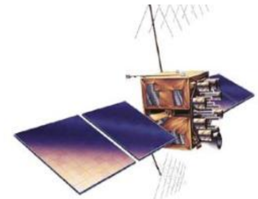
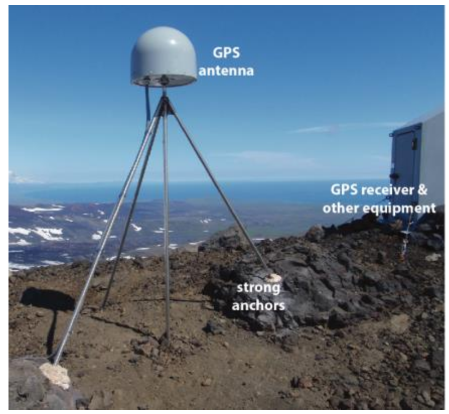
Alaska GPS Analysis

Technology is amazing. The Global Positioning System, known as GPS, has been around for many years, and its applications are many. In a nutshell, GPS can be used to locate where you are on Earth's surface within a few meters. People are most familiar with GPS units in cars to help with directions or for recreation, like hiking. A specific type of GPS called **differential GPS**, or dGPS, is extremely precise and can be used to show tectonic plate movement of just a few millimeters!

Basically, there are 24 GPS **satellites** cruising 12,000 miles above the Earth moving at about 7500 kilometers per hour. That's almost 2 kilometers per second – yes, 2 kilometers every second. The satellites send out radio wave signals in all directions.



GPS Receivers on the ground can tell how long it takes for the radio waves to reach them, and using some math, computers can calculate the **distance** between the receiver and the satellite. Computers can then translate small changes to large changes by looking at larger intervals of time.



dGPS is so much more accurate because it uses some very sophisticated computing to take out errors due to the atmosphere and inaccurate clocks, for example. The picture on the student handout shows a **GPS Monument**, a GPS antenna on a stand that is securely rooted in rock layers below soil. Inside the dome is the GPS antenna that receives the radio waves and sends the signal to an attached receiver. The resulting positional data are then sent via Internet to UNAVCO for further processing. Scientists can then use long-term positional data to interpret plate motions and plate boundary interactions.

NGSS STANDARD ALIGNMENT

Disciplinary Core Ideas	
• Motion and Stability—Forces and Interactions: HS-PS2-1, MS-PS2-2 • Energy: MS-PS3-1, MS-PS3-2, HS-PS3-2, MS-PS3-5 • Waves and Their Applications in Technologies for Information Transfer: HS-PS4-2, MS-PS4-3, HS-PS4-5 • Earth's Systems: 5-ESS2-1, HS-ESS2-1, MS-ESS2-2, HS-ESS2-2, MS-ESS2-3, HS-ESS2-3 • Earth and Human Activity: HS-ESS3-1, MS-ESS3-2	
Science and Engineering Practices	**Crosscutting Concepts**
4. Analyzing and Interpreting Data 5. Using Mathematics and Computational Thinking 6. Constructing Explanations and Designing Solutions	2. Cause and Effect 4. Systems and System Models 7. Stability and Change

LESSON PLAN

This is a multi-day lesson, and could take 2 – 3 lessons (hour long) to complete. IRIS Education and Outreach has a two-part video to demonstrate all parts of this activity:

www.iris.edu/hq/inclass/video/gps_monitors_deformation_in_subduction_zone_part_1_intro
www.iris.edu/hq/inclass/video/gps_monitors_deformation_in_subduction_zone_part_2_using_real_data

Have students stand up and try to move just one millimeter. With every movement, say it's too much. This will impress upon them the accuracy of the dGPS system. This system can detect plate tectonic movements of continents and even millimeter-scale deformation of *parts of continents near plate boundaries*.

PART I: Building a GPS 'Monument'

Materials:

- Sharp wooden toothpicks work best.
- Gumdrops can be found at larger stores in the bulk candy section. Can also use the smaller 'spice drops' available at most stores, but it's tougher to get toothpicks in smaller gumdrops.
- Only small amounts of modeling clay are necessary.
- Transparencies can be cut into quarter sheets. You can even use smaller pieces if necessary. Cutting one sheet into six pieces works well.

Procedure:

1. Building the monument should take a few minutes, and it's the hook. Students will use the gumdrop model for Part II (if doing Pinpointing Location portion in groups), and also to model movement of the monument in Part IV.
2. Have students place gumdrop monument in middle of transparency sheet. Clay represents the concrete that 'glues' the monument to rock layers beneath Earth's soil.
3. Students can also draw and color on the transparency sheet to represent rock layers. The key is that students understand that it's crustal rock, not just the monument or soil, that moves.
4. If doing the activity over two days, have students write their name on a piece of scrap paper and place gumdrop monument on top to save for next day.

PART II: Pinpointing Location

There are three methods to do the demonstration, which vary in scale.

Option One – Smaller Scale

Supplies:

- 3 ring stands (without rings).
- 3 'satellites' to place at top of ring stands. BubbleYum gum has a shape similar to GPS satellites and is an attention grabber. You could also print small pictures of satellites to tape to top of ring stands.
- Strings of 3 different lengths taped to tops of ring stands – all must be at least as long as height of ring stand.
- Gumdrop monument from Part I.

Demonstration Procedure:

1. Premark locations of ring stands so that all 3 strings meet in one location on table surface. You will have to set this up and cut the strings before hand.
2. Explain that satellites are flying above Earth's surface at same altitude and ring stands represent that height.

3. Explain relationship between gumdrop monument (built in Part I) and satellite – they 'talk' to each other and establish the ***distance*** between them.
4. The string represents the *distance from the satellite to the monument.*
5. Have a student move one string (held tautly) in all directions to indicate that the *distance* is known, but the *direction* is not. A sphere around the top of the ring stand is established with radius equaling the distance from that satellite to the monument.
6. Have another student move a 2nd string around and note where strings intersect – there is a circle of possible places this happens. Emphasize again that the only known entity is the *distance* from the satellite to the monument.
7. Have a third student move the 3rd string to show where all 3 strings intersect. There should be two places – one on Earth's surface and one in space – where all 3 strings intersect. Note that computers can automatically detect that the one in space is non-sensical.
8. Place the gumdrop at the point where 3 strings intersect.
9. Remind students that these measurements are taking place while satellites are moving at 2 kilometers/second!
10. Have students complete Part II questions on worksheet.

Note: Activity can be done in groups following same directions.

Option Two – Larger Scale

Supplies:

- 3 long lengths of twine (construction twine works well) that will reach from high up on the walls to a central point somewhere in the room.
- Tape to hold up twine on wall.
- 3 'satellites' to tape to walls. BubbleYum gum still works to represent the satellites. You could also print pictures of satellites to tape on the walls.
- Gumdrop monument from Part I, or a larger version of a GPS monument.

Demonstration Procedure:

11. Tape one end of each length of twine to the wall next to each 'satellite'. Find a location somewhere on the floor of the room where you want the GPS monument to be located. Cut the twine so that all 3 strings meet at the GPS monument. You will have to set this up and cut the strings before hand.
12. Coil up the long strings and tape them up on the wall so you can easily pull them down and hand to a student.
13. Follow the demonstration procedure above to have one, then two, then three students locate the point of intersection of the three lengths of twine = location of the GPS monument.

Option Three – Largest Scale

Demonstration Procedure:

14. Present demonstration just as with Option Two above, only use much longer string and use the gym or outdoor basketball hoops.

