# Barometric Pressure Activity: Teacher Guide

**Level:** Intermediate

**Subject:** Geography and Mathematics

**Duration:** 1 hour

**Type:** Guided classroom activity

**Learning Goals:**

- Use the scientific process to find a relationship between barometric pressure and altitude
- Use data from the School2School.net website
- Use statistics to verify the relationship between barometric pressure and altitude

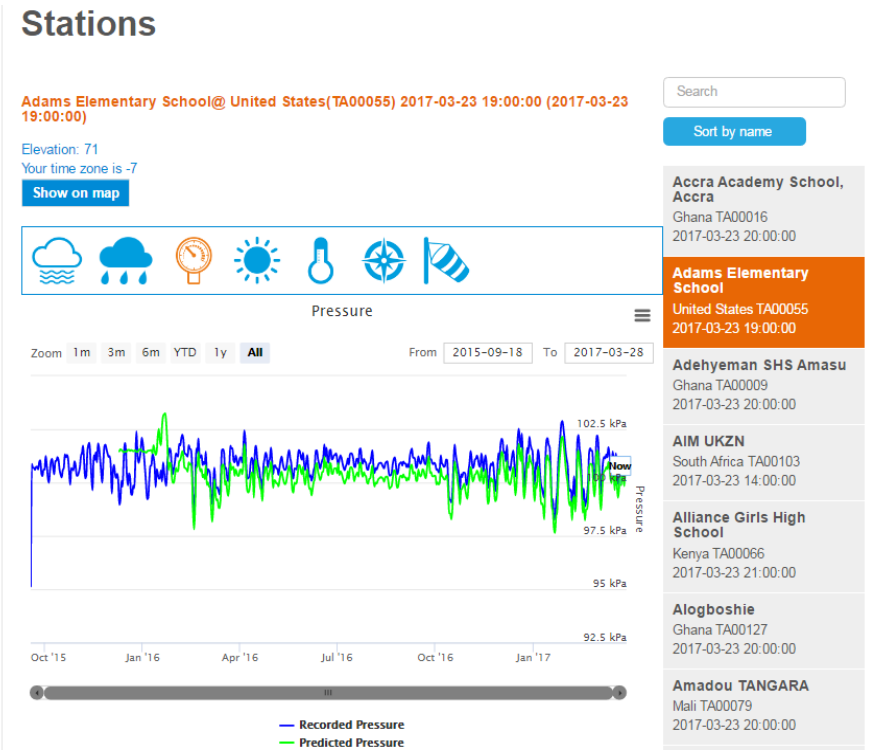
**Materials:**

- Access to the School2School.net website
- Barometric Pressure Powerpoint - https://docs.google.com/presentation/d/1G8R3GJ9aHg2me2-z3OdZV4ke-arQ_ualpZ_AgEE1ycE/edit?usp=sharing
- Pressure and Elevation Spreadsheet - https://drive.google.com/file/d/0BxNcyc_sE4pPcnZya1FIb3BaRlE/view?usp=sharing

**Methods:**

As a class work though the Barometric Pressure Powerpoint using the scientific process

