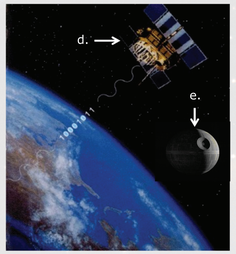
The Breathing Earth

Using Python to Visualize the Ups and Downs of the Ground

Gina M. Schmalzle[1,2], David White[1]
[1]Nordstrom, Seattle, WA
[2]BOS Technologies, LLC, Seattle, WA

The Data: High Precision GPS



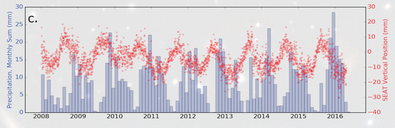
a. GPS Monument
b. GPS antenna and receiver in its case
c. GPS antenna mounted over a Monument
d. GPS Satellite
e. The Death Star

- GPS sites track the North, East and Vertical mm-level position of a monument over time
- We use the vertical component of ~1500 publicly available GPS site time series (http://pbo.unavco.org/data/gps)
- Over 1100 permanent GPS sites were installed as part of the National Science Foundation EarthScope Plate Boundary Observatory starting in 2004, adding to an already existing array of sites

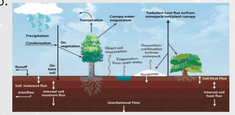
A. Precipitation

- ***Winter***: increased precipitation saturates land, making it heavy and pushes it down (a and b)
- ***Summer***: water evaporates or flows away, the ground rebounds (a and b)

The cyclical behavior is much like the movement of your chest while breathing -- an inhale represents the summer, and exhale the winter.



http://vxside.deviantart.com/art/4-seasons-81436429

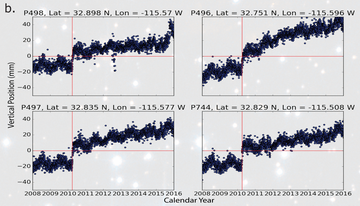


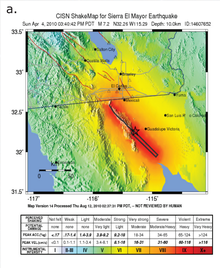
http://www.kristinelarson.net/wp-content/uploads/2015/10/sap3-1-final-all026.png

a. Serendipitous artist rendition of the ups and downs of the ground during the seasons
b. Illustration of water flow, storage and evaporation
c. Monthly precipitation recorded at KSEA station (blue bars, mm) and vertical positions of SEAT GPS station (red, mm) over time. Weather data, both near Seattle-Tacoma Airport

B. Earthquakes

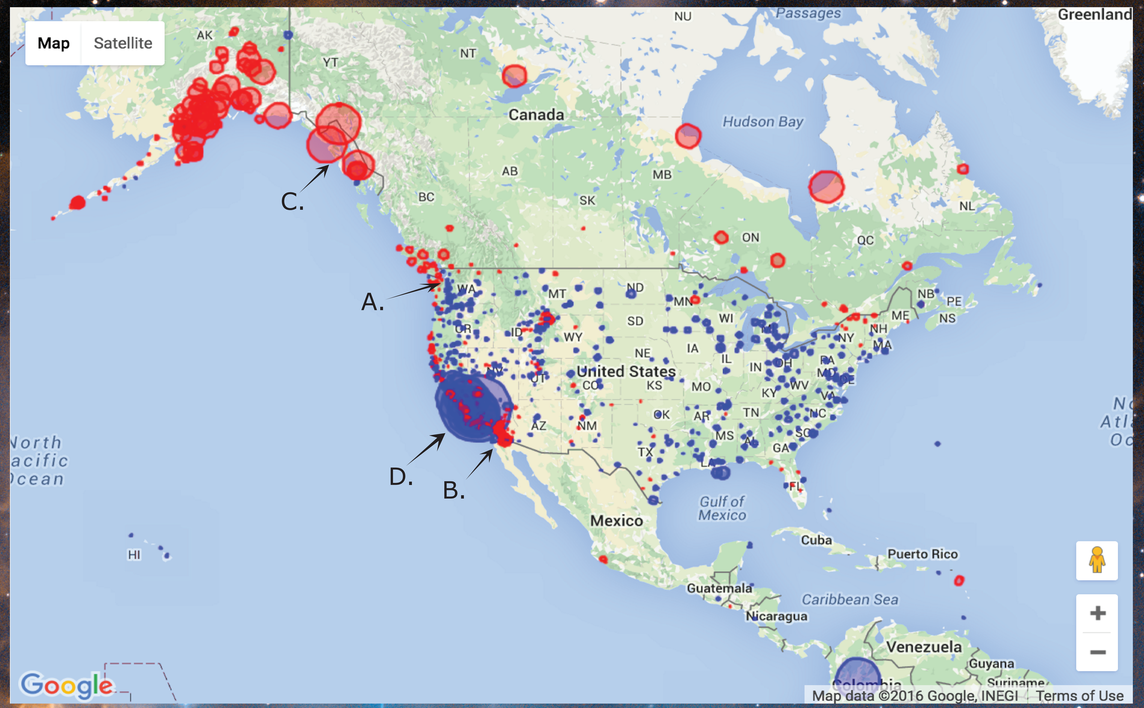
- Earthquakes cause a sudden change in position of the ground surface
- Some large earthquakes influence ground position over many years due to the viscosity of the underlying mantle





