GPS Altitude vs Pressure Altitude

There seems to be a lot of misunderstanding in the soaring community about the difference between GPS Altitude and Pressure Altitude so I've written this article to make it clear what both are and what differences you can expect to see. It is by no means a complete discussion, just a simple explanation of the difference.

Let's begin with GPS.

For a 3D fix (latitude, longitude, altitude) at least 4 working satellites need to be in view of the GPS receiver antenna. For any reasonable accuracy to be achieved at least one satellite should be somewhere near the vertical, overhead. Fortunately 30 or so GPS satellites make up the constellation and this condition is usually easily fulfilled, especially in a glider cockpit where the view of the sky is essentially unobstructed.

Modern GPS receivers use all the satellites in view and compute the best solution from this.
Since SA (Selective Availability) was abandoned in the year 2000 horizontal position accuracy is usually well under 10 meters and vertical accuracy of the order of 10 to 20 meters is achievable. Any discrepancies here are due mainly to the passage of the GPS signals through the Ionosphere because the speed that radio waves travel through the Ionosphere can vary with Ionospheric density and GPS works out the range to each satellite by measuring time and assuming a fixed speed for the radio waves. Civilian receivers will eventually use two radio frequencies and then even these errors can then be corrected for in the mathematical processing in the receiver.

So the GPS altitude is the GEOMETRIC altitude above Mean Sea Level accurate to 10 to 20 meters.

Pressure Altitude (PA), while being measured and spoken of in length units (feet or meters), is really no such thing.
A pressure altimeter measures PRESSURE. This is converted to altitude by applying various assumptions and corrections.
Lets take the case where we want to know the altitude above Mean Sea Level using a pressure altimeter. The first thing we know is that the surface pressure varies due to weather systems as we've all seen the surface pressure charts with lines of constant pressure called isobars. The average surface pressure over the entire Earth over the year is taken as 1013.25 HectoPascals(HPa). If our altimeter at the seaside is adjusted so that the reference pressure is 1013.25 HPa the altimeter will read ZERO feet AMSL. As the pressure varies this reference pressure needs to be adjusted so the altimeter still reads ZERO feet AMSL and then the current value for the sea level pressure can be read in the subscale window.

Now suppose the sea level pressure happens to be 1013.25 Hpa and the altimeter reads ZERO feet. If we now move our altimeter up to where the pressure is 697 HPa. The instrument will now show that we are at 10,000 feet. However we must add that this is 10,000 feet Pressure Altitude. Only under certain circumstances will this also be the GEOMETRIC altitude above Mean Sea Level.

Why is this so (as the late Prof Julius Sumner-Miller used to say)?

Consider the column of air between 1013.25 HPA and 697 Hpa. If we heat it, it will expand, cool it, it will shrink. So how far above the 1013.25HPa the 697HPa level is depends on the average temperature of that column of air.
Over the years atmospheric observations showed us that the average pressure at sea level was

1013.25 Hpa. Likewise the average temperature of the surface is close to 15 deg C and the average lapse rate is 2 deg C per thousand feet in the lower atmosphere(troposphere) and this “average atmosphere” is called the International Standard Atmosphere (ISA) and aircraft performance calculations and measurements are referenced to this also.

Only when the average temperature of the layer between 1013.25 Hpa and 697 Hpa is equal to that in the ISA (in this case 5 deg C) will our Pressure Altitude and GEOMETRIC altitude be equal.

How important is this? Well let's take a hot day at Waikerie. Waikerie is close to sea level(~100 feet or so) and let's assume the surface temperature is 42 deg C and we're soaring in thermals so the lapse rate will be very close to Dry Adiabatic (3 deg C per thousand feet). At 10,000 feet Pressure Altitude the temperature will be 12 deg C making the average temperature in the layer to 10,000 feet PA 27 deg C.

How do we figure out our GEOMETRIC altitude? Remember those Ideal Gas Laws from high school physics? The volume of a gas at constant pressure is proportional to its Absolute Temperature. In this case we have a constant pressure difference (1013.25 - 697HPa) and a column of constant cross section – say one square meter, so the height of the column will vary according to Absolute temperature. Deg C is converted to Deg Kelvin(Absolute Temperature) by adding 273.15 to the Deg C number so the temperature in the ISA layer is 273.15 + 5 =278.15 deg K and the temperature in the layer on our hot day at Waikerie is 273.15 + 27 = 300.15. The height of the layer will have expanded by the ratio 300.15/278.15 which is 1.079 or close to 8% which is 800 feet! So our GPS receiver which measures GEOMETRIC altitude will read 10,800 feet plus or minus the 35 to 70 feet possible error.

At 1000 feet the difference is even worse, about 13% or 130 feet in 1000 feet.

You've just discovered why final glides on hot days have a built in margin because your glider cares about GEOMETRIC altitude when it comes to the distance you can glide at a certain glide angle and also why your GPS will report a greater altitude than your pressure altimeter on warm days. Of course we mostly fly gliders in summer when even in Europe the temperature is usually above that in the ISA so it isn't surprising that Flight recorders which record both GPS altitude and Pressure Altitude will on average show that the GPS altitude is greater than Pressure Altitude.

Careful consideration of other errors in Pressure Altitude such as static port errors (can easily be greater than 50 feet especially cockpit static as used in Flight Recorders) and instrument errors due to temperature changes in the instrument (easily 30 to 50 feet) convinces me that GPS altitude at 10 to 20 meters (35 to 70 feet) error is superior to Pressure Altitude for soaring performance purposes and this should be used for calculating final glides. Just be careful to add your safety margin as you no longer have the one you didn't know was there.

Other branches of sport aviation such as ballooning convert measured pressure altitudes to GEOMETRIC altitude for Record purposes. Soaring doesn't, as far as I know, for badges or records.

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