VAISALA

Vaisala Radiosonde RS41 GNSS-based Height and Pressure

Technical Paper

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CHAPTER 1

Introduction

The purpose of this document is to introduce GNSS-based height and atmospheric pressure measurements with the Vaisala Radiosonde RS41 and Vaisala Sounding System MW41 or Vaisala Cirrus® Sounding System MW51.

A global navigation satellite system (GNSS) such as Global Positioning System (GPS), BeiDou or Galileo provides accurate height and time estimates from satellites orbiting Earth. GPS observations of wind, height, and horizontal location have been used in radiosoundings since the 1990s. Furthermore, atmospheric pressure can be derived from GNSS height complemented with radiosonde temperature and humidity observations. The GNSS-based pressure measurement method has been validated in WMO intercomparisons in Mauritius in 2005 [1], in Yangjiang in 2010 [2], and in Lindenberg in 2022 [3].

The Vaisala Radiosonde RS41 provides high-quality GNSS-based height and pressure measurements either combined with differential corrections from the ground system's local GPS receiver (DGPS) or using multiple GNSS systems (multi-GNSS) which enhance accuracy and mitigate GPS interference. The latter advancement is unlocked by the Vaisala Cirrus Sounding System MW51 while DGPS is used in the Vaisala Sounding System MW41.

This technical paper gives an overview of the measurement methods and GNSS technology used in the RS41, along with an analysis of the measurement performance. The performance of GNSS-based pressure measurement is compared to RS41-SGP equipped with the silicon pressure sensor. This paper also provides technology selection recommendations for different environments and applications.

GNSS wind measurement performance and RS41 temperature and humidity measurements are described in a separate document [4].

Executive summary of measurement performance

The accuracy of GNSS-based height and pressure measurements was evaluated using a comprehensive uncertainty analysis. The method is based on the recommended evaluation of measurement data described in JCGM 100:2008 [5] and used theoretical estimates and performance tests in different geographical locations. For multi-GNSS, the accuracy of height and pressure is equivalent to that of differential GPS (DGPS) in most conditions globally, although the weight of individual sources of uncertainty affecting the accuracy differs between the methods.

Table 1 presents a summary of the performance of RS41, with height expressed in geopotential meters (gpm). The height range where the results are valid is unlimited in balloon soundings.

The performance fulfills WMO recommendations and meets the high accuracy requirements of radiosonde data applications. RS41 radiosondes obtain a good level of reproducibility for both height and pressure, which demonstrates the solid performance of the GNSS design and algorithms for both DGPS and multi-GNSS.

Measurement	RS41 Accuracy specifications	RS41 reproducibility (DGPS)	RS41 reproducibility (multi-GNSS)
	Combined uncertainty with k=2 confidence level (95.5%)	Standard deviation of differences in twin soundings (n = 42)	Standard deviation of differences in twin soundings (n = 15)
Geopotential height	10 gpm	< 6 gpm	< 4 gpm
Pressure > 100 hPa	1 hPa	< 0.5 hPa	< 0.4 hPa
100–10 hPa < 10 hPa	0.3 hPa 0.04 hPa	< 0.2 hPa < 0.04 hPa	< 0.1 hPa <0.02 hPa

Table 1. Summary of GNSS-based geopotential height and atmospheric pressure measurements with the RS41 radiosonde. DGPS reproducibility results are from sounding campaigns in Malaysia (lat. 5° N) and Finland (lat. 60° N). Multi-GNSS reproducibility results are from a sounding campaign in Finland (lat. 64° N).

CHAPTER 2

GNSS Technology in Vaisala Radiosonde RS41

Radiosonde GNSS receiver

The RS41 radiosonde's GNSS receiver consists of the antenna, RF front-end, and GNSS chip. The GNSS antenna is a robust, high-efficiency integrated antenna. The GNSS receiver components have been selected to improve tolerance of interference sources and to provide high measurement precision. RS41 not only supports GPS but can be enabled to support multiple GNSS constellations including GPS, Galileo and BeiDou or a combination.

