Water Cycle: Lessons using data skills

Lesson 1: The global water balance

Lesson Objective
- To understand the different components of the global water balance
- To understand how changes to any component of the global water balance can have significant effects on global water security
- To understand the effect of data record lengths in describing patterns and trends

Setting the Scene

All water on our planet moves in a global cycle called the hydrological cycle. The presence or absence of water at any given location is vitally important since it determines climate features, typical landscapes and opportunities for human land use. Given the global water industry is worth an astonishing amount of money, which Siemens estimated at just over $400 billion a year, it is vital we understand how water moves around our planet. This is complicated by the fact that water requirements are changing; by 2030 demand will outstrip accessible water supply by 40% (McKinsey Consultants). Understanding the global availability of water is therefore vital if we are to manage our current and future resources.

We can estimate how much water might be available to us by using a Water Balance approach. Water balance is the ratio between water inflow and outflow estimated for different space and time scales, i.e. for the Earth as a whole, for oceans, continents, countries, natural-economic regions, and river basins, for a long-term period or for particular years and seasons. This lesson is focused on beginning to explore how we can use a water balance approach to estimate how much water is stored and moved between the land, atmosphere and oceans. We can then estimate how those proportions change through time and what factors affect this movement.

Note: Be aware that the graphs used in these exercises are in °F not °C.

1) Estimating Global Water Flux – Just how much water is there?

Scientists have been attempting to estimate just how much water there is for over 100 years. No correct answer has so far been found so we have to use estimates. Precipitation, evaporation, river runoff and ground water outflow are the four basic components used to determine the water balance. Besides these there are minor components e.g. moisture due to atmospheric water vapour. Figure 1 estimates the global water balance.

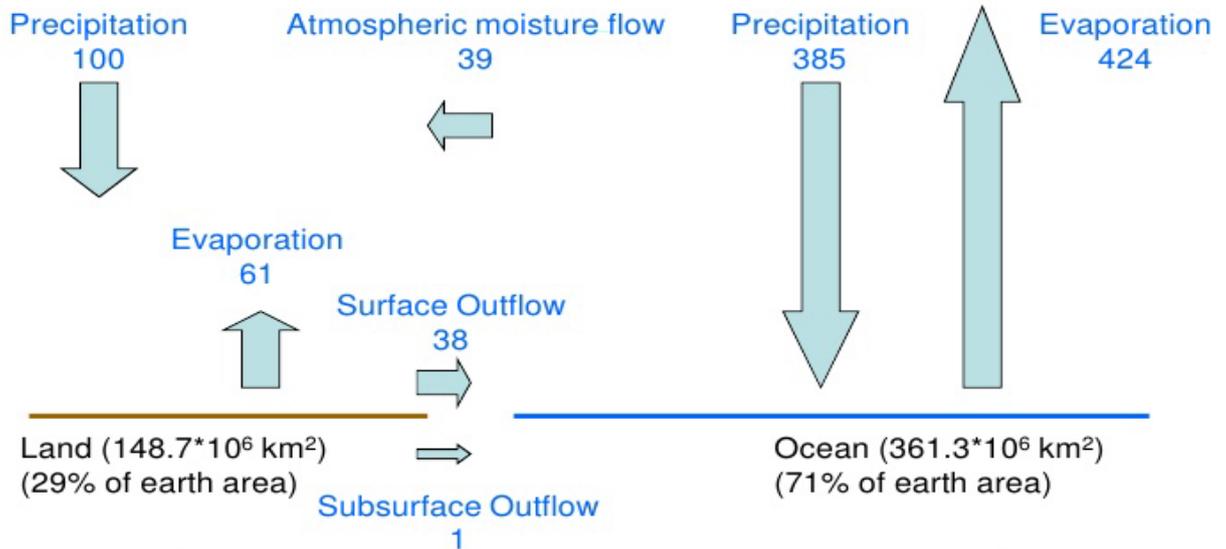# Global Water Balance (Volumetric)

Figure 1: Estimate of the Global Water Balance. Units are in volume per year relative to precipitation on land which is 100 units (Chow, 1964).

