

Barometric Altimetry Using the Vernier LabPro

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Purpose:

Part of the Annual Balloon Fest held in Paso Robles CA is to accurately determine the altitude of each experiment's instrument package throughout the range from ground level to 1000 ft above ground level. This is not easily done by using line length or by using theodolite techniques. It is most commonly done using barometric pressure changes. However, the technique has not previously been tested or properly documented.

Research:

The specifications for the Vernier Barometer sensor used with the LabPro gives a sensitivity of 13.08 V/atm and a resolution of 0.003 mBar. As will be shown later, this translates as a resolution of altitude of 0.8m.

In order to use the barometer as an altimeter we need to convert pressure changes into altitude changes. Several mathematical models for pressure change with altitude are given on our "Atmospheric Research in the High School" website. All of them are exponential in nature. However, it is reasonable to assume that over a small change in elevation, the slope is very close to linear.

Using the Standard Atmosphere Model, the average slope from sea level to 1000ft is calculated as:

$$m = -8588 \text{ m/atm} = -84.75 \text{ m/kPa} = -656.6 \text{ m/V}$$

However, from 1000ft to 2000ft the average slope is 4% larger, from 2000ft to 3000ft it is 7% larger, and from 6000ft to 7000ft it is 24% larger.

During a normal weather day, the ambient pressure will often vary by about 0.1 to 0.2 kPa per hour. This translates to an ambient pressure-induced drift of about 8 to 16 m per hour.

Converting Sensor output to altitude data

(Calculations detailed in Mathematical Analysis. See References below)

Sensor output	Slope	Intercept
Volts (direct sensor output)	- 656.6 m/V	+ 5385 ft = 1642 m
kPa	- 84.75 m/kPa	+ 28175 ft = 8588 m
Atm	- 8588 m/Atm	+ 28175 ft = 8588 m
in Hg	- 287.0 m/inHg	+ 28175 ft = 8588 m

“Altitude” = Slope * “Pressure” + Intercept

The slope is calculated from the US Standard Atmosphere Model for an elevation of about 500 ft. The intercept is based on the average sea level pressure being 101.33 kPa. However, the Intercept is often set to an arbitrary value so as to “zero” the starting altitude.

Sources of relevant environmental data

Altitude data is available for various locations using USGS topographic maps typically with 20 ft contour intervals or from Google Earth with an unspecified accuracy.

Atmospheric pressure is available in three forms: “Station”, “Barometric”, and “Altimeter”. Station pressure is the direct barometer reading at the reporting weather station. Barometric pressure is the station pressure corrected for equivalent pressure at sea level. Altimeter pressure is the theoretical pressure setting needed to have a standard altimeter read correct altitude at the airport or other location referenced in the reading.

Local airports provide very accurate altitude data along with “altimeter” pressure readings. The METAM automated messages typically give the Altimeter pressure in inches of mercury and can be listened to by cell phone.

Barometric pressure is commonly available from weather services: online, radio, TV or newspaper.

Station pressure is most appropriate to compare with our sensor readings. It is not commonly available. However, it can be derived from the other two.

The difference in pressure exerted by air with a relative velocity, v, on the leading Elevation Error due to Dynamic Pressure effects

The difference in pressure exerted by air with a relative velocity, v, on the leading edge of a body compared with the ambient pressure is given by ΔP . This error correction is only 1m for speeds up to 10 miles per hour. But it quickly rises to 36m for highway speed of 60 mph or greater. Measuring altitude when the barometer is mounted in a moving platform can be subject to substantial error.

$$\rho := 1.204 \frac{\text{kg}}{\text{m}^3}$$

$$\Delta P(v) := \frac{v^2 \cdot \rho}{2}$$

$$v := 60\text{mph}$$

$$\Delta H(\Delta P) := \Delta P \cdot 84 \frac{\text{m}}{\text{kPa}}$$

$$\Delta P(v) = 433\text{Pa}$$

$$\Delta H(\Delta P(v)) = 36\text{m}$$

Field Tests

Altitude Test

Data was taken during a drive home from Paso Robles high school to Grover Beach (See Appendix Figure 1). This drive starts out at 770 ft rises above 1560 ft and then drop to 62 ft MSL in a period of 45 minutes. A Vernier barometer sensor attached to a LabPro DAQ (battery powered) was used. The sensor was allowed to measure the pressure while the car was sitting with its window open at the beginning, end and highest points. In between these points the car windows were up and the car was driven at freeway speeds. Reference altitudes were derived from Google Earth and are believed to be accurate to about +/- 5m. The data was offset to make the ending altitude (most accurately known) to be correct.