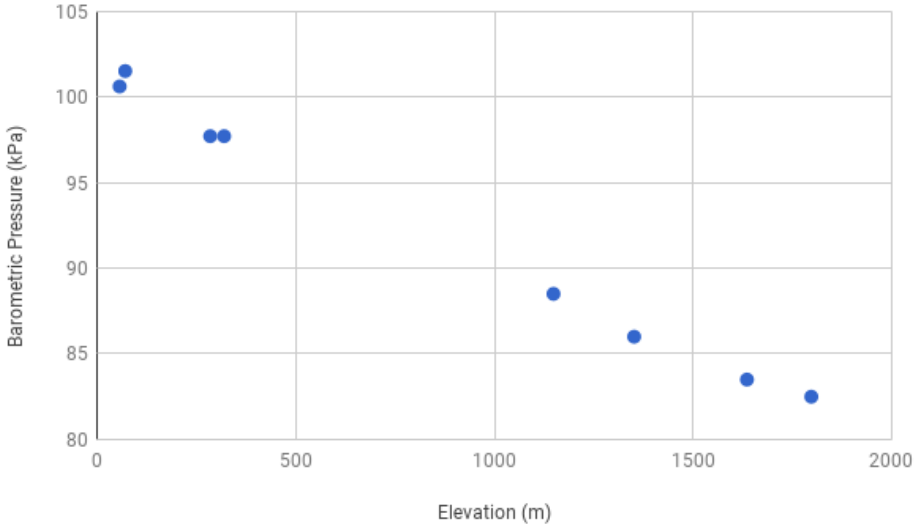
1. The first step of the scientific process is to ask a question. In this case, the question is: is barometric pressure different between stations? Start making observations by going to School2School.net, and clicking on the "Stations" tab. Navigate to your school's station if you have your own TAHMO station, or else just choose a close station. Pick the Barometric Pressure icon (third from the left) to display the graph of the recorded pressures (See image below). Note the maximum, minimum, and average pressure values (using estimations is okay- just a rough guess by eye is appropriate). Choose another station and compare your results, do you see a difference in the range of pressures for different stations? [Answer: the maximum pressure recorded is different for different stations, it doesn't seems like the variable is bounded]



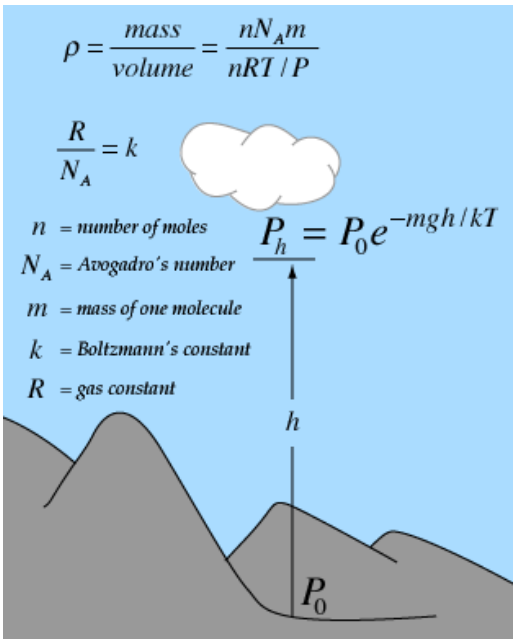

2. The second step of the scientific process is to develop a hypothesis. Now that you have seen that there are different pressure ranges for different stations, ask the class why they think barometric pressure is different for different stations? Have students develop multiple hypothesis for explaining the different barometric pressure ranges, remember that all hypotheses should be considered, this step is all exploring a wide variety of different explanations. What information from the School2School site can help formulate these hypotheses? Another piece of information given for each station is the elevation (in meters) and is located just under the station name. Once the concept of a relationship between pressure and altitude is suggested by a student, suggest that you use this as your primary hypothesis for the remainder of the activity. [Answer: A good working hypothesis might be that barometric pressure is controlled by elevation, or that barometric pressure and elevation and inversely related]
3. The third step of the scientific process is to test the hypothesis. Brainstorm with the class how you might test the hypothesis. A great way to start testing the hypothesis is to start collecting data for the two variables of interest: barometric pressure and elevation. Which variable is the explanatory variable and which one is the response variable? [Answer: Elevation is the explanatory variable because it is independent. The pressure is the response variable because it is dependent on the elevation]
4. The fourth step of the scientific process is to record the data, so create a spreadsheet with barometric pressure vs altitude for numerous stations (columns A-E in Sheet 1). A good question to ask the class is how many stations they think should be compared. [Answer: As a general rule, more than 7 data points is best]. Record the estimated average pressure for each station and record in the Excel sheet. You can you a rough eye-ball estimate the average pressure for each station- you do not need to calculate an exact average. [Note: Below is an example table of 7 stations with a wide range of elevations that is used in the following analysis in the calculations section, but any stations can be used for the analysis]