Task

Describe the patterns of the global water balance. You might want to think about:

- How do the evaporation and precipitation volumes over the land compare to those over the ocean? Why do you think these patterns exist?
- What properties of the land's surface might affect the volumes of evaporation?
- Which components do you think will be most sensitive to future changes in the climate? Why?
- Figure 1 is derived from estimates of global average values - how representative do you think that is? Do you think there would be much variation through time and space?

2) Changes to the Sea Surface Temperature

From Figure 1 we can see that evaporation and precipitation from our oceans play a huge role in controlling the global water balance. Both components are strongly controlled by the temperature of the ocean and average global sea surface temperature has been noted to be changing over time. Increases in sea surface temperature have the potential to lead to an increase in the amount of atmospheric water vapour over the oceans. This water vapour feeds weather systems that produce precipitation, increasing the risk of heavy rain and snow. Changes in sea surface temperature can shift storm tracks, potentially contributing to droughts in some areas. Increases in sea surface temperature are also expected to lengthen the growth season for certain bacteria that can contaminate seafood and cause food borne illnesses, thereby increasing the risk of health effects. Therefore, it is vital we understand how past changes have occurred such that we can predict and manage future water resources. The data in this exercise are shown as anomalies, or differences, compared with the average sea surface temperature from 1971 to 2000 i.e. a positive anomaly would mean that the temperature was higher than the average sea surface temperature from 1971 to 2000 and a negative anomaly the opposite.

Task

- Open the Microsoft Excel Global Water Balance data file. In the Global Sea Surface Temperature tab there are four columns: 1) year 2) annual anomaly 3) lower 95% confidence Interval and 4) upper 95% confidence interval.
- Using the data plot a line graph of the year and annual temperature anomaly. You can do this by hand or use excel (it's much quicker!!)
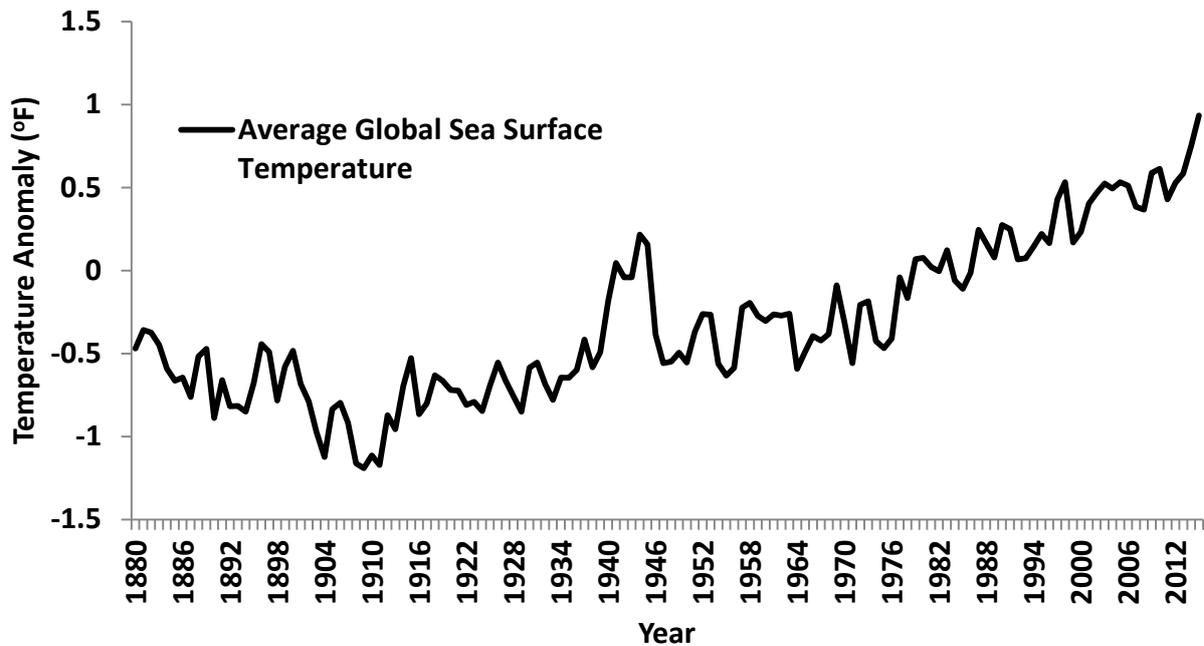- Your graph should look like the example below in Figure 2.