Here is a video you could also use:

https://www.youtube.com/watch?v=IoRQiNFzT0k

PART III: Measuring Alaska GPS/Tectonic Movement

Procedure:

1. Review metric system (millimeter, centimeter, meter, kilometer).
2. Review cardinal directions.
3. There are thousands of dGPS stations in operation, more than 1100 station in the USA's Plate Boundary Observatory
   https://www.unavco.org/instrumentation/networks/status/pbo
4. Instruct students how to 'read' a Time Series Plot (TSP). Use example from Montague Island as example to do as whole class.
5. Vertical is not used because it is more it is more complex to interpret. Winter snow loads and deglaciation can complicate vertical motions of GPS monuments in Alaska.
6. With a ruler, draw a line of best fit to show trend of TSP. Try to draw the line so that there are as many data points above that line as below the line. Using a clear ruler works well.
7. Using y-axis mm scale, determine overall change in position in given time period.
8. Calculate annual movement by dividing overall change in position by total time period.

Detail on Interpreting Time Series Plots (TSP)

a) All plots have a Y-axis with 'zero' and positive numbers above the line and negative numbers below the line. Numberless tickmarks on the right mirror the measurements.
b) The 'North' plot shows North and South movement – anything moving in the 'positive' (up) direction is moving North, and anything moving in the 'negative' (down) is moving South.
c) The same is true for East/West – movement in a positive direction (up) is movement to the East, and anything moving in the negative (down) direction is moving West.
d) Most time series do not include gridlines, so it's helpful to use a ruler or straightedge (a clear one is best) to calculate how much movement there is.
e) The scale on the axes will vary and the units may vary as well so examine the labels carefully.
f) Remember that the underlying technology is complex and there are occassional problems like instrument failures. So the Time Series Plots can have gaps and glitches and nonlinearities. The example Time Series Plots in this activity are relatively clean and clear.
g) The time scale is shown by years and twelfths of years (months).
h) Receivers collect a positional measurement every second. That's 86,400 measurements a day. These are averaged to get the one data point for each day that is shown on a time series.
i) Most plots now start right at '0' on the y-axis; what is important is the *change* in position. However, sometimes you will need to use the trend lines, not the points, to determine change in position.
j) The velocities of dGPS monuments are small – millimeters or centimeters per year. But just think how much movement that would mean over thousands of years! An easy equivalent to remember is 1 mm/yr is the same velocity as 1 kilometer/1 million years.

Answers to Student Worksheet are shown below on Answer Key.

PART IV: Plotting GPS Monument Motion

Procedure:

1. Follow procedures on student handout. Confusion may arise about scale translation of centimeters to millimeters. Scale used on the grid is designed to make graphing easy. Actual movement is in millimeters but this is too hard to see if the grid were drawn at 1:1 scale.
2. Vector graph should look like the example provided on Answer Key. Colors used may vary.
3. The GPS gumdrop monuments will move along path of vectors, mimicking the movement of the tectonic plate with GPS monument attached.

PART V: Analysis of GPS Monument Motion

The big picture result of the activity is that GPS monuments in the Prince William Sound area and southeast coast of the Kenai Peninsula are being pushed toward the northwest with respect to interior Alaska. These GPS monuments are moving northwest because the shallow portion of the North American continental margin is locked by friction to the Pacific Plate that is northwest toward North America in the Gulf of Alaska. The rate of northwest motion is highest for locations farthest to the southeast, like Montague Island, that are closest to the Aleutian Trench where the Pacific and North American plates meet on the seafloor. Along a transect from Montague Island to Anchorage, the rate of northwest motion gets progressively slower until the GPS monuments near Anchorage are moving very slowly compared to the rapid northwest motion of Montague Island. The clear implication is that the continental margin between the Aleutian Trench and Anchorage is being compressed in SE – NW direction. Strain is building within the continental margin of the North American Plate as the Pacific Plate pushes the North American Plate margin toward the northwest. This accumulating strain will eventually be released in the next major or great earthquake on the Alaska - Aleutian Subduction Zone or thrust fault(s) within the continental margin. The plate boundary regions of the Pacific and North American plates are essentially "locked and loading" as they store elastic energy that will be released in future earthquakes. When the stored energy due to the slow northwest motion is suddenly released in the next major earthquake, the Prince William Sound area and southeast coast of the Kenai Peninsula will move towards the southeast. For example, during the 1964 Great Alaska Earthquake, Latouche Island in Prince William Sound was displaced nearly 20 meters toward the southeast and uplifted by 3 meters.

Procedure:

1. Lead students to answers from observations of the GPS vector map.
2. Discuss big picture after students realize that the region is being squeezed.
3. A further demonstration is taking a piece of paper or cloth and holding the right side of it stationary, and then pushing the left side towards the right. The paper/cloth will buckle.

Name: ____ **ALASKA- GPS ANALYSIS**

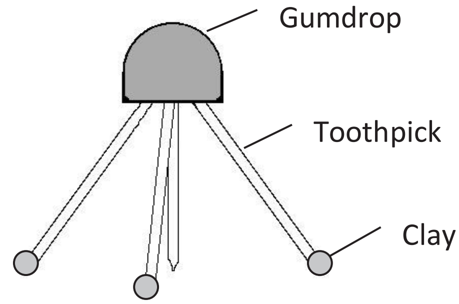
Today's Date: ________________________

PART I: Building a GPS 'Monument'

Materials:
4 toothpicks, 1 gumdrop, modeling clay, ruler, 1/4 sheet transparency

Procedure:

1. Insert 3 toothpicks diagonally into the gumdrop. These will act as the legs.
2. Insert a slightly shorter toothpick sticking straight down from the middle of the gumdrop. The tip of this toothpick should be just barely above the surface. This will be the *'place marker'*.
3. Put very small pieces of clay on the bottom of the legs (not the place marker). The clay will act as a cement to hold the GPS monument in place. In reality the legs of a GPS monument are cemented deep into rock below the soil so when that rock moves, so does the monument.
4. Position the GPS monument on top of a piece of clear transparency.



PART II: Pinpointing Location

1. What do the tops of the string holders on the walls represent?

2. What does the length of string represent?

3. How many satellites are needed to pinpoint a location on Earth's surface?

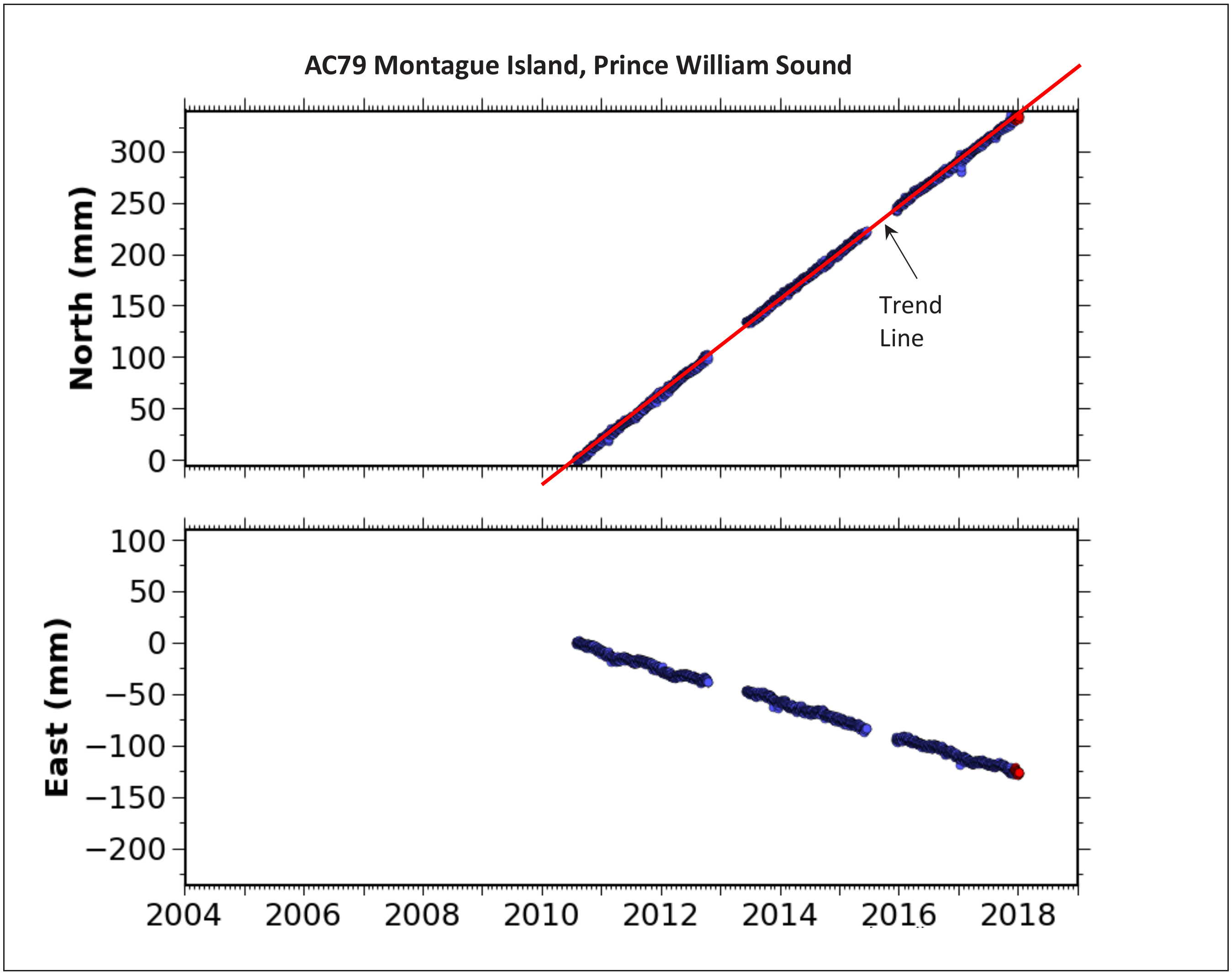
4. Why wouldn't one or two satellites work? Expain and draw a diagram to show this?