| Station Name | Location | Station # | Elevation (m) | Pressure (kPa) |
|---|---|---|---|---|
| Réseau MARP | Burkina Faso | TA00082 | 320 | |
| St. Scholastica Catholic School | Kenya | TA00057 | 1636 | |
| Accra Academy School | Ghana | TA00016 | 57 | |
| Bol Matafo2 | Chad | TA00084 | 285 | |
| Gashora Girls Academy | Rwanda | TA00075 | 1352 | |
| Entebbe WME | Uganda | TA00033 | 1149 | |
| Kenya Met. Dept | Kenya | TA00025 | 1798 | |
| Adams Elementary School | United States | TA00055 | 71 | |

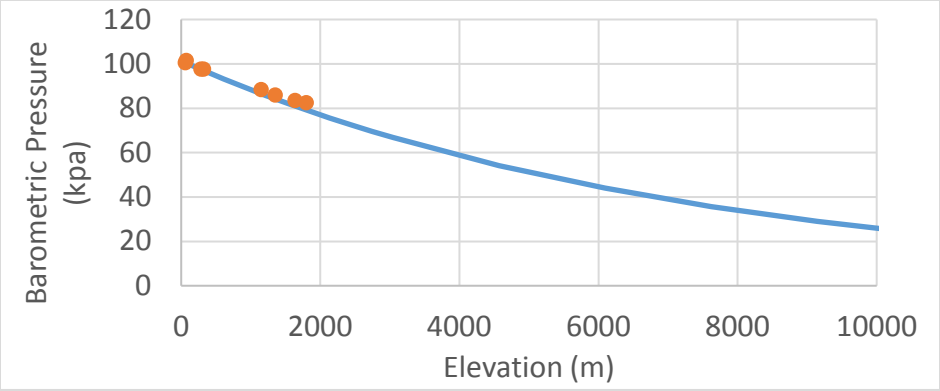
5. The fifth step of the scientific process is making conclusions. Once the data has been recorded, creating a plot is useful for seeing the relationship between the two variables (see image below). What kind of relationship do the data points show? [Answer: The trend that can be identified from the plot is that for lower elevations there is a higher pressure, and for higher elevations the pressure is lower- this is an inversely proportional relationship




6. Now that the relationship has been identified as inversely proportional, can it be validated using meteorology and mathematics. Ask the class, how can we look for a mathematical relationship barometric pressure and elevation? [Answer: Based on the idea gas law, there is a known mathematical relationship between pressure and elevation based on the barometric formula assuming the standard temperature lapse rate equals zero: Pressure = 101.325 * exp(-1.37*10-4*elevation). This formula is given in the spreadsheet on Sheet2 in columns L-M. Figure from http://hyperphysics.phy-astr.gsu.edu/hbase/Kinetic/barfor.html]




7. Does our data follow this formula? Try plotting our 7 data points on the same graph as the barometric formula relationship. [Answer: Yes, our data does seem to follow the barometric formula relationship. The data points only cover a small ranges of elevation but it does seem to correctly represent the relationship.] Can this model be used to extrapolate the barometric pressure for elevations much higher than we have data for? [Answer: generally extrapolate outside of the collected range of values for the explanatory variable is not recommended. Even though we do have a mathematical relationship between elevation and barometric pressure, we should not extrapolate to calculate pressure for very high elevations.]




**Discussion**

Have the class summarize the activity by asking questions such as:

- What is the relationship between pressure and elevation? [Answer: they are inversely proportional]
- What are other factors that affect pressure besides elevation? [Answer: local weather such as temperature and wind speed also affect air pressure and air density]
- How did we use the scientific theory to reach our conclusions?

# Barometric Pressure Activity: Student Worksheet

Navigate to the School2School.net website, explore the barometric pressure trends for numerous stations for this activity. Using the 5 main steps of the scientific method, describe how each step was used in this activity.