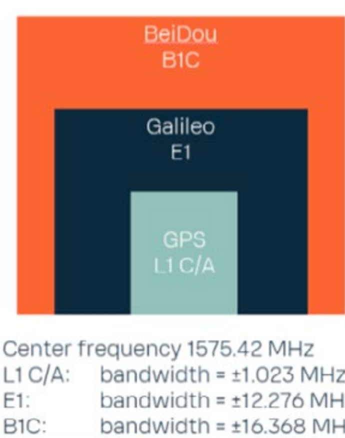


Figure 1. The center frequency and bandwidth of GPS, Galileo and BeiDou satellite systems.

Typical time to first satellite tracking after cold start is 35 seconds. However, due to the high sensitivity of the receiver, RS41 usually finds some GNSS signals indoors during sounding preparation, which shortens the time for proper satellite tracking.

Differential GPS correction – DGPS

Traditionally, Vaisala radiosondes have utilized GPS constellation combined with the differential correction from the local GPS receiver at the ground equipment. This remains the default setting for RS41 radiosondes, guaranteeing seamless integration with existing systems.

Calculation algorithms

The Sounding System MW41 uses custom signal processing for location and GPS-based pressure and wind measurements. Vaisala has optimized the algorithms for radiosonde applications. High-quality height measurements are essential for accurate atmospheric pressure observations.

The algorithms include methods such as filtering designed for typical radiosonde ascent rates. Ionospheric modeling is used to minimize the impact of atmospheric effects on measurement. In addition, fixed stations combine GPS measurements from the radiosonde and the local GPS receiver to produce differential GPS corrections. These eliminate many common GPS positioning errors.

Local GPS receiver

The Sounding System MW41 and Cirrus Sounding System MW51 both include a GNSS receiver with a local GNSS antenna at the station. The antenna is a Vaisala GPS Antenna GA31 [6], which meets the specified height and GPS-based pressure measurement performance requirements at well-designed installation sites.

Multi-GNSS

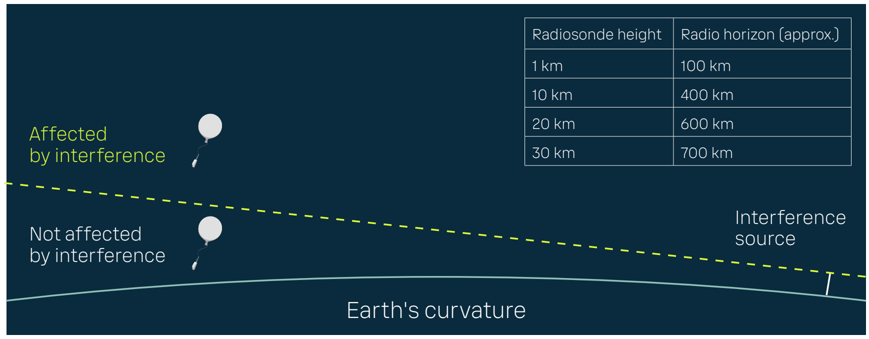


Figure 2. Illustration of the estimated interference range.

Improved accuracy

RS41 with multi-GNSS utilizes multiple satellite constellations to improve signal reliability and accuracy. By diversifying signal sources, these systems reduce the impact of jamming and spoofing, providing a more robust framework for data collection.

RS41 uses multi-GNSS technology to increase resilience against GPS interference and secure accurate weather forecasts in challenging environments. It supports multiple GNSS constellations including GPS, Galileo and BeiDou, which can be selected or deselected using MW51 and DigiCORA sounding software.

Resilience against GPS interference

Radiosondes can be vulnerable to ground-based GPS signal interference because of the radio horizon phenomenon. Even if the interference source is not nearby, a radiosonde at higher altitudes can pick up interference from a very wide area, for example, up to 700 km radius at 30 km altitude as shown in Figure 2. Reaching a higher altitude without interference is important for ensuring the availability and reliability of weather data.

