GNSS meteorology:
Ground-based estimation of atmospheric precipitable water vapor using GNSS

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For the TRYAT project

Link to the YouTube video: https://www.youtube.com/watch?v=3xI9AkPvBUI

Monitoring the lower atmosphere is one of the so many applications of GNSS. It is known as ground-based GNSS meteorology, which is the topic of this video.

The atmosphere might be imagined as a blanket that is wrapped around the earth's body. It is a layer of gases and particles that extends from the earth's surface to altitudes of about 1000 kilometers. The atmosphere keeps the earth's temperature comfortable for living, prevents harmful rays and radiations from reaching the earth, and preserves the water.

The atmosphere can be subdivided into different layers: the troposphere, stratosphere, mesosphere, thermosphere, and exosphere. In geodesy, we use another subdivision, as you will see in a minute.

The atmosphere consists of 78% ~~78.08%~~ Nitrogen and 21% ~~20.95%~~ Oxygen. The remaining 1% ~~0.97%~~ contains water, carbon dioxide and other gases. In this video, we will focus on the water, especially the water vapor.

Water exists in the atmosphere in three phases: gas, liquid, and ice.

It is the most interesting and challenging parameter for understanding the complex interactions and patterns of the weather and climate systems.

The water evaporates, rises into the atmosphere, cools and condenses into clouds, and falls as precipitation. This natural process that provides fresh water from the salty ocean water is called the hydrological cycle.

The cycle of water in and out of the atmosphere is vital for forming the weather.

Also, water evaporation and water vapor condensation are linked to heat absorption and radiation. Therefore, Water vapor is an extremely important greenhouse gas that keeps the Earth's climate suitable for living.

Do you know that water vapor also exists under a clear sky?

Want to prove it? Take a bottle from the fridge and put it out for a while. You will notice that the vapor starts to condense on it.

Precipitable water vapor (PWV) is the amount of water that would result from condensing a column of humid air with one square meter cross section that extends from the surface to the top of the troposphere. It is measured in millimeters or kilograms per square meter.

Being essential for weather and climate, the PWV is regularly measured.

Meteorological instruments such as radiosondes are used, but they are expensive and the data do not have sufficient temporal and spatial resolutions. Also, in situ measurements are not always easy to collect. Think of Polar Regions, for instance.

Therefore, other useful techniques are welcome. GNSS meteorology is an attractive alternative!

Okay. Let's see what that is.

On its way from the satellite to the ground, the microwave signal penetrates the earth's atmosphere. For GPS satellites that fly at 20000 kilometers, the propagation time of a signal travelling in a straight path is 67 milliseconds. However, due to different error sources, the signal's propagation time is significantly longer. One of these errors is the delay due to the propagation in the atmosphere.

For geodetic applications, the atmosphere is subdivided into two layers: the ionosphere, which is the ionized layer that extends between altitudes of 60 to 1000 kilometers.

The other is the electrically neutral layer, the neutrosphere, which extends from the earth's surface to 60 kilometers. The troposphere is the lowest layer of the neutrosphere with a thickness of about 20 kilometers at the equator. This is where most of the moisture exists, so it is our focus.

The microwave signal is refracted when it enters the troposphere since, unlike vacuum, the troposphere is a medium with refractive index greater than 1. So, instead of a straight path, the signal travels a bent path. It is the same as when light is refracted in glass or water. This "bending" increases the amount of time the signal takes to reach the receiver.

If the GPS signal is travelling downwards, the troposphere adds about 8.2 nanoseconds delay to the measurement. For highly precise positioning, this error has to be corrected. It also can be used to provide useful information about the troposphere.

In the presence of observations from more than four visible satellites and using a technique called precise point positioning, PPP, we can estimate the receiver's coordinates X, Y, Z and time, and the tropospheric delay known as the zenith total delay (ZTD). The ZTD is the tropospheric delay a signal would encounter if the satellite transmits downwards (90° elevation). The tropospheric delay along the satellite line-of-sight is called slant total delay. It is larger in value since the travel path is longer.

Now, we know this quantity, the ZTD.

The ZTD depends on the air temperature, pressure and water vapor pressure. Therefore, we can extract information about the amount of water vapor (the PWV) from the ZTD.

The ZTD is the sum of the zenith hydrostatic delay (ZHD) caused mainly by dry gases such as oxygen and nitrogen, and it is about 90% of the ZTD. The remaining 10% represent the zenith wet delay (ZWD) caused by water vapor.

This is what we are looking for. ZWD = ZTD – ZHD. ZTD is known.

Given the measurement of the air pressure in hectopascal, the ZHD can be calculated from this formula: ZHD≈ 0.002277 * p

Then ZWD is obtained, so it can then be converted into PWV. PWV = pi * ZWD

pi is an empirical constant that depends on the location of the GNSS antenna and the weather conditions. For simplicity, pi can be set to 0.15, which is a rough rule of thumb. This means that 6.5 millimeters of ZWD is equivalent to 1 millimeter of PWV.

Here is a time series of PWV estimated from GNSS measurements. It shows its rapid temporal variations and we see a seasonal dependence. When it is warmer, evaporation increases and hence the amount of water vapor in the air. When it is colder the PWV decreases.

That’s it for today’s video. I hope you learned a thing or two about GNSS meteorology.

Thank you for watching!