Figure 2: Change in sea surface temperature of the world's oceans since 1880. This graph uses the 1971 to 2000 average as a baseline for depicting change.

Look at Figure 2 and discuss the findings. You might want to think about:

- Is the change in average sea surface temperature consistent through time or is there a specific period of time during which average sea surface temperature seems to be changing more rapidly?
- How might the changes to the global sea surface temperature affect the volumes of the evaporation and precipitation over the ocean?
- Do you think that the global warming of the ocean will be the same for every ocean?
- How do you think spatial variations in the warming of the oceans will affect the global water balance?

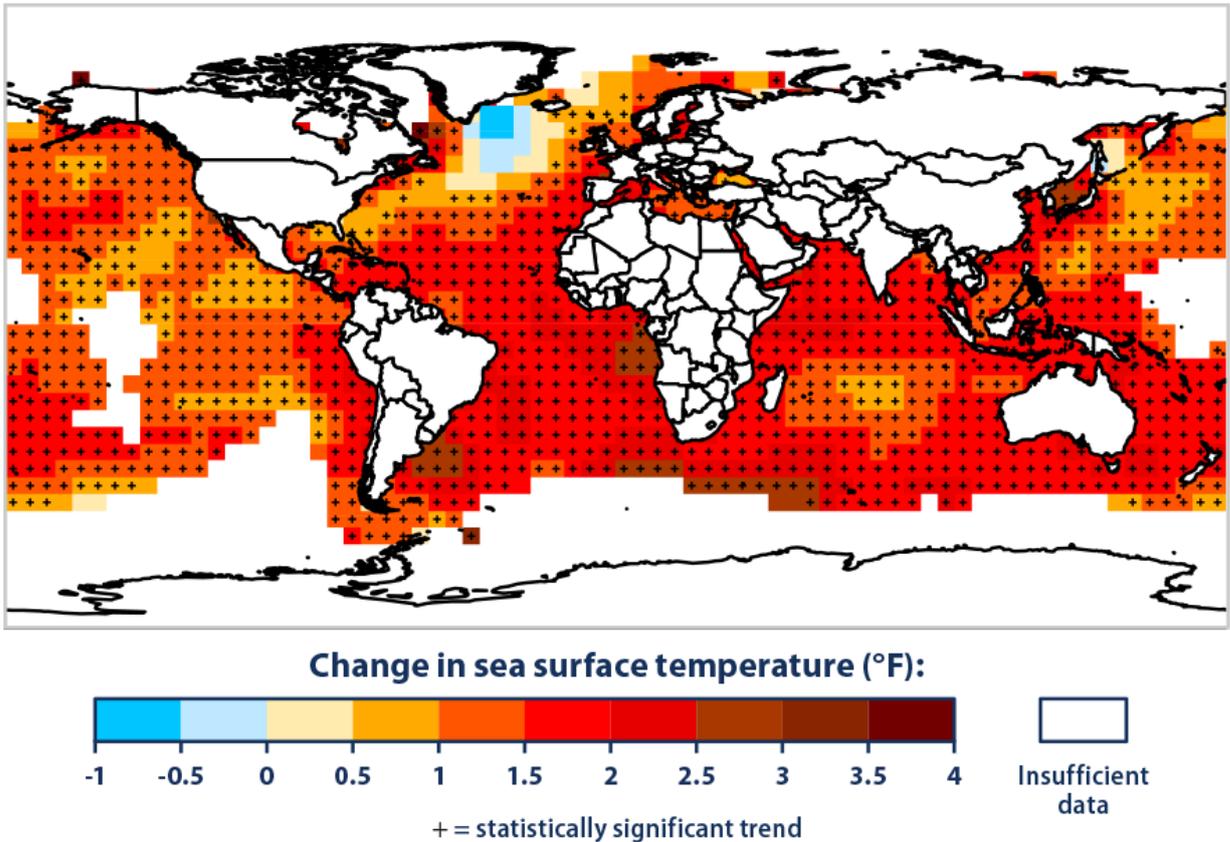You can use figure 3 to help you think about the spatial pattern of oceanic warming trends.