Measured altitudes were in error up to 54 m. Earlier altitude measurements were higher than expected and moving altitude measurements were lower than expected. The earlier high measurements can be explained as a general drift toward higher pressures with time. The lower altitude measurements while moving can be explained as dynamic pressure effects. Both are substantial.

Accuracy and Drift test

A series of fixed-position measurements of ambient air pressure were made using 3 Vernier barometer sensors attached to a LabPro DAQ running on AC power (See Appendix Figure 2). The measurements were all made at home at an elevation of 62 ft = 19 m MSL. Barometric measurements were compared to web-posted reading at San Luis Obispo County Regional Airport. The Airport is located about 9 miles to the North at an altitude of 212 ft = 65 m.

Run 1: Begin: 6:30am PDT 6/9/07 End: 8:30 am

Cold Startup.

Data shows dramatic warm-up drift and discrepancy between sensors.

Run 2: Begin 9:30 am PDT, 6/9/07 End: 9:40

Follows Run 1 after LabPro USB was disconnected for 10 minutes

Data shows no discernable warm-up drift

Run 3: Begin 10:30 am PDT, 6/9/07 End: 10:42 am

Follows run 2 after LabPro USB disconnected for 1 hr

Data shows no discernable warm-up drift

Run 4: Begin: 12:12 pm PDT, 6/9/07 End: 2:15pm PDT

After sensors were disconnected from LabPro for 1.5 hours

Data shows marked warm-up drift but much smaller than in run 1.

From 6:30 am till 2:30 pm this day, the SLO airport weather service reported barometric pressures varying from 29.86 to 29.92 in Hg = 101.14 to 101.31 kPa => 14 m of elev change. When adjusted to 19 m MSL these pressures range from 100.98 to 101.14 kPa.

Observations:

Sensors 1 & 3 have almost identical readings. Sensor 2 reads higher than 1 & 3 by 0.3 to 0.4 kPa (25 to 35 m). All sensors "warmed-up" over the first hour by about the same amount of 1.3 kPa (110m)

Summary of Observations

The typical barometer sensor is observed to "warm up" with a 0.1 to 0.2 kPa (8 to 16 m of elevation) increase during the first two minutes of operation even though ambient conditions are unchanged.

The typical Vernier barometer sensors:

- vary from sensor to sensor by up to 0.4 kPa. This corresponds to a discrepancy of up to 35 m of altitude.
- drift upward by 1.3 kPa in an apparent "warm-up" process over the first hour of operation. This corresponds to a discrepancy of up to 110 m of altitude.
- read about 1 kPa (9 m) too high compared with official sources.
- have a digital resolution of 0.8 m. Typical random variations are about ± 2 steps. This gives a typical uncertainty (std deviation) of ± 1.6 m.

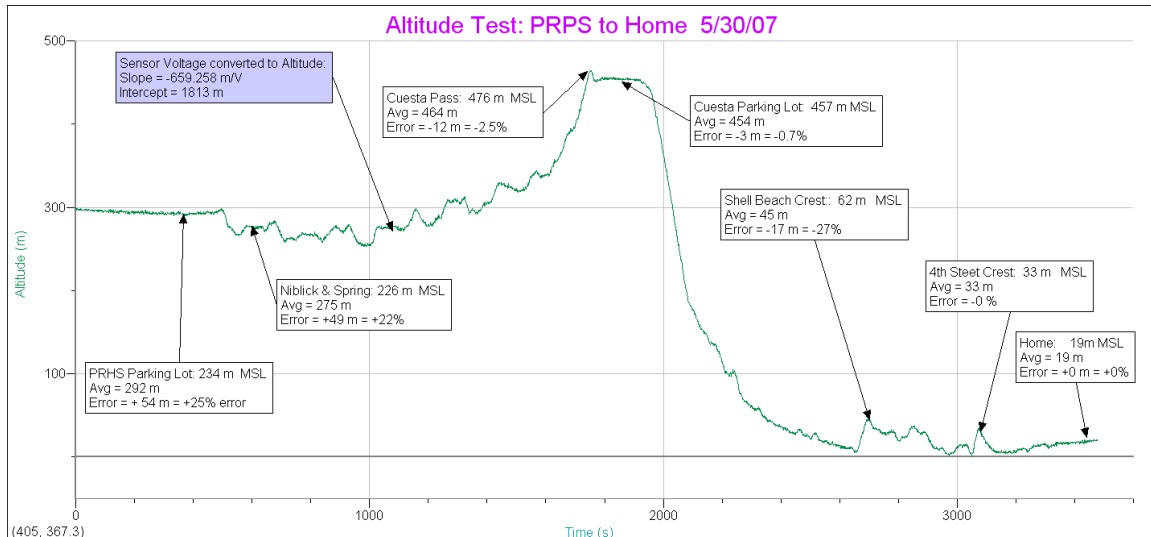
Conclusion

Relative altimetry data from the Vernier sensors is possible to an accuracy of 2 or 3 meters between different altitudes but only after painstaking effort to minimize or mathematically remove “warm-up” drift, pressure drift due to weather changes, and dynamic pressure changes due to wind or motion.

