Worksheet: Oceans on the Rise

Background Information

Sea surface altimetry

One of the most challenging consequences of the ongoing climate change on Earth is the rise of the sea levels that poses a threat to many coastal areas. Monitoring sea levels used to be a quite difficult task, as until a few decades ago, this could only be done via direct measurements and probes on open seas. With the advent of Earth observing satellites and radar altimetry missions, it became possible to monitor sea levels very efficiently and effectively. While in situ measurements only provide a very local perspective of a given probe and the resolution of the global network is rather low, satellite measurements allow observing the entire Earth at a high redundancy and frequency with at the same time high spatial resolution.

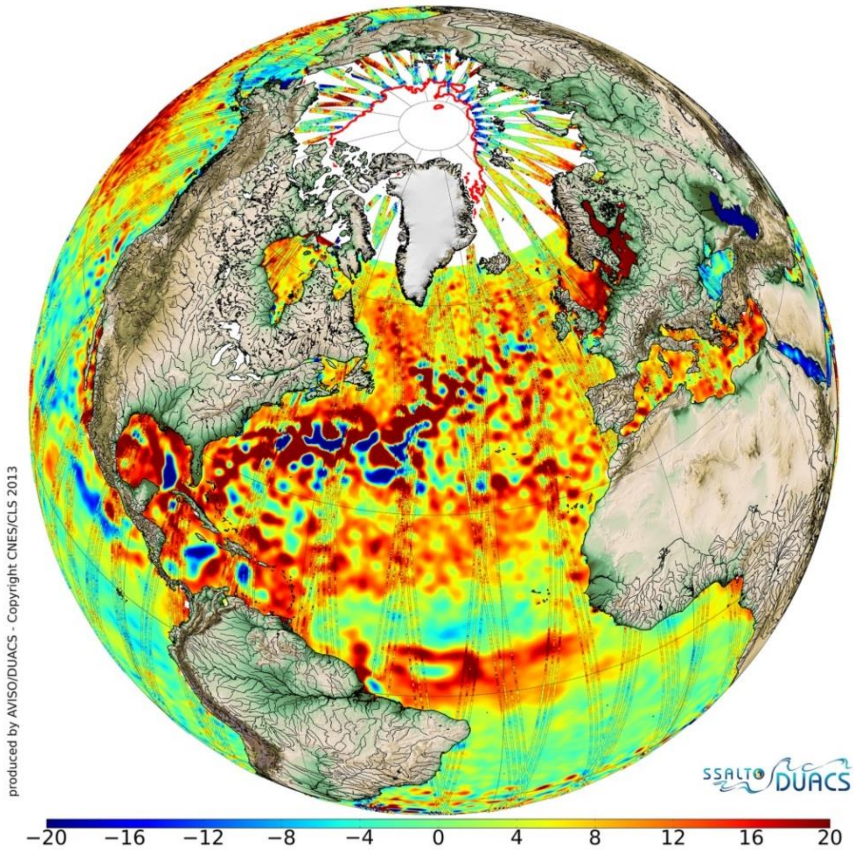

Figure 1: Average sea-surface topography for 2013 as mapped by CryoSat combined with data from other missions. Red represents higher sea levels (up to 20 mm above average) while blue represents lower areas (down to –20 mm). The perturbations seen in the Northern Atlantic are caused by the warm Gulf Stream current (ESA/CNES/CLS, http://www.esa.int/spaceinimages/Images/2014/06/2013_sea-surface_topography).

Known satellites with altimetry capabilities are e.g. CryoSat and Jason 2/3. The most recent addition is Sentinel 3, a flagship of the European *Copernicus* Earth observing programme that offers an unprecedented spatial resolution.