Change in sea surface temperature (°F):

-1 -0.5 0 0.5 1 1.5 2 2.5 3 3.5 4   Insufficient data

+ = statistically significant trend

Figure 3: Change in average sea surface temperature around the world between 1901 and 2015. It is based on a combination of direct measurements and satellite measurements. A black "+" symbol in the middle of a square on the map means the trend shown is statistically significant. White areas did not have enough data to calculate reliable long-term trends. Data Sources
(i)   IPCC (2013): The physical science basis. Working group 1 contribution to the IPCC Fifth Assessment Report and (ii) NOAA (2016): Merged Land Ocean Global Surface Temperature Analysis.

Take it Further

The accuracy with which we can measure sea surface temperature will depend on the number of measurements collected and the precision of the methods used. To take this into account, uncertainty values (confidence intervals) are used. You can add the 95% upper and lower confidence intervals to the graph you plotted in Figure 2. Your graph should look like the example below in Figure 4.
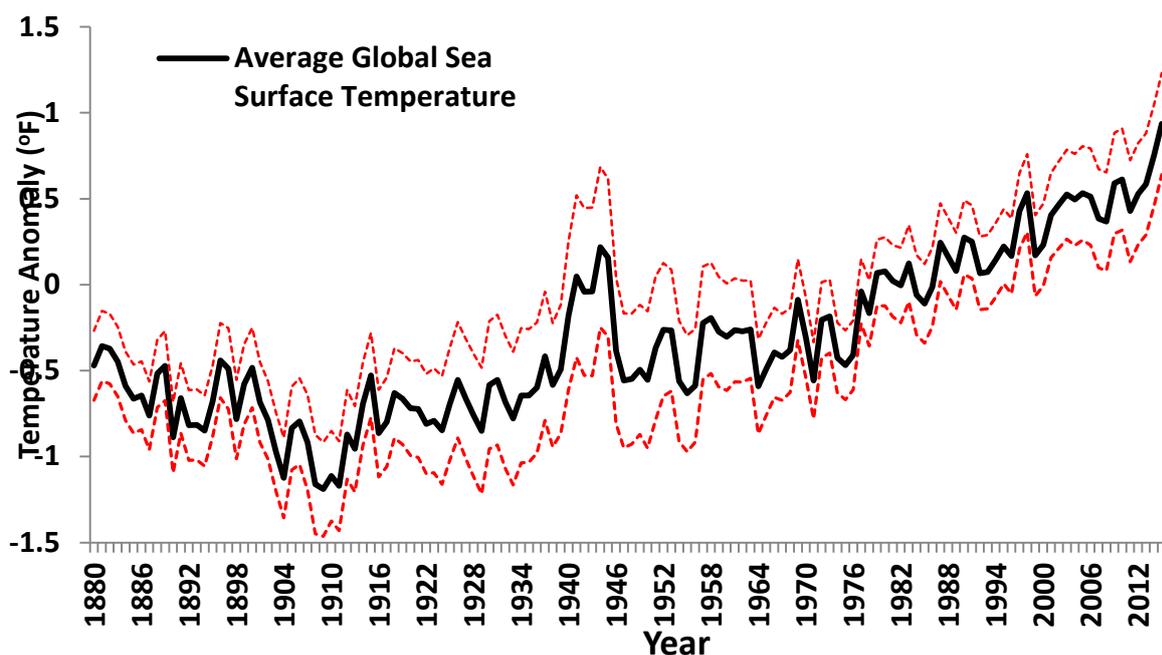
Figure 4: Change in average surface temperature anomalies of the world's oceans since 1880. This graph uses the 1971 to 2000 average as a baseline for depicting change. The red dotted lines represent the 95% upper and lower uncertainty bounds.

Looking at figure 4:

- Are there any differences in the overall trends of the averaged data compared to the uncertainty data?
- What extra information does the addition of the confidence intervals give?
- Think about the methods used to measure sea surface temperature and how they differ in accuracy – how would any inaccuracies show up in estimates of uncertainty? What effect could this have on how accurately you can describe the trends in the data?