5. Draw the setup of the demonstration in the space to the right.

PART III: Measuring Alaska GPS/Tectonic Movement

Materials:
Colored pencil (for drawing trend lines), clear ruler, calculator

- High precision GPS stations collect data in 3 parts shown in **Time Series Plots (or TSP)**:
  - North/South movement over time (abbreviated N/S)
  - East/West movement over time (abbreviated E/W)
  - Height (up/down) movement over time (not shown in this activity)
- X-axis measures time.
- Each dot on the TSP is the average position of the monument for one day.



The first thing to do is draw a "**trend line**." Position a ruler (clear works best) so there are an equal number of points above and below the line. Draw the line so that it crosses the axes on both sides. The first one has been done as an example above. Draw a trend line for the East portion of the Montague Island TSP.

6. What are the units of measurement for these time series? Circle the best choice.

a) centimeters and months
b) meters and years
c) millimeters and years
d) centimeters and years

7. For how many years has this station been collecting data?

a) 5 years b) 7.5 years c) 11 years d) 14.5 years

8. How far North did the Montague Island monument move on the time series? Hint: calculate the *change* in position over time.

a) 188 millimeters b) 260 milllimeters
c) 340 millimeters d) 450 millimeters

9. Did the station move South over the period of time relative to its starting position (1st measurement)?

a) No, because trend line only moves up.
b) Yes, because trend line moves down.
c) Can't tell from time plots given.

10. How far West (down on the graph) did the monument move on the TSP? Remember to use a straightedge to help.

a) 125 millimeters b) 175 milllimeters
c) 220 millimeters d) 250 millimeters

11. What overall direction was this station moving?

a) North only b) Northwest
c) Northeast d) Southwest

12. What was the rate of movement in the North direction? *(Hint: Divide distance traveled by # of years)*

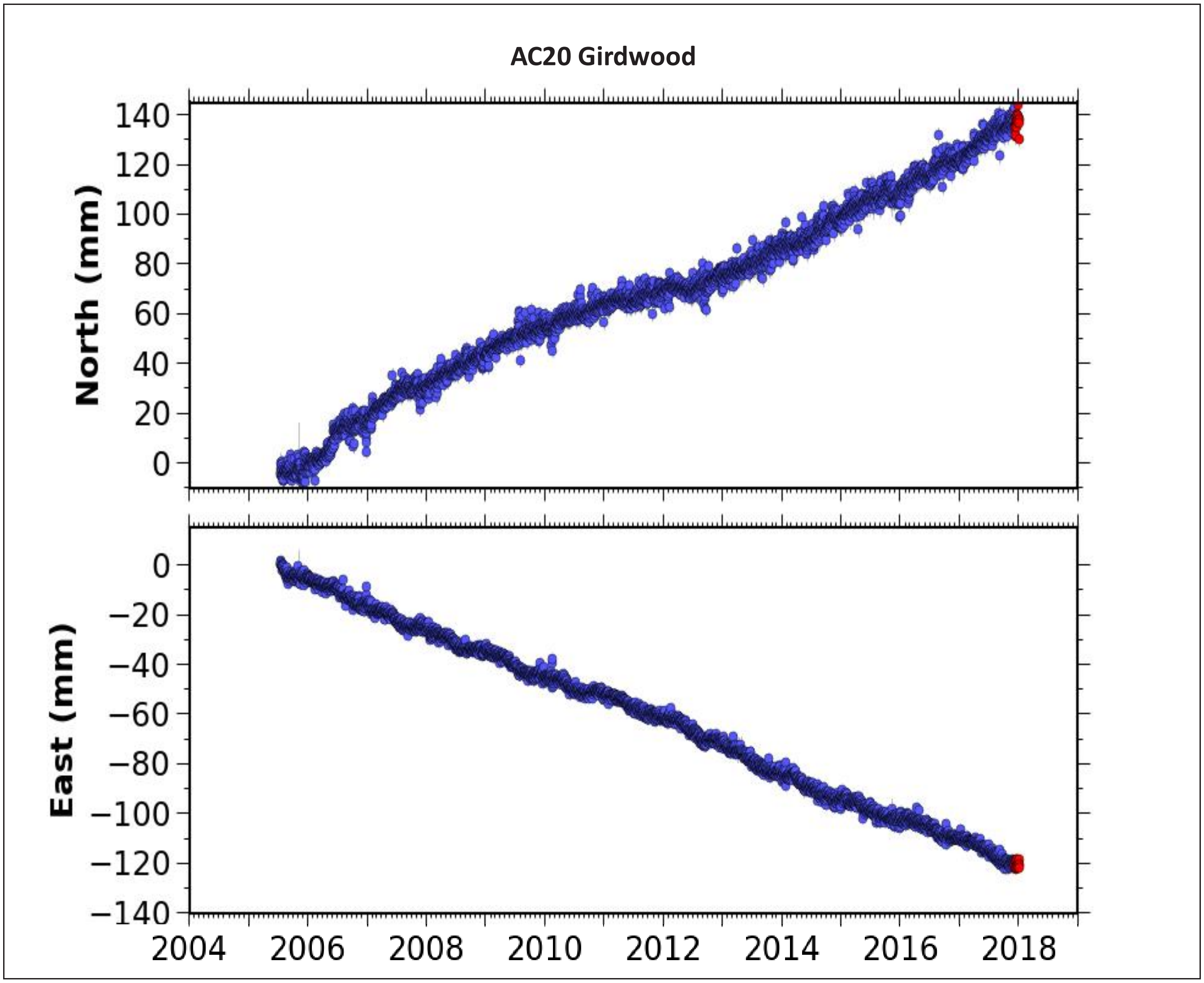
a) 15 mm/yr b) 25 mm/yr c) 35 mm/yr d) 45 mm/yr

13. Calculate the rate of movement in the West direction:

a) 12 mm/yr b) 17 mm/yr c) 24 mm/year d) 30 mm/yr

Using the TSPs below for Girdwood and Mt Susitna calculate N/S and E/W motion and answer questions for each TSP. Start by drawing trend lines that cross both vertical axes.

Note that some positions (dots) are 'off' the general trend, or there is a gap in the data. Those might be times when maintenance was being done on the station, or there was some error that was being corrected. You can ignore those points when drawing your trend lines and doing calculations.