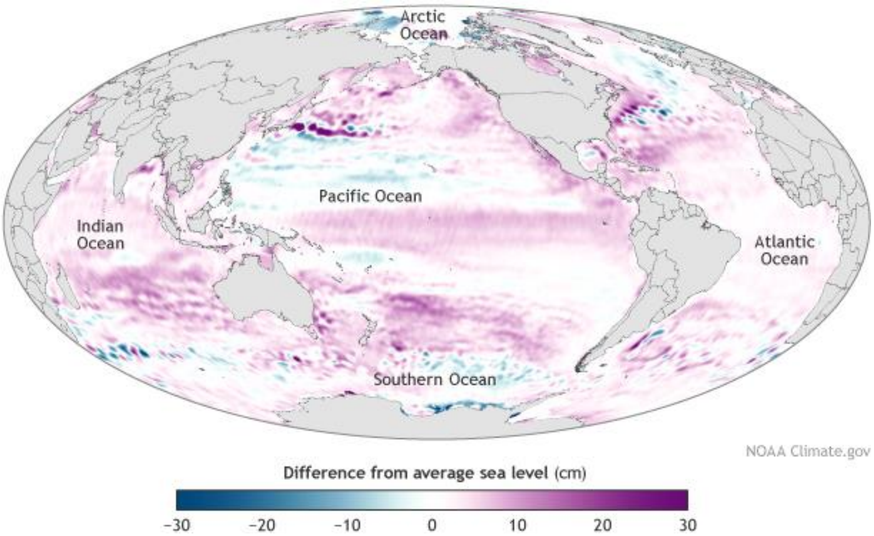

Figure 2: Sea level in 2014 compared to the global average at the mid-point of the 1993-2013 time series (NOAA Climate.gov map, adapted from Figure 3.25a in State of the Climate in 2014 report, https://www.climate.gov/news-features/understanding-climate/2014-state-climate-sea-level).

Oceans are on the rise

When combining such data obtained at different acquisition times, a general trend of the sea level evolution can be derived. When analysing all the data at hand, it is obvious that sea levels have been rising during the last one and a half centuries (Figure 3).

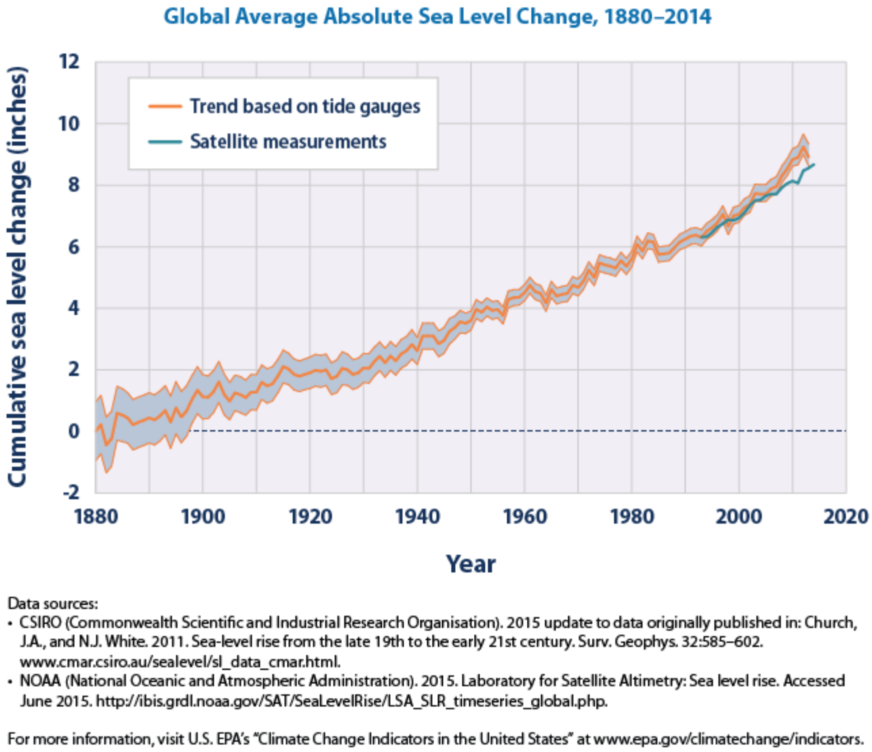

Figure 3: This graph shows cumulative changes in sea level for the world's oceans since 1880, based on a combination of long-term tide gauge measurements and recent satellite measurements. This figure shows average absolute sea level change in inches (1 inch = 25.4 mm), which refers to the height of the ocean surface, regardless of whether nearby land is rising or falling. Satellite data are based solely on measured sea level, while the long-term tide gauge data include a small correction factor because the size and shape of the oceans are changing slowly over time. (On average, the ocean floor has been gradually sinking since the last Ice Age peak, 20,000 years ago.) The shaded band shows the likely range of values, based on the number of measurements collected and the precision of the methods used (United States Environmental Protection Agency, https://www3.epa.gov/climatechange/science/indicators/oceans/sea-level.html).