1. Ask a question

_____

_____

_____

2. Make a hypothesis

_____

_____

_____

3. Develop a method to test your predictions

_____

_____

_____

_____

_____

4. Collect data to test your hypothesis

_____

_____

_____

_____

_____

5. Analyze data and draw conclusions

_____

_____

_____

_____

_____

# Advanced Topics: Barometric Pressure

This advanced topic is intended for classes that want to continue to explore the barometric formula for pressure and elevation. As a general rule, the pressure drops approximately by 11.3 Pascals per meter in first 1000 meters above sea level. This following exercise will use Excel and mathematical principals to quantify how well our data fits the barometric formula.

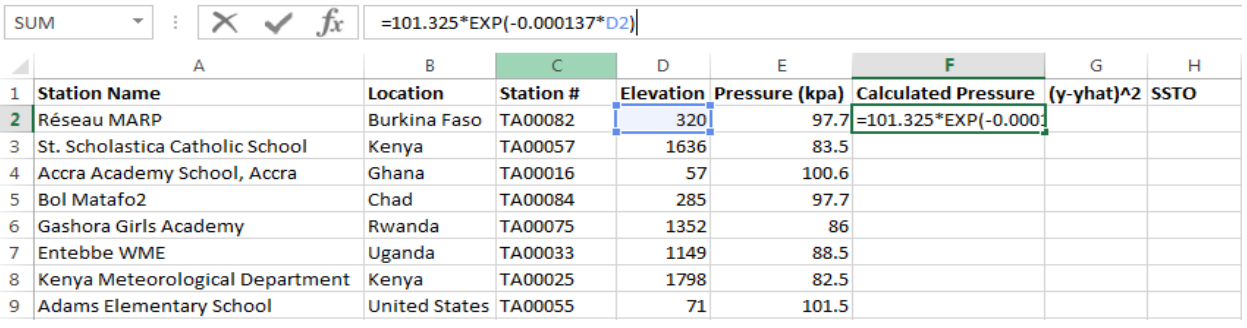
The following calculations are based on the preselected 7 stations and the estimated average pressures. Your results may be slightly different based on stations chosen, estimated pressures, or dates chosen. The following calculations are for reference and to be used as a guide for the analysis only.

In mathematics, what strategies are there for determining the relationship between two variables? [Answer: sum of the square error (SSE), total sum of the square (SSTO), correlation coefficient (R), coefficient of determination ($R^2$)].

We can use statistics and the sum of the square error to determine how well our data fits the known relationship (Sheet2 columns G-H).] We will be using Excel's capabilities to calculate these variables. Start by setting up the spreadsheet with three additional columns titled: "Calculated Pressure", "y-yhat)^2", and "SSTO".

| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| 1 | **Station Name** | **Location** | **Station #** | **Elevation** | **Pressure (kpa)** | **Calculated Pressure** | **(y-yhat)^2** | **SSTO** |
| 2 | Réseau MARP | Burkina Faso | TA00082 | 320 | 97.7 | | | |
| 3 | St. Scholastica Catholic School | Kenya | TA00057 | 1636 | 83.5 | | | |
| 4 | Accra Academy School, Accra | Ghana | TA00016 | 57 | 100.6 | | | |
| 5 | Bol Matafo2 | Chad | TA00084 | 285 | 97.7 | | | |
| 6 | Gashora Girls Academy | Rwanda | TA00075 | 1352 | 86 | | | |
| 7 | Entebbe WME | Uganda | TA00033 | 1149 | 88.5 | | | |
| 8 | Kenya Meteorological Department | Kenya | TA00025 | 1798 | 82.5 | | | |
| 9 | Adams Elementary School | United States | TA00055 | 71 | 101.5 | | | |

In column F we are calculating the theoretic pressure given the recorded elevation from the mathematical relationship. Type into the formula bar an equals sign (=) followed by 101.325 * EXP (-1.37 * 10-4 * D2. Use the cell reference of D2 instead of typing in the number. Push enter.




| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| 1 | **Station Name** | **Location** | **Station #** | **Elevation** | **Pressure (kpa)** | **Calculated Pressure** | **(y-yhat)^2** | **SSTO** |
| 2 | Réseau MARP | Burkina Faso | TA00082 | 320 | 97.7 | =101.325*EXP(-0.000 | | |
| 3 | St. Scholastica Catholic School | Kenya | TA00057 | 1636 | 83.5 | | | |
| 4 | Accra Academy School, Accra | Ghana | TA00016 | 57 | 100.6 | | | |
| 5 | Bol Matafo2 | Chad | TA00084 | 285 | 97.7 | | | |
| 6 | Gashora Girls Academy | Rwanda | TA00075 | 1352 | 86 | | | |
| 7 | Entebbe WME | Uganda | TA00033 | 1149 | 88.5 | | | |
| 8 | Kenya Meteorological Department | Kenya | TA00025 | 1798 | 82.5 | | | |
| 9 | Adams Elementary School | United States | TA00055 | 71 | 101.5 | | | |

Hover your curser over the bottom right corner of the F2 cell until your curser shows a small black plus sign (this is the fill command). Click and drag the curser down to F9, this action will fill each of the cells with the same formula.

F2 =101.325*EXP(-0.000137*D2)

| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| 1 | Station Name | Location | Station # | Elevation | Pressure (kpa) | Calculated Pressure | (y-yhat)^2 | SSTO |
| 2 | Réseau MARP | Burkina Faso | TA00082 | 320 | 97.7 | 96.97887512 | | |
| 3 | St. Scholastica Catholic School | Kenya | TA00057 | 1636 | 83.5 | 80.97991594 | | |
| 4 | Accra Academy School, Accra | Ghana | TA00016 | 57 | 100.6 | 100.5368345 | | |
| 5 | Bol Matafo2 | Chad | TA00084 | 285 | 97.7 | 97.44500548 | | |
| 6 | Gashora Girls Academy | Rwanda | TA00075 | 1352 | 86 | 84.19278027 | | |
| 7 | Entebbe WME | Uganda | TA00033 | 1149 | 88.5 | 86.56712915 | | |
| 8 | Kenya Meteorological Department | Kenya | TA00025 | 1798 | 82.5 | 79.20244523 | | |
| 9 | Adams Elementary School | United States | TA00055 | 71 | 101.5 | 100.3441896 | | |

Column G will be used to calculate the sum of the square error (SSE). In the column you will calculate the square error between the calculated pressure and the recorded pressure, which will later be summed to give you the SSE. Type into the formula bar an equals sign "=" followed by a set of parenthesis and subtract column F from column E, after the end parenthesis raise your unit to the 2nd power. Push enter after adding the formula. Use the fill command to drag the formula in the rest of the stations in that column. In the cell G10 use the SUM function in excel to add all up all the values in column G. [Note: there is also an excel function to directly calculate SSE. In an empty cell type the following formula: =SUMXMY2(E2:E9,F2:F9)]