14. For how many years has this station been collecting data?

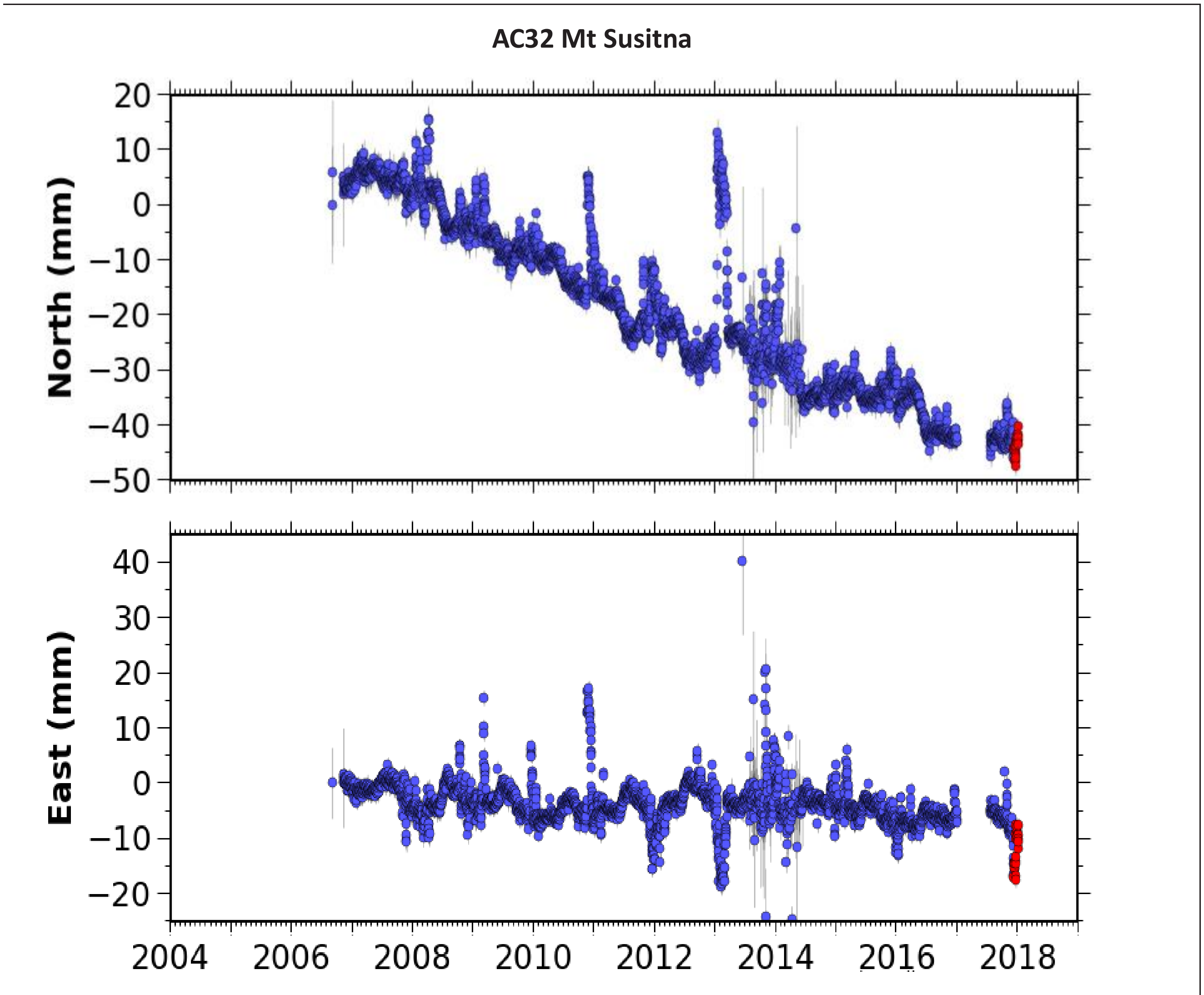
15. Was Girdwood moving North or South? How do you know?

16. How far North or South did it move since data has been recorded?

17. Overall, was Girdwood monument moving East or West? How do you know?

18. How far East or West did it move over the whole time period of data collection?

19. Calculate <u>rates</u> of motions in N/S and E/W directions.



20. For how many years has this station been collecting data?

21. Was Mt Susitna moving North or South? If so, how far? *Use the trend line to better estimate the starting position. Be careful with measurements because these data are somewhat messy.*

22. Was Mt Susitna moving East or West? If so, how far? *Again, be careful.*

23. Calculate <u>rates</u> of motions in N/S and E/W directions.

PART IV: Plotting GPS Monument Motion

Materials:
Alaska GPS Analysis Grid (next page of packet), 3 different colored pencils, ruler.

Procedure:

1. Using one colored pencil, start at (0,0) and draw a faint arrow to show the **rate** of North movement of the Montague Island GPS monument.
2. From *end point* of the North arrow, draw an arrow to show the **rate** of West motion.
3. Draw a diagonal arrow from (0,0) to the end point of the ***West*** arrow. This final arrow (vector) shows the overall rate and direction of motion of the Montague Island GPS Monument.
4. Using a ruler, measure the length of the final arrow (vector) and label that arrow with overall rate in mm/year. **Note**: Scale on grid was adjusted to fit the page.
5. Using different colors, draw arrows (vectors) for Girdwood and Mt Susitna GPS monuments.
6. Complete key indicating colors of your 3 GPS monument vectors.

KEY: Color Station Location

Color	Station Location
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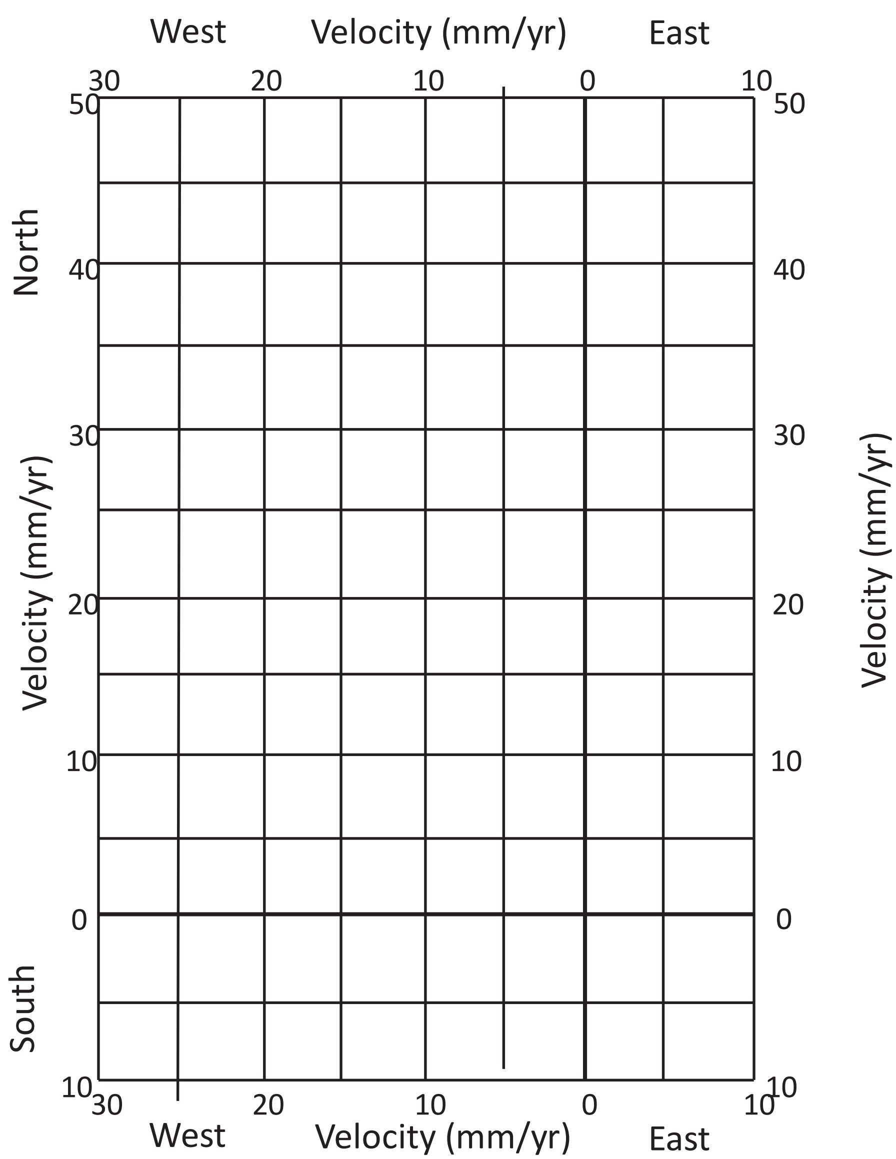