Selecting multi-GNSS increases resilience against GPS interference by 60% on average and secures accurate weather forecasts in challenging environments. Depending on the level of interference, the DGPS method may experience performance degradation or, in the most severe cases, early termination of the sounding before the balloon reaches its burst altitude due to missing data.

Figure 3 summarizes the tests done in Finland during 2024 in interfered conditions. Comparison was done between RS41 versions utilizing DGPS and RS41 versions configured for multi-GNSS with GPS, Galileo and BeiDou satellite systems enabled. Soundings utilizing DGPS terminated before reaching the target balloon burst height (approx. 30 km). Soundings utilizing multi-GNSS reached the normal burst height which demonstrates improved resilience against interference.

Feature unlocked by MW51

The Cirrus Sounding System MW51 is built around the Vaisala Sounding Processing Subsystem SPS511 and Vaisala DigiCORA software. The multi-GNSS feature is available with DigiCORA, enabling operators to select whether multi-GNSS is used as well as which GNSS satellite constellations are in use, as shown in Figure 5.

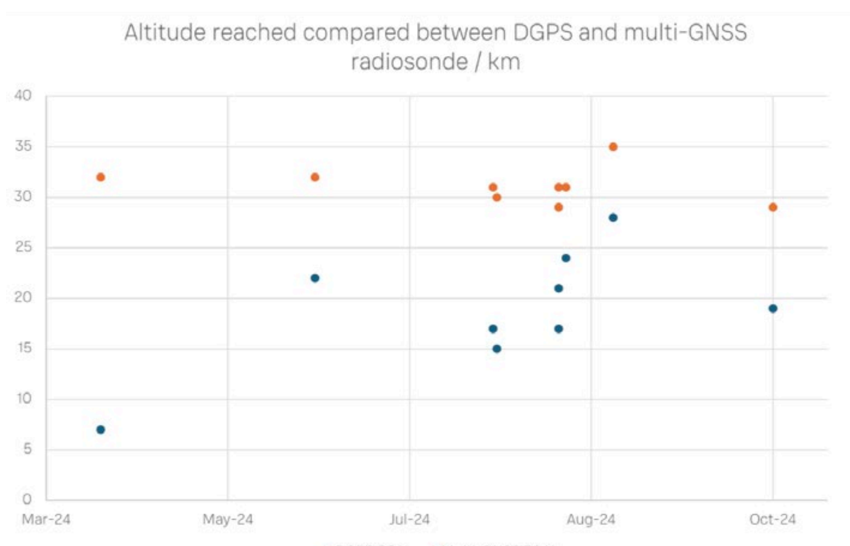


Figure 3. The reached altitude of using DGPS and multi-GNSS in interfered conditions in Finland during 2024.

Figure 4. SPS511 is the heart of the MW51 sounding system.