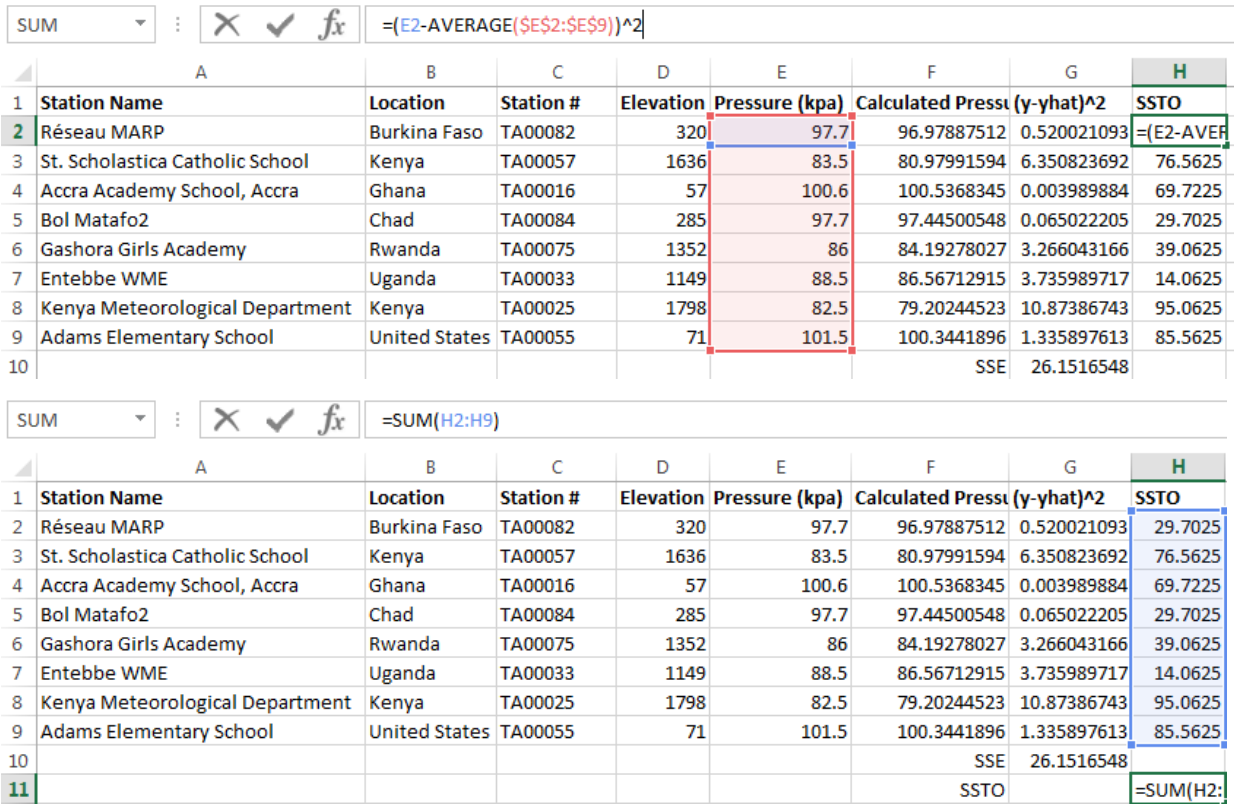
SUM =(E2-F2)^2

| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| 1 | Station Name | Location | Station # | Elevation | Pressure (kpa) | Calculated Pressu | (y-yhat)^2 | SSTO |
| 2 | Réseau MARP | Burkina Faso | TA00082 | 320 | 97.7 | 96.97887512 | =(E2-F2)^2 | |
| 3 | St. Scholastica Catholic School | Kenya | TA00057 | 1636 | 83.5 | 80.97991594 | | |
| 4 | Accra Academy School, Accra | Ghana | TA00016 | 57 | 100.6 | 100.5368345 | | |
| 5 | Bol Matafo2 | Chad | TA00084 | 285 | 97.7 | 97.44500548 | | |
| 6 | Gashora Girls Academy | Rwanda | TA00075 | 1352 | 86 | 84.19278027 | | |
| 7 | Entebbe WME | Uganda | TA00033 | 1149 | 88.5 | 86.56712915 | | |
| 8 | Kenya Meteorological Department | Kenya | TA00025 | 1798 | 82.5 | 79.20244523 | | |
| 9 | Adams Elementary School | United States | TA00055 | 71 | 101.5 | 100.3441896 | | |

SUM =SUM(G2:G9)

| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| 1 | Station Name | Location | Station # | Elevation | Pressure (kpa) | Calculated Pressu | (y-yhat)^2 | SSTO |
| 2 | Réseau MARP | Burkina Faso | TA00082 | 320 | 97.7 | 96.97887512 | 0.520021093 | |
| 3 | St. Scholastica Catholic School | Kenya | TA00057 | 1636 | 83.5 | 80.97991594 | 6.350823692 | |
| 4 | Accra Academy School, Accra | Ghana | TA00016 | 57 | 100.6 | 100.5368345 | 0.003989884 | |
| 5 | Bol Matafo2 | Chad | TA00084 | 285 | 97.7 | 97.44500548 | 0.065022205 | |
| 6 | Gashora Girls Academy | Rwanda | TA00075 | 1352 | 86 | 84.19278027 | 3.266043166 | |
| 7 | Entebbe WME | Uganda | TA00033 | 1149 | 88.5 | 86.56712915 | 3.735989717 | |
| 8 | Kenya Meteorological Department | Kenya | TA00025 | 1798 | 82.5 | 79.20244523 | 10.87386743 | |
| 9 | Adams Elementary School | United States | TA00055 | 71 | 101.5 | 100.3441896 | 1.335897613 | |
| 10 | | | | | | | =SUM(G2:G9) | |

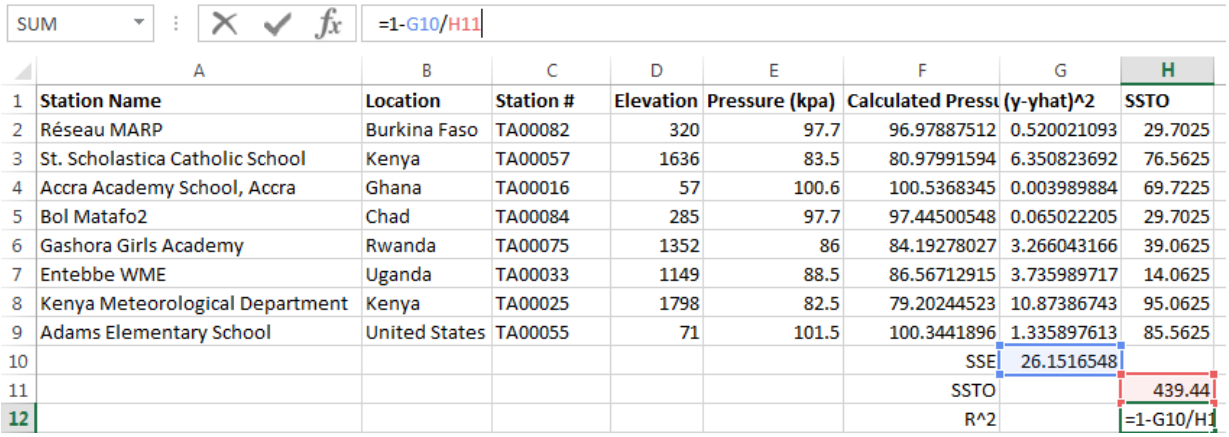
In column H you will calculate the total sum of the squares (SSTO). The SSTO is calculated by the difference between the sample and the sample average, this quantity is square. To calculate the sample mean, use the Excel AVERAGE command. The formula for column H uses the following formula structure: =(E2-Average(E2:E9))^2. Sum the column in cell H11 representing the SSTO.




| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| 1 | Station Name | Location | Station # | Elevation | Pressure (kpa) | Calculated Pressu | (y-yhat)^2 | SSTO |
| 2 | Réseau MARP | Burkina Faso | TA00082 | 320 | 97.7 | 96.97887512 | 0.520021093 | =(E2-AVER |
| 3 | St. Scholastica Catholic School | Kenya | TA00057 | 1636 | 83.5 | 80.97991594 | 6.350823692 | 76.5625 |
| 4 | Accra Academy School, Accra | Ghana | TA00016 | 57 | 100.6 | 100.5368345 | 0.003989884 | 69.7225 |
| 5 | Bol Matafo2 | Chad | TA00084 | 285 | 97.7 | 97.44500548 | 0.065022205 | 29.7025 |
| 6 | Gashora Girls Academy | Rwanda | TA00075 | 1352 | 86 | 84.19278027 | 3.266043166 | 39.0625 |
| 7 | Entebbe WME | Uganda | TA00033 | 1149 | 88.5 | 86.56712915 | 3.735989717 | 14.0625 |
| 8 | Kenya Meteorological Department | Kenya | TA00025 | 1798 | 82.5 | 79.20244523 | 10.87386743 | 95.0625 |
| 9 | Adams Elementary School | United States | TA00055 | 71 | 101.5 | 100.3441896 | 1.335897613 | 85.5625 |
| 10 | | | | | | SSE | 26.1516548 | |

| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| 1 | Station Name | Location | Station # | Elevation | Pressure (kpa) | Calculated Pressu | (y-yhat)^2 | SSTO |
| 2 | Réseau MARP | Burkina Faso | TA00082 | 320 | 97.7 | 96.97887512 | 0.520021093 | 29.7025 |
| 3 | St. Scholastica Catholic School | Kenya | TA00057 | 1636 | 83.5 | 80.97991594 | 6.350823692 | 76.5625 |
| 4 | Accra Academy School, Accra | Ghana | TA00016 | 57 | 100.6 | 100.5368345 | 0.003989884 | 69.7225 |
| 5 | Bol Matafo2 | Chad | TA00084 | 285 | 97.7 | 97.44500548 | 0.065022205 | 29.7025 |
| 6 | Gashora Girls Academy | Rwanda | TA00075 | 1352 | 86 | 84.19278027 | 3.266043166 | 39.0625 |
| 7 | Entebbe WME | Uganda | TA00033 | 1149 | 88.5 | 86.56712915 | 3.735989717 | 14.0625 |
| 8 | Kenya Meteorological Department | Kenya | TA00025 | 1798 | 82.5 | 79.20244523 | 10.87386743 | 95.0625 |
| 9 | Adams Elementary School | United States | TA00055 | 71 | 101.5 | 100.3441896 | 1.335897613 | 85.5625 |
| 10 | | | | | | SSE | 26.1516548 | |
| 11 | | | | | | SSTO | | =SUM(H2: |

At this time, we have all the information necessary to calculate the coefficient of determination ($R^2$). The coefficient of determination indicates that the model explains a certain percent of the variability of the response data. In the example spreadsheet, the $R^2$ is in cell H13 of Sheet2, with a value of 0.94.




| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| 1 | Station Name | Location | Station # | Elevation | Pressure (kpa) | Calculated Pressu | (y-yhat)^2 | SSTO |
| 2 | Réseau MARP | Burkina Faso | TA00082 | 320 | 97.7 | 96.97887512 | 0.520021093 | 29.7025 |
| 3 | St. Scholastica Catholic School | Kenya | TA00057 | 1636 | 83.5 | 80.97991594 | 6.350823692 | 76.5625 |
| 4 | Accra Academy School, Accra | Ghana | TA00016 | 57 | 100.6 | 100.5368345 | 0.003989884 | 69.7225 |
| 5 | Bol Matafo2 | Chad | TA00084 | 285 | 97.7 | 97.44500548 | 0.065022205 | 29.7025 |
| 6 | Gashora Girls Academy | Rwanda | TA00075 | 1352 | 86 | 84.19278027 | 3.266043166 | 39.0625 |
| 7 | Entebbe WME | Uganda | TA00033 | 1149 | 88.5 | 86.56712915 | 3.735989717 | 14.0625 |
| 8 | Kenya Meteorological Department | Kenya | TA00025 | 1798 | 82.5 | 79.20244523 | 10.87386743 | 95.0625 |
| 9 | Adams Elementary School | United States | TA00055 | 71 | 101.5 | 100.3441896 | 1.335897613 | 85.5625 |
| 10 | | | | | | SSE | 26.1516548 | |
| 11 | | | | | | SSTO | | 439.44 |
| 12 | | | | | | R^2 | | =1-G10/H1 |

What does the coefficient of determination mean? [Answer: The correct interpretation of this value is that 94% of the variability in pressure is explained by the elevation.]

Ask the class, does this value mean that we have a good agreement between our data and the mathematical model? [Answer: Generally, a value for $R^2$ greater than 0.75 indicated good agreement between the data and the model. We got a value of 0.94 for the relationship between elevation and pressure, so yes there is a strong relationship between these two variables.]

Does the statistical analysis confirm our hypothesis?