Procedure (continued):

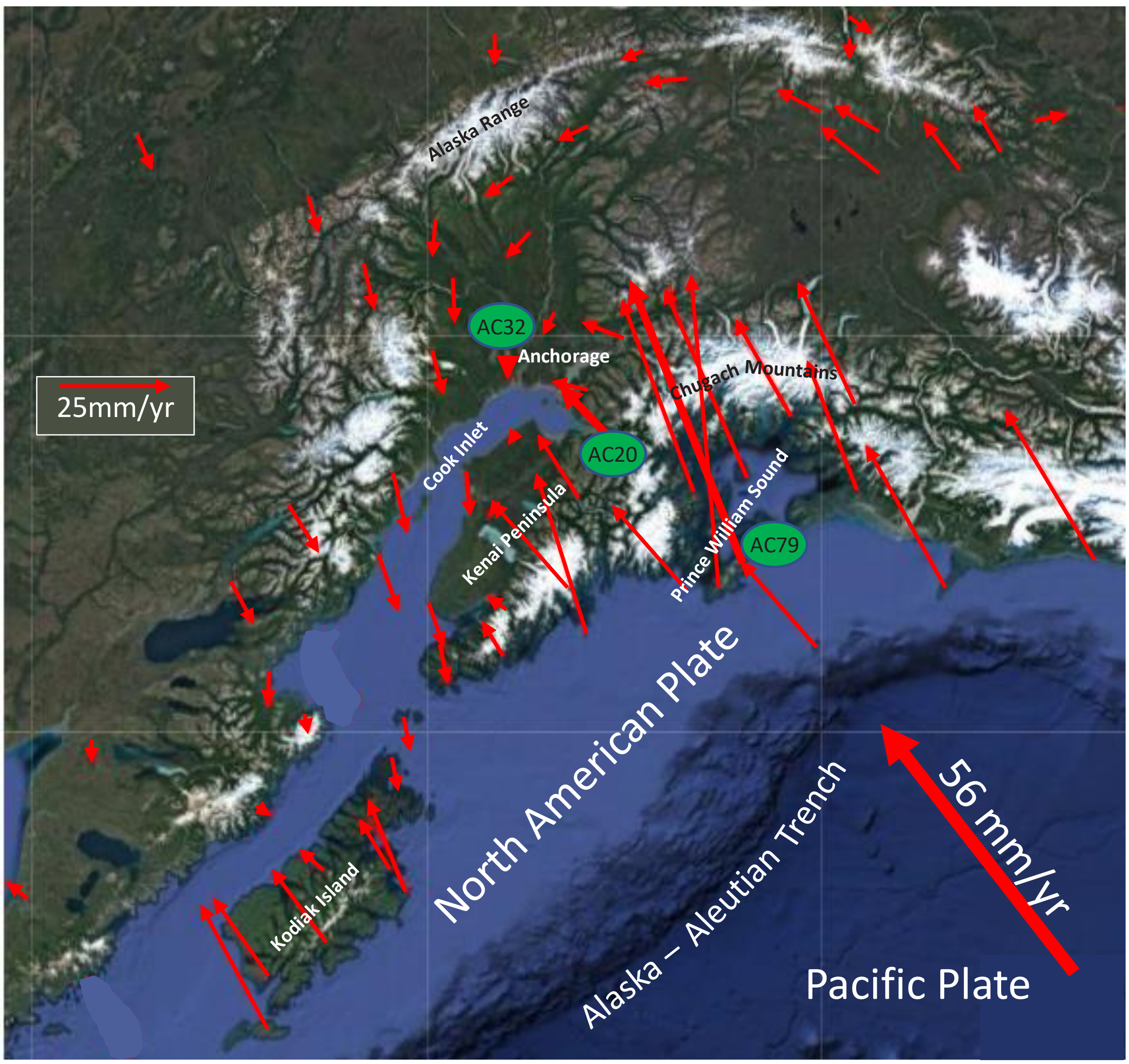
7. Place gumdrop monument (on top of transparency) at 0,0 and move the transparency sheet along one of the arrows to simulate the direction and rate of motion of the land at that point.

PART V: Analysis of GPS Monument Motion

24. The map below shows the direction and rate of motion of GPS momuments in south-central Alaska. The motion of the Pacific Plate is indicated by the bold arrow. What do you observe about:

    a) the monuments in the Prince William Sound southern Kenai Peninsula area?

    b) the monuments near Anchorage?



25. Over time, what will happen to the distance between Prince William Sound and Anchorage?

    a) Distance gets shorter
    b) Distance gets longer
    c) Distance stays the same

26. What does this indicate about the forces acting on the edge of the continent in south-central Alaska?

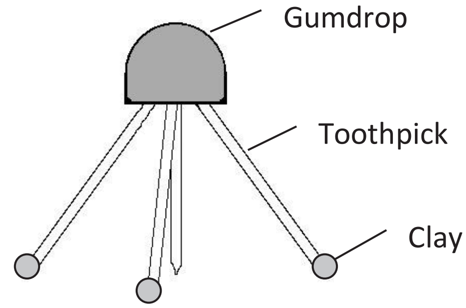
Name: TEACHER ANSWER KEY

ALASKA GPS ANALYSIS

Today's Date: ____________________

PART I: Building a GPS 'Monument'

Materials:
4 toothpicks, 1 gumdrop, modeling clay, ruler, 1/4 sheet transparency



Procedure:
1. Insert 3 toothpicks diagonally into the gumdrop. These will act as the legs.
2. Insert a slightly shorter toothpick sticking straight down from the middle of the gumdrop. The tip of this toothpick should be just barely above the surface. This will be the *'place marker'*.
3. Put very small pieces of clay on the bottom of the legs (not the place marker). The clay will act as a cement to hold the GPS monument in place. In reality the legs of a GPS monument are cemented deep into rock below the soil so when that rock moves, so does the monument.
4. Position the GPS monument on top of a piece of clear transparency.

PART II: Pinpointing Location

1. What do the tops of the string holders on the walls represent?

   The tops of the strings represent where satellites are – all are at the same height above the Earth.

2. What does the length of string represent?

   The length of string represents the distance between the satellite and the monument.

3. How many satellites are needed to pinpoint a location on Earth's surface?

   At least 3 satellites are needed to pinpoint the location of the monument. In reality more than 3 are used.

4. Why wouldn't one or two satellites work? Expain and draw a diagram to show this.

   One satellite wouldn't work because the monument could be anywhere on a sphere around that satellite. Two satellites wouldn't work because the two spheres around those satellites intersect at many points along a circle where the two spheres intersect.