https://en.wikipedia.org/wiki/2010_Baja_California_earthquake#/media/File:April_2010_Baja_California_earthquake_intensity_USGS.jpg

a. USGS Shake map of the M7.2 Sierra El Mayor Earthquake (April 4, 2010)
b. Vertical positions (blue dots) of 4 GPS sites north of the quake (vertical red line)



(Above) Screenshot of the Breathing Earth application, showing the change in vertical position estimated by GPS from January 1, 2008 to February 18, 2016. Red circles indicate uplift, blue subsidence. Circle size represents their magnitude. Letters represent the causes described in the side panels labeled A-D. For reference, the red circle at B indicates about 60 mm of uplift and the blue circle at D indicates about 200 mm of subsidence over the 8 year time period, corresponding to rates of about 7.5 mm/yr and -25 mm/yr, respectively.

How We Did It

DATA PREPARATION AND BACK END

For each site:
1. Download data: ftp://data-out.unavco.org/pub/products/position/
2. Vertical position, latitude and longitude --> sqlite3 database
3. 7 day rolling median calculated (pandas)
4. Only sites with data on 2008-01-01 are used in the visualization
5. Median position value on 2008-01-01 is subtracted from the time series
5. One value every 30 days written to JSON file.

Future work:
1. Send data to Amazon Relational Database Service for time series API service.

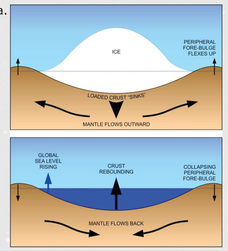
VISUALIZATION

1. Python Flask Application
2. Deployed on AWS Elastic Beanstalk
3. Javascript Frameworks: jQuery, Google Maps API
4. Data from JSON file

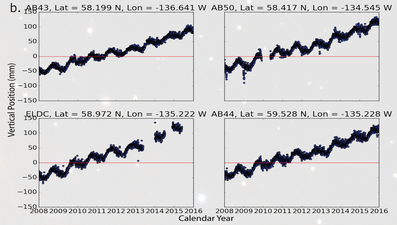
Future Work:
1. Add time series plot using API service -- click on point, retrieve time series
2. Reduce latency -- Currently split up into regions to reduce data rendering

https://github.com/ginaschmalzle/BreathingEarth

C. Glaciers and Snow Melt



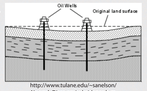
- Heavy glaciers and ice sheets cause the ground to depress
- When the ice melts, the crust rebounds (uplifts)



a. Schematic of ground depression and rebound due to the presence and subsequent removal of ice
b. GPS vertical position time series (blue dots) in Glacier Bay National Park and Preserve, Alaska, indicate uplift

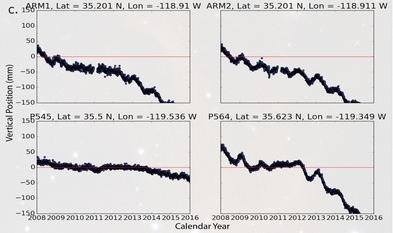
D. Water/Oil/Gas Pumping

http://www.watereducation.org/aquapedia/land-subsidence



http://www.tulane.edu/~sanelson/Natural_Disasters/subsidence.htm

- Permeable rock holds fluids such as oil, gas and water
- When liquids are pumped fluid pressure reduces in surrounding rock, causing compaction and subsidence



a. Photo showing massive subsidence from water pumping in the San Joaquin Valley from 1925 to 1977
b. Illustration of subsidence induced by pumping at oil wells
c. Southern California GPS vertical position time series (blue dots) show large subsidence due to oil pumping

Takeaways

- High precision GPS are used to monitor vertical motions of points on the earth's crust with millimeter level accuracy.
- Ground level changes with the seasons -- lots of precipitation in the winter makes the ground heavy, depressing it. In the summer the water evaporates or flows away, allowing the earth to rebound.
- Other causes of vertical motion include earthquakes, glacial melt and oil, gas and water pumping. This is not a complete list.
- This is still a work in progress! Comments and suggestions welcome.

Background image: http://hubblesite.org/gallery/album/star/