In summary, current scientific results show that from 1993 until 2014 the ocean levels have been rising with a rate of up to (2.9 ± 0.4) mm per year. That is 6 cm within 20 years. And the rate seems to be increasing.

The connection to sea level rise

When heated, liquids expand isotropically. This is the principle of the common thermometer. The reason behind this is the change of the density with varying temperature. Density is defined as mass per volume.

$$\varrho = \frac{m}{V}$$

The mass of a given volume of water does not change, i.e. it is a constant. Therefore:

$$m = \varrho \cdot V$$

Since the density ϱ changes with temperature, the volume V does as well. This behaviour of water is one possible contribution to the observed sea level rise, in particular when considering the global warming and the role of the oceans as a heat sink. Current research amounts the contribution to the global sea level rise to a rate of about 0.5 mm per year between 1955 and 2010.

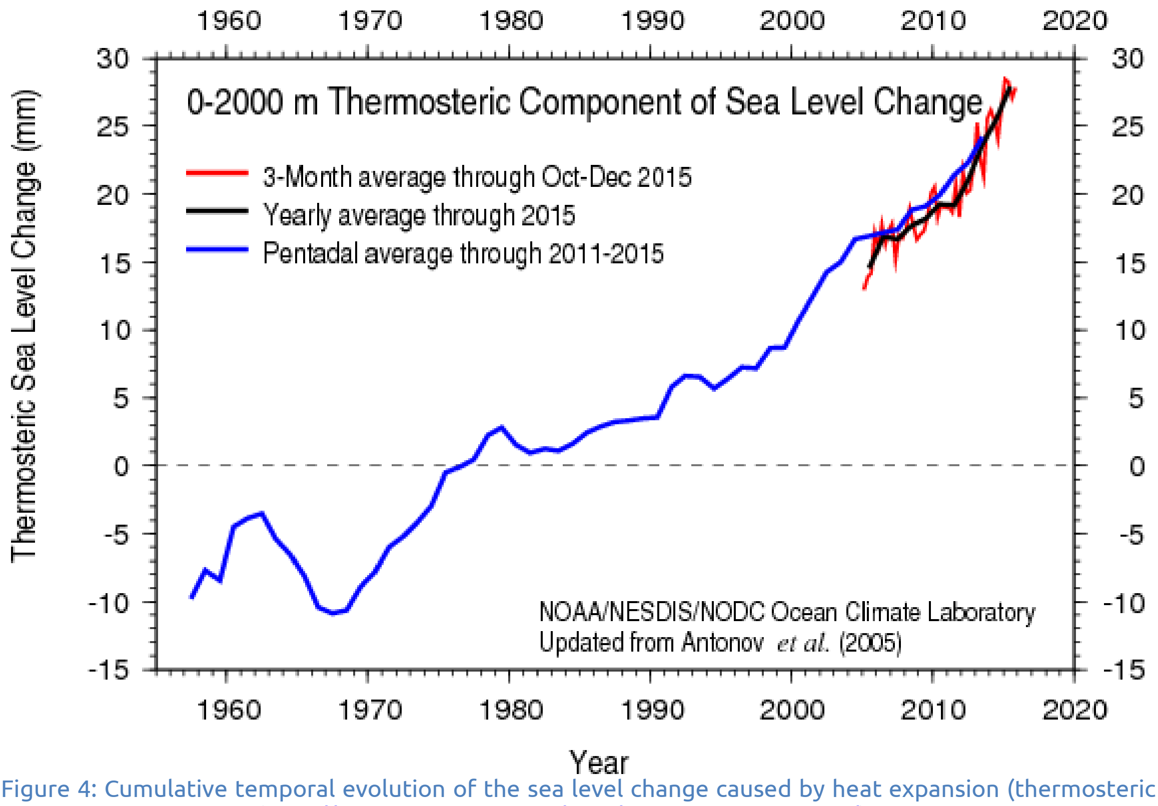

Figure 4: Figure 4: Cumulative temporal evolution of the sea level change caused by heat expansion (thermosteric sea level change) between 1955 and 2015 (http://www.nodc.noaa.gov/OC5/3M_HEAT_CONTENT/).