5. Draw the setup of the demonstration in the space to the right.

PART III: Measuring Alaska GPS/Tectonic Movement

Materials:
Colored pencil (for drawing trend lines), clear ruler, calculator

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    - North/South movement over time (abbreviated N/S)
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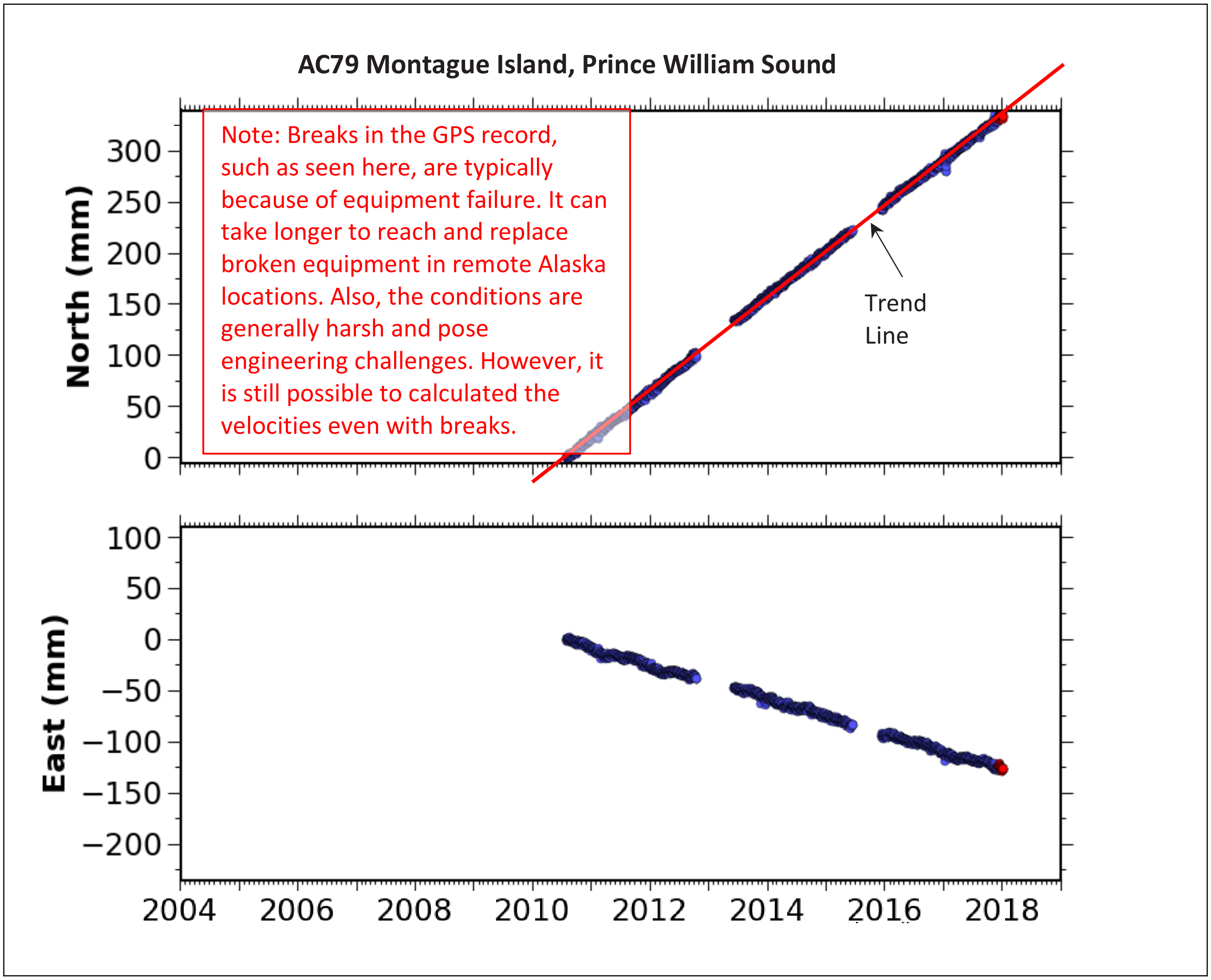

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6. What are the units of measurement for these time series? Circle the best choice.

a) centimeters and months
b) meters and years
c) millimeters and years
d) centimeters and years

7. For how many years has this station been collecting data?

a) 5 years b) 7.5 years c) 11 years d) 14.5 years

8. How far North did the Montague Island monument move on the time series? Hint: calculate the *change* in position over time.

a) 188 millimeters
b) 260 milllimeters
c) 340 millimeters
d) 450 millimeters

9. Did the station move South over the period of time relative to its starting position (1st measurement)?

a) No, because trend line only moves up.
b) Yes, because trend line moves down.
c) Can't tell from time plots given.

10. How far West (down on the graph) did the monument move on the TSP? Remember to use a straightedge to help.

a) 125 millimeters
b) 175 milllimeters
c) 220 millimeters
d) 250 millimeters

11. What overall direction was this station moving?

a) North only
b) Northwest
c) Northeast
d) Southwest

12. What was the rate of movement in the North direction? *(Hint: Divide distance traveled by # of years)*

a) 15 mm/yr b) 25 mm/yr c) 35 mm/yr d) 45 mm/yr

13. Calculate the rate of movement in the West direction:

a) 12 mm/yr b) 17 mm/yr c) 24 mm/year d) 30 mm/yr

Using the TSPs below for Girdwood and Mt Susitna calculate N/S and E/W motion and answer questions for each TSP. Start by drawing trend lines that cross both vertical axes.

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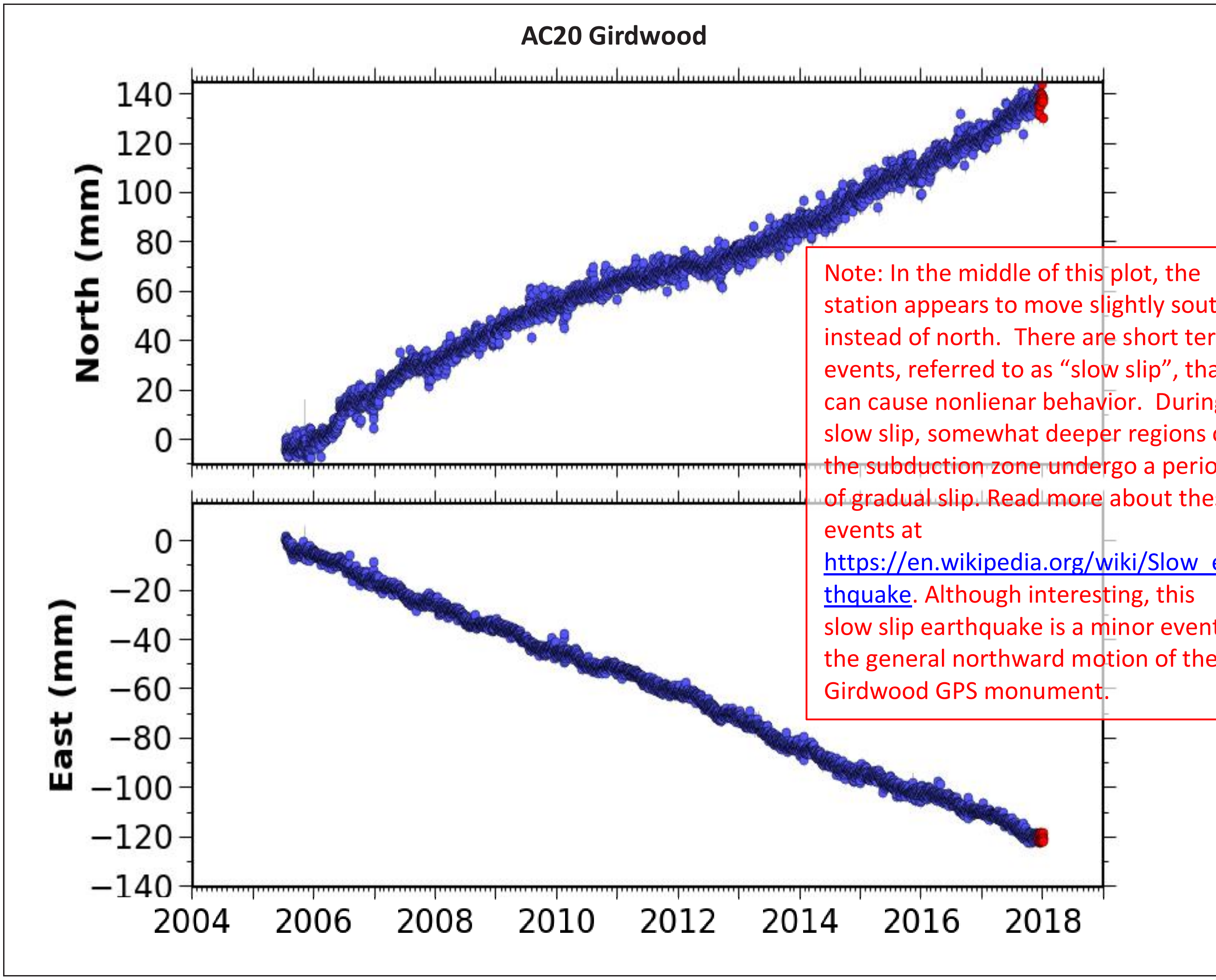