3) Trends through time – the importance of record length

Figures 2 and 4 plot the anomaly in sea surface temperatures between 1800 and 2015. Between 1880 and 2015, on average, there is a -0.3°F temperature anomaly suggesting that sea surface temperature is actually decreasing. But how accurately does that represent what you are actually seeing on the graph? Further, if we look at the period between 1970 and 2015 there is a 0.18°F increase in sea surface temperature anomalies. This tells us that the length of time in which we look at data records for is fundamentally important.

Task

- Calculate the average sea surface temperature anomaly values over (i) the entire data series; (ii) every 15 years; (iii) every 45 years.
- Plot all three data sets on the same line graph and label them appropriately. Your graph should look like the example below in Figure 5.
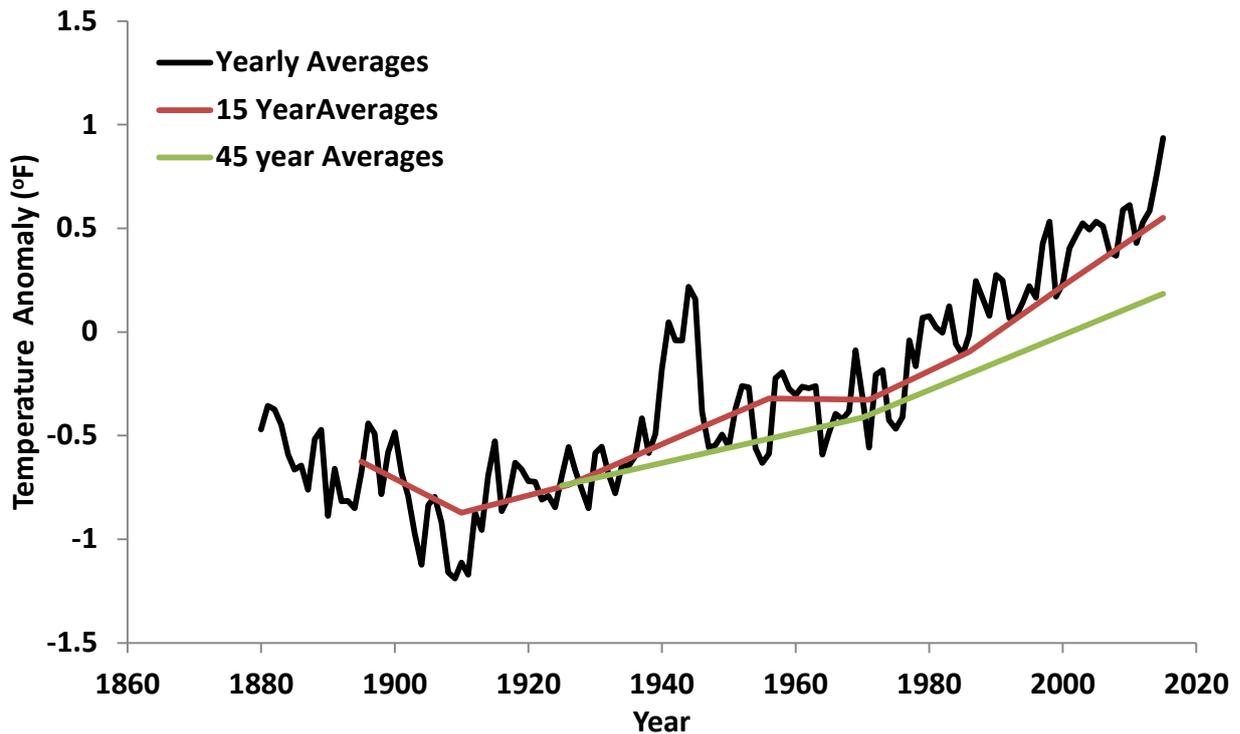
Figure 5: Change in average surface temperature of the world's oceans since 1880 using yearly averages, 15 year averages and 45 year averages.

Looking at Figure 5:

- When you compare the data averaged over the three different time periods are there any differences in the overall trends in the data?
- Which do you think is the best time period over which to average? Why?

Take it Further

Understanding how the mean of a data population changes through time is a useful indicator however this disguises the shape of the data population. For example, two data sets may have an identical mean value but the distribution of the population of data may be skewed. This tells us important information, particularly about outlier data. This can be viewed using a frequency histogram.