Activity 1: See the water rise

List of material:

- Flask
- Rubber stopper with a hole
- Glass tube with small diameter
- Strong lamp
- Thermometer (optional)
- Overhead marker (water based)

Questions

What are the characteristics of a body, a liquid or a gas when warming-up? Have you seen a balloon filled with air and then heated?

When dealing with water, is this effect rather strong or small? Can you observe an obvious rise of the water level when heating water in a pot (before boiling)?

What does this effect mean for the oceans on Earth?

Experiment

Follow the instructions:

1. Fill the flask with water.
2. Measure the temperature of the water with a thermometer (optional).
3. Close the tube including the glass tube with the stopper and avoid air bubbles. The water level in the glass tube should be visible.
4. Mark the water level on the glass tube with the overhead marker.
5. Position the lamp at a distance of approx. 5 cm in front of the flask.
6. Shield the glass tube to avoid heating the water inside.

Figure 5: Experimental set-up (own work).

Now, switch on the lamp and observe the water in the glass tube for about 10 minutes.

By how much does the water rise in the glass tube?

Write down your observations and discuss the results with your classmates. What conclusions can be drawn for the Earth, especially for the oceans?

Activity 2: Calculate it!

We have learned that the volume of water changes with temperature, because the density depends on the temperature as well. This means: If we knew the density for a given temperature, we can calculate the change in volume.

The chart below shows the density of liquid fresh water vs. its temperature. Note that the values for salty sea water differ. They depend on its salinity. However, the density of sea water is higher and the expansion effect is stronger.

Table 1: Densities of fresh water at standard pressure for given temperatures (according to NIST, https://is.gd/joDUoD).

Temperature ϑ in °C	Density ϱ in $\frac{g}{dm^3}$	Temperature ϑ in °C	Density ϱ in $\frac{g}{dm^3}$
0	999.844	16	998.944
1	999.902	17	998.776
2	999.943	18	998.597
3	999.967	19	998.406
4	999.975	20	998.205
5	999.966	21	997.993
6	999.943	22	997.771
7	999.904	23	997.539
8	999.850	24	997.297
9	999.783	25	997.045
10	999.702	26	996.784
11	999.607	27	996.513
12	999.499	28	996.233
13	999.379	29	995.944
14	999.246	30	995.646
15	999.101	31	995.340

Exercise 1:

Imagine 1 litre (1 dm^3) of water is heated from 10°C to 20°C.

What is the volume of the water after warming? Note that the total mass of water does not change. Hint: Use the definition of density.

What is the increase of the volume in percent?

Exercise 2:

The average sea depth on Earth is approximately 3800 m. Now, imagine a small portion of the ocean that consists of a column of water that is 3800 m high and has a base area of 1 m^2.

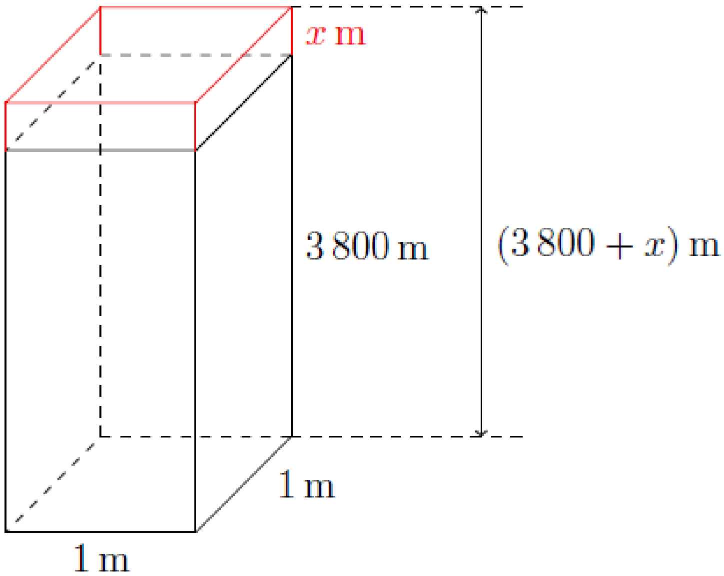

Figure 6: Sketch of a water column with a square base area of 1 m x 1 m and an altitude of 3800 m (own work).

What is the volume of the water column?

Provided the temperature of the ocean would have an average of 5°C. What would be the volume of the water with a temperature increase of 1°C?

By how much does the sea level rise?

What does that mean for the rise of the sea levels by storing heat due to global warming?