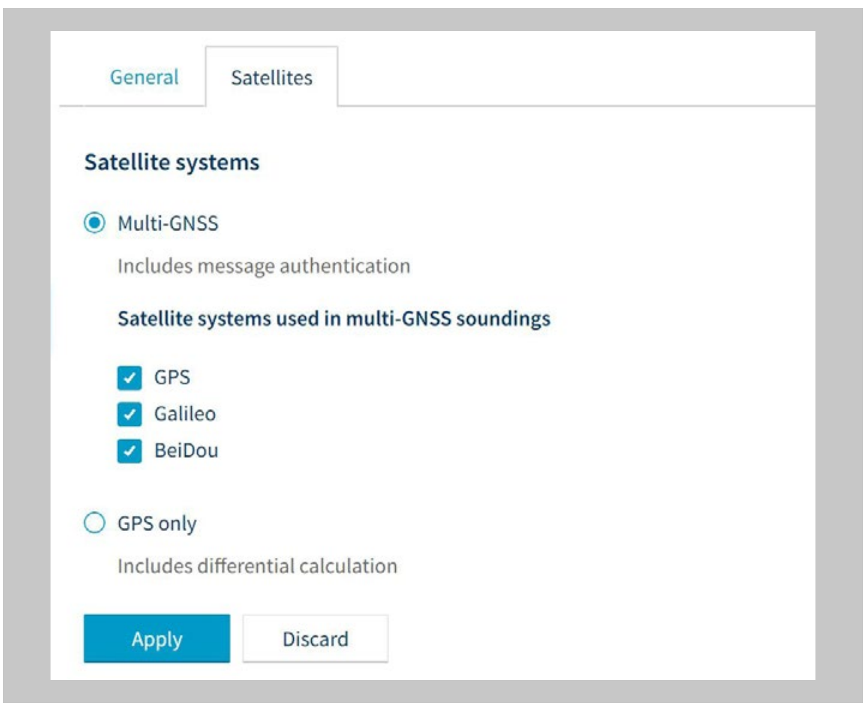


Figure 5. Satellite constellation selection in DigiCORA.

CHAPTER 3

GNSS-Based Measurement Methods

Height measurement

The GNSS receiver calculates the location of the radiosonde using timing and position information received from GNSS satellites. Each satellite generates a unique pseudo-random code containing the transmission time and satellite position. The GNSS receiver calculates the time differences between the transmission and reception of the coded messages and, multiplying by the speed of light, determines the so-called "pseudorange" distances between the radiosonde and satellites. Pseudoranges from four or more satellites are required to obtain the horizontal and vertical position of the radiosonde.

Raw GNSS height is expressed relative to the WGS 84 reference ellipsoid model of Earth. This value is then converted to express height from local mean sea level (MSL), specified in WGS 84 using the EGM96 Earth geoid model. MSL height is also converted into geopotential height, which adjusts the MSL height to compensate for the variation in Earth's gravity with altitude and latitude. It is expressed in geopotential meters (gpm).

The difference between the two is negligible, especially in the lower atmosphere. Geopotential height is the height reported by the radiosonde in TEMP and BUFR messages.

Pressure measurement

Atmospheric pressure is equivalent to the force per unit of area exerted on Earth's surface by the weight of the air column above the surface. It is an important component in meteorology and other atmospheric sciences.

RS41 uses a GNSS-based measurement principle for estimating the atmospheric pressure. This technique requires a pressure sensor at the sounding station. The pressure-sensor value calibrates all observations in the pressure profile. It is very important to use a properly calibrated surface pressure sensor. Station height parameters, including the height of the pressure sensor and the height of the local GPS antenna, are also essential factors in the calculation. The sounding systems enable configuration of these height parameters via a convenient graphical interface.

Air density along the flight path varies according to temperature and humidity conditions. The radiosonde measures the change in pressure between each measurement point during the flight by observing these quantities. The vertical position and distance between measurement points are obtained from the GNSS height measurement. The magnitude of the change, δP, can then be derived, for example, from hydrostatic equation and ideal gas law,

$$\frac{\delta P}{P} = -\frac{g \cdot \delta Z}{R_a \cdot T_v}$$

where P is pressure, g is the gravity constant, δZ is the change in geopotential height, Ra is the gas constant for dry atmosphere, and Tv is the virtual temperature. The virtual temperature is the temperature that dry air would have if its pressure and density were equal to those of a given sample of moist air. The calculation is illustrated in Figure 6. Air pressure contributions over each layer are added up from ground level to obtain the pressure at the measurement height.

Pressure measurement (cont.)

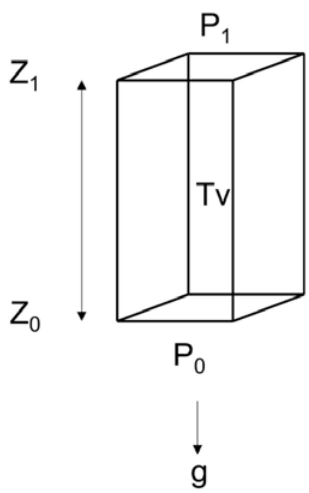


Figure 6. Calculating atmospheric pressure at the top of an air layer.