Note: In the middle of this plot, the station appears to move slightly south instead of north. There are short term events, referred to as "slow slip", that can cause nonlienar behavior. During slow slip, somewhat deeper regions of the subduction zone undergo a period of gradual slip. Read more about these events at https://en.wikipedia.org/wiki/Slow_earthquake. Although interesting, this slow slip earthquake is a minor event in the general northward motion of the Girdwood GPS monument.

14. For how many years has this station been collecting data?

About 12.5 years.

15. Was Girdwood moving North or South? How do you know?

Girdwood was moving North due to the upward direction on the N/S plot.

16. How far North or South did it move since data has been recorded?

It moved about 136 mm North, although the rate of motion seems to have varied a bit over this time interval.

17. Overall, was Girdwood monument moving East or West? How do you know?

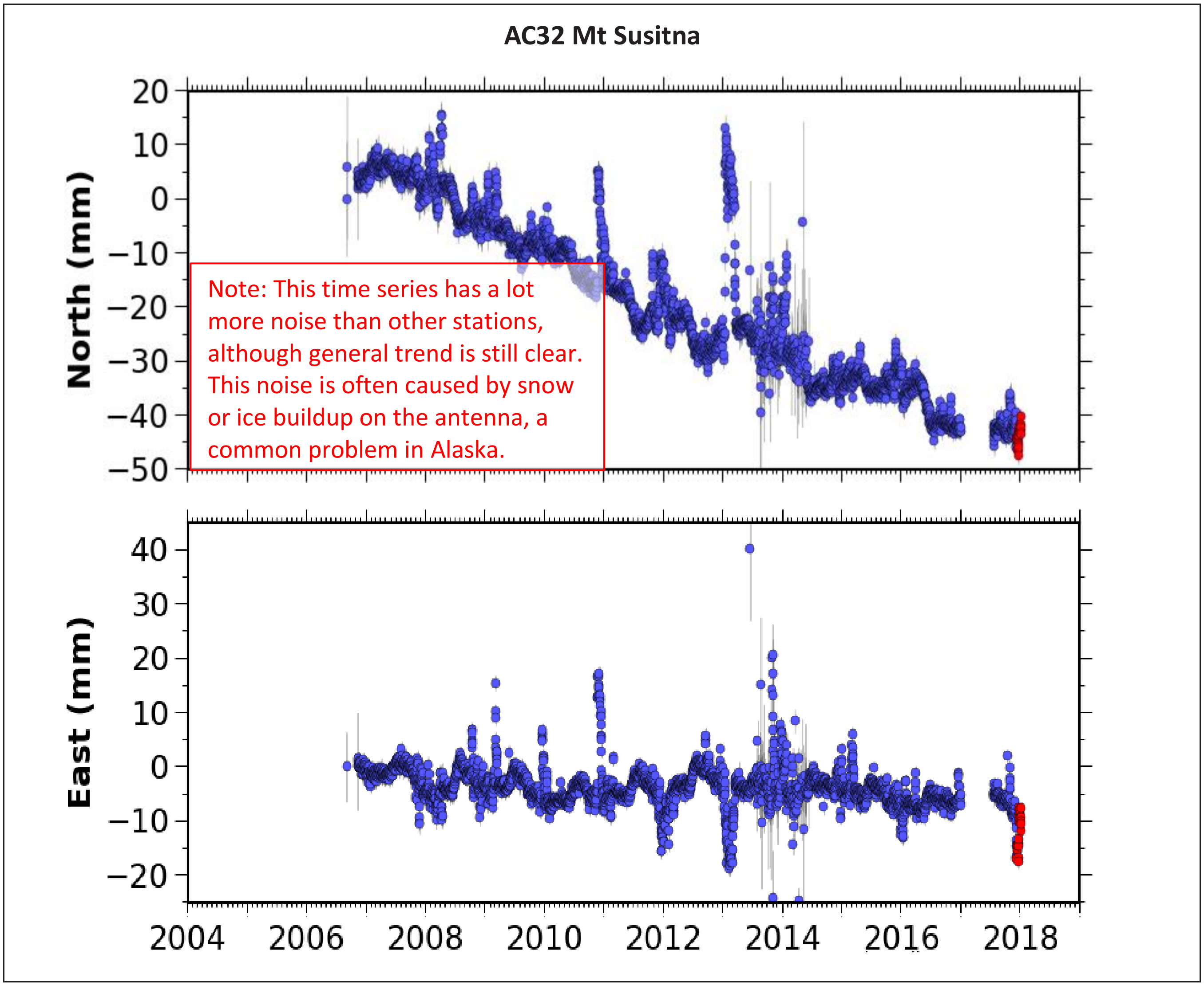
Girdwood was moving West due to the downward direction on the E/W plot.

18. How far East or West did it move over the whole time period of data collection?

It moved approximately 122 mm West.

19. Calculate <u>rates</u> of motions in N/S and E/W directions.

Rates are North 11 mm/year (136 mm / 12.5 yr) and West 10 mm/yr (122 mm / 12.5 yr).



20. For how many years has this station been collecting data?

About 11.5 years

21. Was Mt Susitna moving North or South? If so, how far? *Use the trend line to better estimate the starting position. Be careful with measurements because these data are somewhat messy.*

Mt Susitna was moving South. Trend line shows it's starting at +6 and moving to about -45, for change of -51 mm.

22. Was Mt Susitna moving East or West? If so, how far? *Again, be careful.*

Mt Susitna was moving very slightly West. Trend line shows it moved about 10 mm.

23. Calculate <u>rates</u> of motions in N/S and E/W directions.

Annual motions are South at about 5 mm/year (51 mm / 11.5 yr) and West at about 1 mm/yr (10 mm / 11.5 yr)

