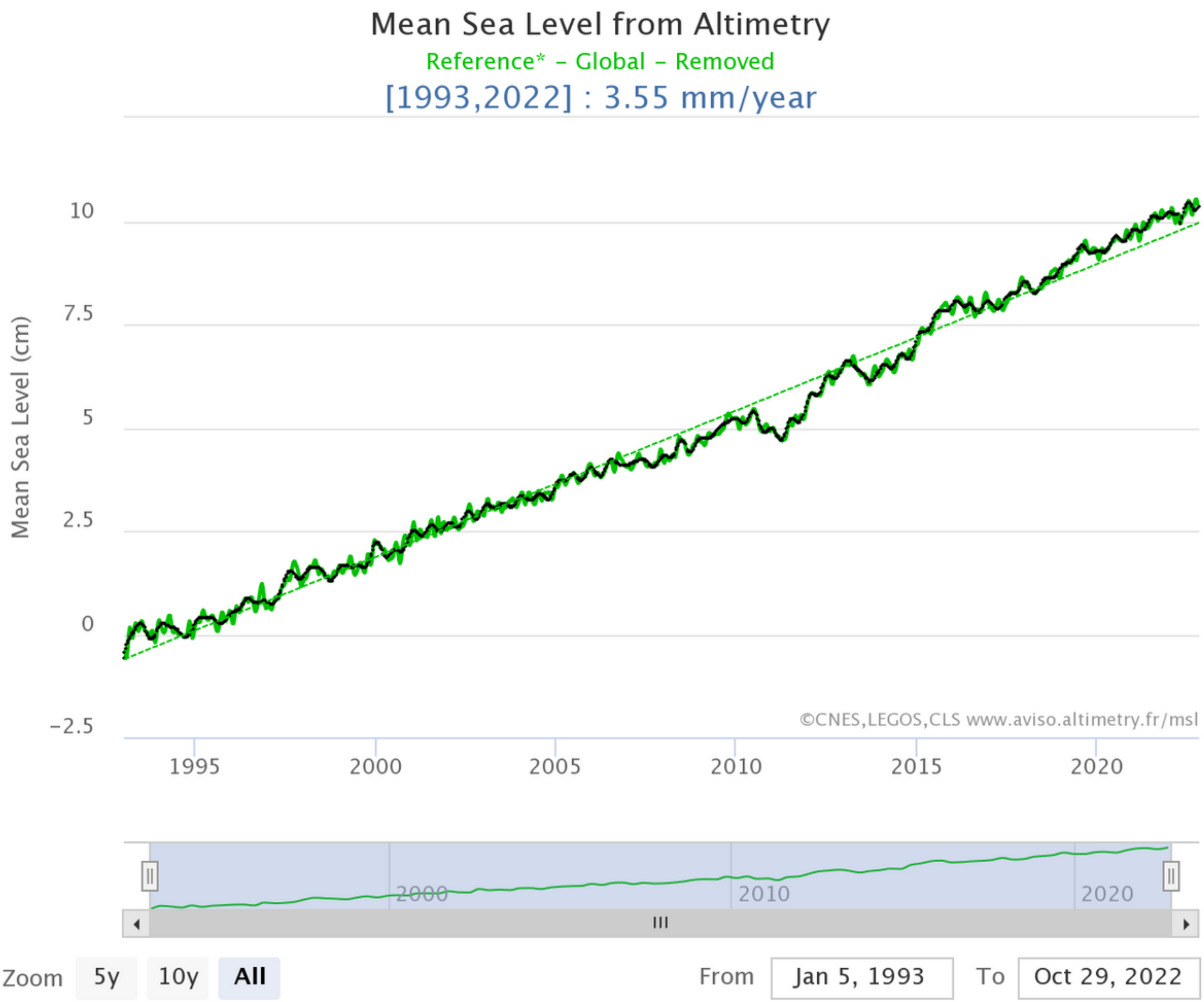

Figure 8

The last curve of Mean Sea level from Altimetry (AVISO, https://www.aviso.altimetry.fr/en/data/products/ocean-indicators-products/mean-sea-level/data-acces.html#c12195, acceded 13 December 2022)