- Produce a frequency histogram for the entire data set and for years 1880-1985, 1985-1910, 1986-2001 and 2001-2015.
- Plot the five histograms on the same graph. Your graph should look like the example below in Figure 6.

Looking at Figure 6:

- Describe the overall shape to the data population for the entire data set (1880 – 2015). Which category has the highest frequency of data points? Is the data skewed in any way i.e. are there more data points for positive temperature anomalies compared to negative temperature anomalies? What does this mean?
- Compare the shape of the populations of data for the other data periods you have plotted. Are there any shifts in the data? Is the shape of the data population the same? Why might this be?
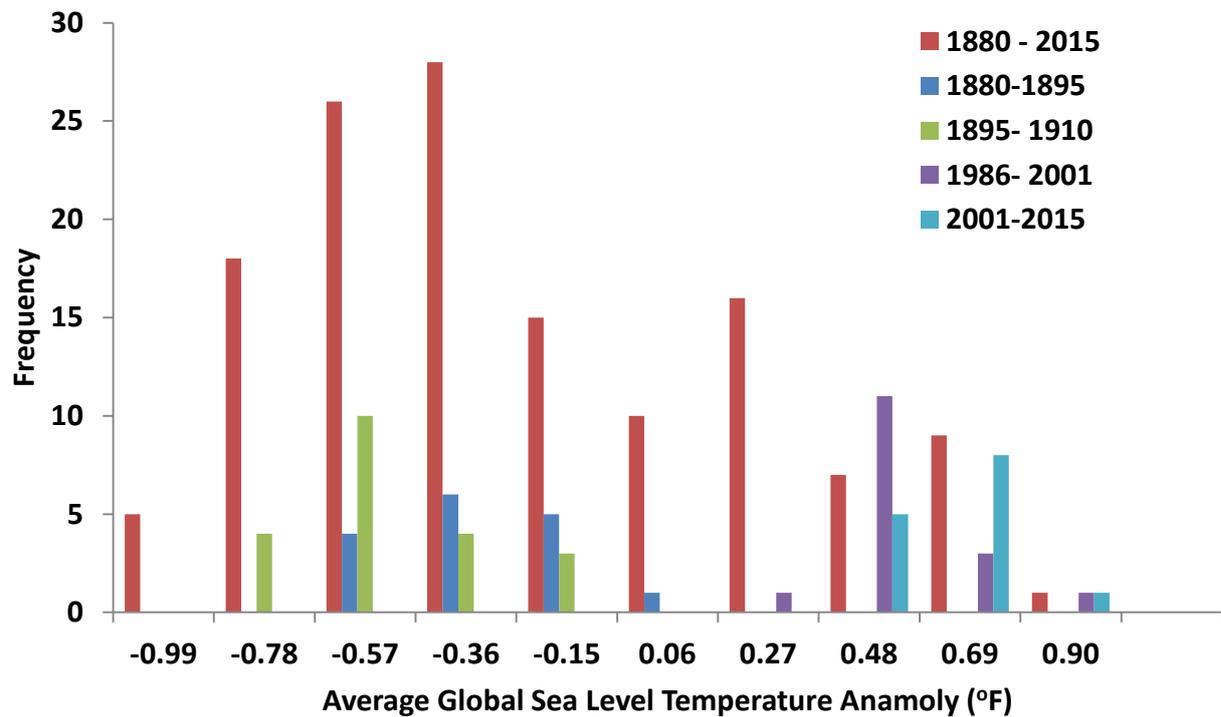
Figure 6: frequency histograms of global sea surface temperature anomaly for 1800 – 2015, 1880-1895, 1895-1910, 1986-2001 and 2001-2015.

Plenary

Return to the main lesson question. Discuss:
- How future changes to the climate might affect each component of the global water balance.
- How the feedbacks between the different components of the water balance work and how a change in one component might track through to changes in other components.
- How important is it to have long records for data? What happens if we don't have these records?

If you are conducting your own fieldwork investigation then have a look at our Student Guide to the A Level Independent Investigation: www.rgs.org/nea.