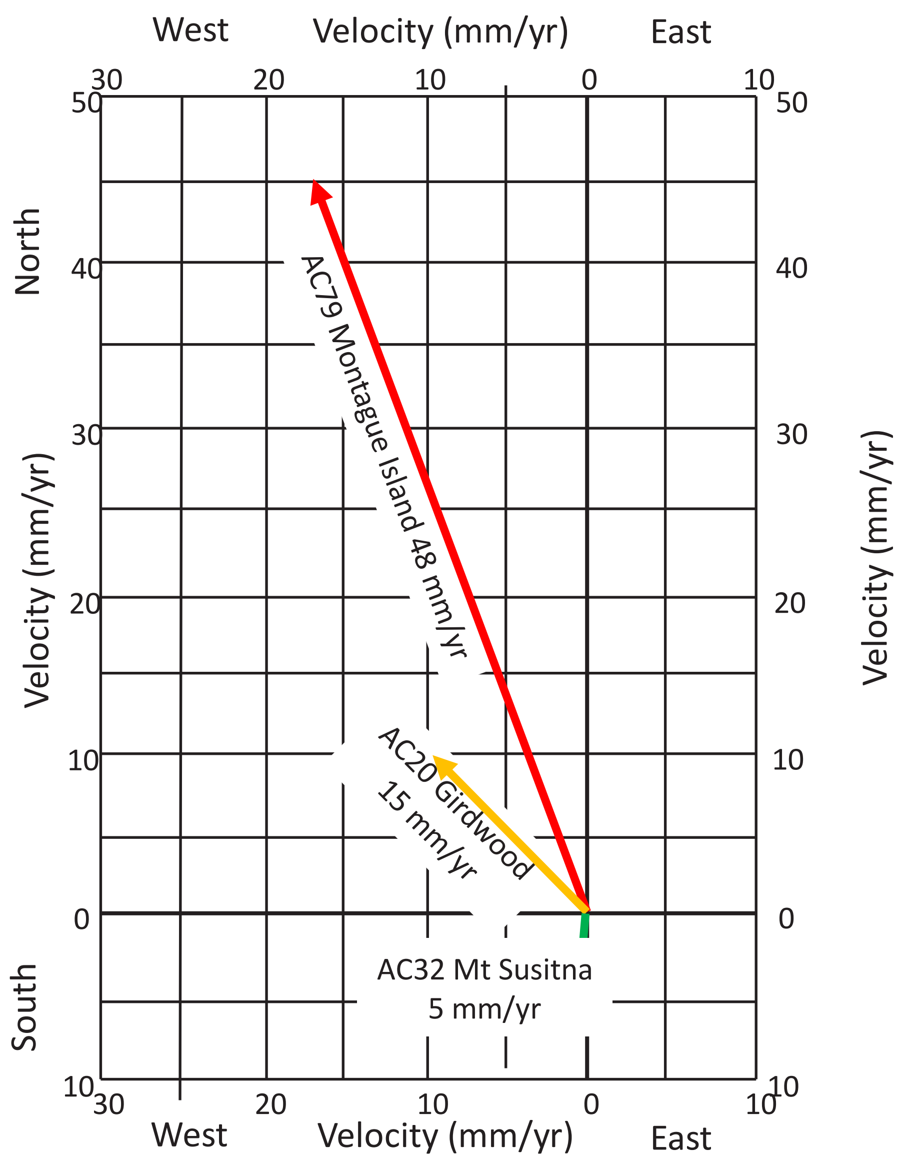
PART IV: Plotting GPS Monument Motion

<u>Materials</u>:
Alaska GPS Analysis Grid (next page of packet), 3 different colored pencils, ruler.

Procedure:

1. Using one colored pencil, start at (0,0) and draw a faint arrow to show the **rate** of North movement of the Montague Island GPS monument.
2. From *end point* of the North arrow, draw an arrow to show the **rate** of West motion.
3. Draw a diagonal arrow from (0,0) to the end point of the ***West*** arrow. This final arrow (vector) shows the overall rate and direction of motion of the Montague Island GPS Monument.
4. Using a ruler, measure the length of the final arrow (vector) and label that arrow with overall rate in mm/year. **Note**: Scale on grid was adjusted to fit the page.
5. Using different colors, draw arrows (vectors) for Girdwood and Mt Susitna GPS monuments.
6. Complete key indicating colors of your 3 GPS monument vectors.

KEY:	Color	Station Location
	Red	Montague Island
	Blue	Girdwood
	Green	Mt Susitna



Procedure (continued):

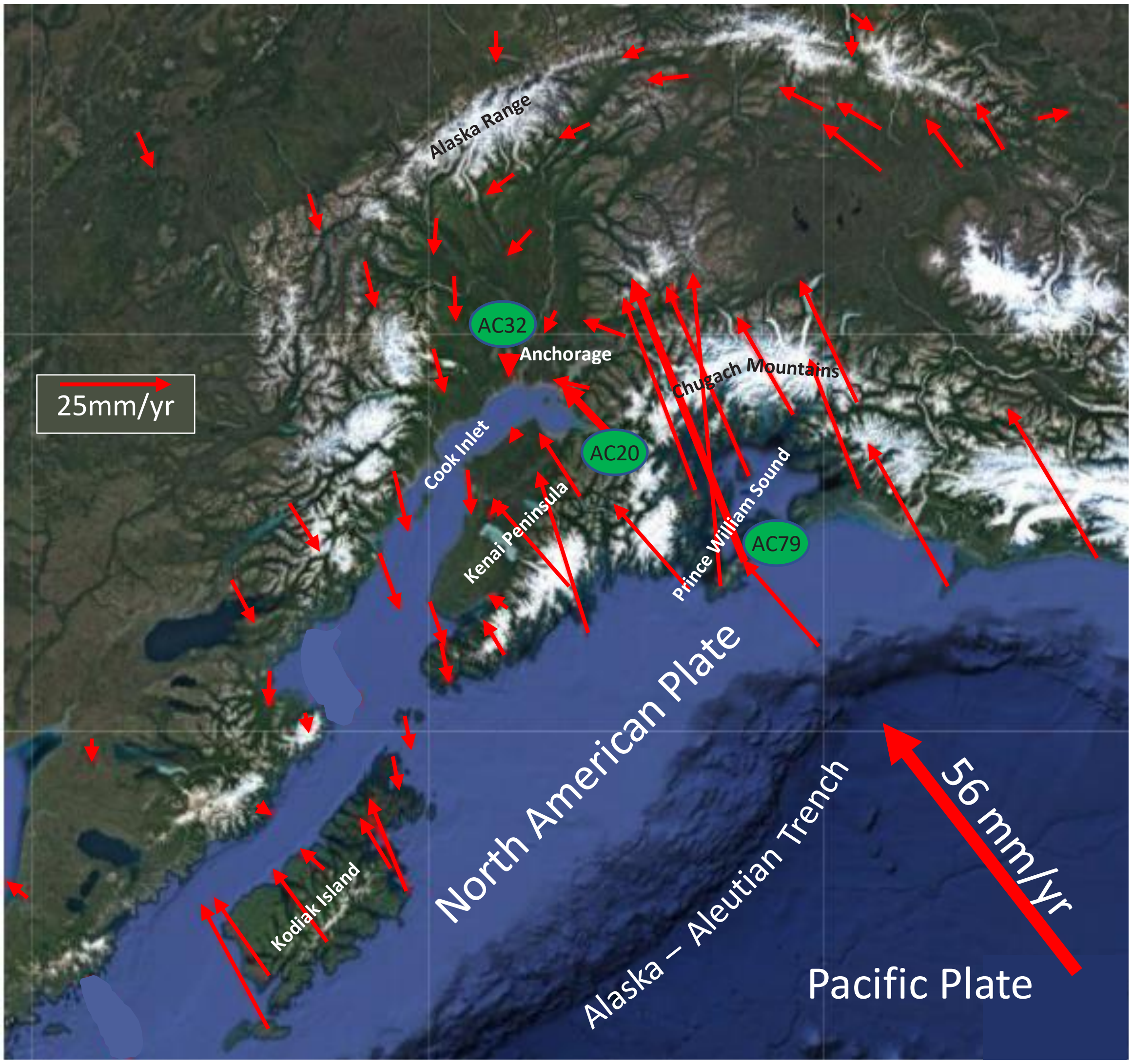
7. Place gumdrop monument (on top of transparency) at 0,0 and move the transparency sheet along one of the arrows to simulate the direction and rate of motion of the land at that point.

PART V: Analysis of GPS Monument Motion

24. The map below shows the direction and rate of motion of GPS momuments in south-central Alaska. The motion of the Pacific Plate is indicated by the bold arrow. What do you observe about:

a) the monuments in the Prince William Sound southern Kenai Peninsula area? They are rapidly NW.

b) the monuments near Anchorage? They are moving slowly.



25. Over time, what will happen to the distance between Prince William Sound and Anchorage?

a) Distance gets shorter
b) Distance gets longer
c) Distance stays the same

26. What does this indicate about the forces acting on the edge of the continent in south-central Alaska?

The continental margin near the Alaska – Aleutian Trench is moving NW faster than inland areas. As it does so, the region is being compressed in a NW – SE direction. The region is being loaded like a spring.