Appendix

Data

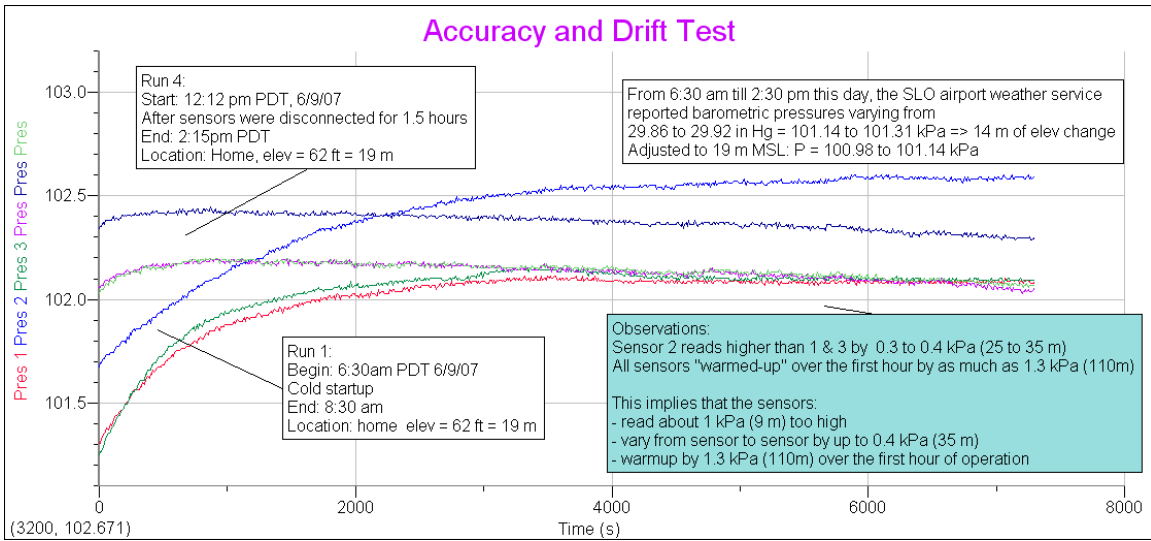
Figure 1:
Altitude test



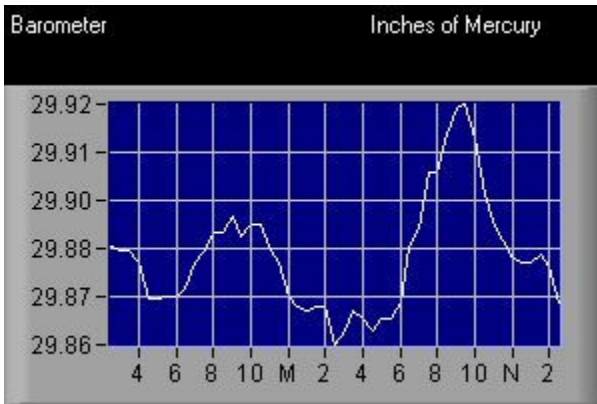
Observations:

Errors of up to 54 m were found. The early readings are the highest altitudes. Readings taken while driving at high speed yield low altitudes. The reference altitudes are taken from Google Earth and are probably uncertain to about ± 5 m. Possible explanation: Warmup drift (up to 110 m) and dynamic pressure (up to 35 m) could easily explain the discrepancies.

Figure 2:



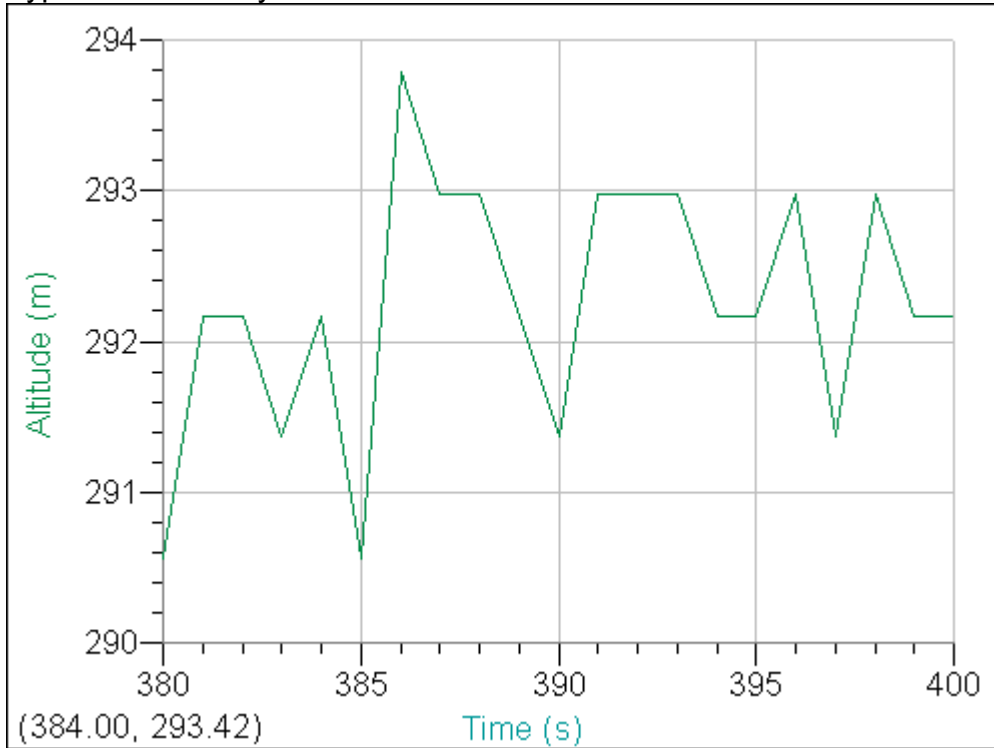
**Barometric Pressure during Accuracy and Drift Test
 24 hour graph from SLO Airport Weather Service.**



2 pm 06/08/07 thru 2:30pm 06/09/07
 Barometer Record from SLO Airport 070609.jpg from
<http://www.sloweather.com/graphs.htm>

Figure 3:

Typical uncertainty and resolution



Observations:

The sensor resolution in altitude readings are determined by the sensor sensitivity and the 12 bit resolution of the LabPro DAQ. The minimum step in data is 0.8 m and the typical random variations are about ± 2 steps. This gives a typical uncertainty (std deviation) of ± 1.6 m.

Typical Operations Procedure

- 1 Setup LabPro with Barometer
- 2 Attach to computer with USB
- 3 Run LoggerPro 3.4 or above
- 4 Use Experiment tab and attach interface to verify LabPro is attached
- 5 Select "Setup Sensor" to verify Barometer is attached
- 6 Select "Calibrate" and then "Equation" tab to enter the Intercept, Slope, & Units
- 7 Use the "Calibration Storage" tab to specify that the new calibration be stored in the Experiment File.
- 8 Select Done to update the LabPro.
- 9 Select "Zero" to set the current altitude to zero.
10. Use Experiment | Data Collection to set the collection parameters
11. Use Remote setup to prepare the LabPro to collect data while unconnected to the computer.
12. Disconnect the LabPro. Shutdown and save the Logger Pro exp. file.
13. Wait for at least 1 hour before collecting data to allow for the sensor "warm-up".
14. Call airport for barometric reading before and after experiment to get measure of environmental pressure drift.
15. Press Start/Stop to initiate data collection.
16. Collect fixed-position data for at least 10 minutes to verify lack of drift.
17. Perform experiment. Return equipment to original fixed-position and collect data for another 10 minutes to provide data closure. Make sure that green light is still flashing indicating that LabPro is still collecting data.
18. Reconnect the LabPro and open the original Logger Pro exp. file
19. Choose to retrieve the data from the LabPro into the current file.

References

Mathematical Analysis: "Barometric Measurements of Altitude.xmcd"

Data and Observations: "Barometric Altitude School to Home.cmb1"

Atmospheric Research in the High School:

<http://scipp.ucsc.edu/outreach/balloon/index.html>

Atmospheric Pressure: http://en.wikipedia.org/wiki/Barometric_pressure

The Use of Altimeters in Height Measurements:

<http://www.biber.sfnnet.co.uk/altim.html>

Understanding Air Pressure: <http://www.usatoday.com/weather/wbarocx.htm>

The International Standard Atmosphere:

http://en.wikipedia.org/wiki/International_Standard_Atmosphere

Altimeter Adjustments: <http://www.avocet.com/vertechpages/vertfaq.html>