Measurement accuracy

GNSS measurements have high accuracy, determined by the GNSS receiver quality and the geometry and availability of GNSS satellites. Errors in the location may be caused by various factors, including primarily those related to the satellite RF signal propagation through the atmosphere. The impact of these factors can be reduced, for example, using modeling and differential corrections. The RF environment is more challenging when the radiosonde is flying close to the ground, where reflections and diffractions of GNSS signals may cause multipath propagation. GNSS height estimates are typically less accurate than horizontal location estimates, but vertical accuracy of 10 m or less is obtainable in most conditions with the Radiosonde RS41, which is sufficient for radiosonde applications.

GNSS-based pressure accuracy is almost entirely determined by the height accuracy. The relation between the two is illustrated in Figure 7. Other factors include the accuracy of the surface pressure and the radiosonde temperature measurements.

Figure 7 shows the effect of temperature bias in different conditions. A persistent bias of 0.1 – 0.2 °C causes a small error of up to 0.15 – 0.3 hPa in the pressure profile. A short period (60 sec) bias of 1.0 °C in lower troposphere causes an error of around 0.1 hPa. The accuracy of station-height settings (station altitude, GPS antenna, and barometer heights) also contributes to measurement accuracy.

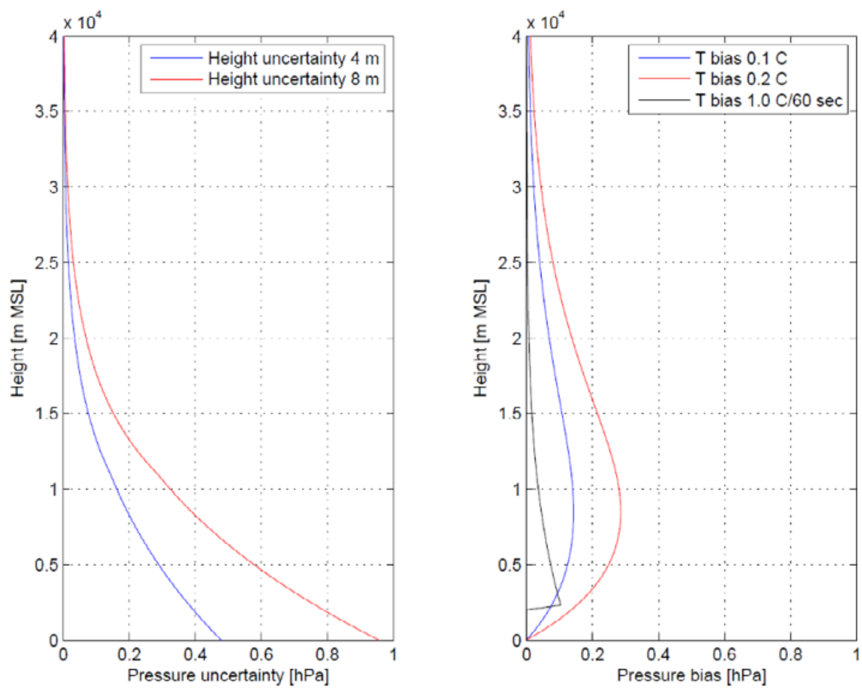


Figure 7. 1) Impact of height measurement uncertainty on pressure. 2) Impact of persistent temperature errors (=bias) on pressure. Results were calculated using the ISA standard atmosphere model.

CHAPTER 4

Performance of RS41

Method of evaluation

The accuracy of RS41 height and pressure measurements was evaluated using a comprehensive uncertainty analysis. The analysis was based on results from rig soundings, factory tests of GNSS reception quality, and theoretical estimates of other contributors.

Sounding campaigns for DGPS were carried out in two locations, Malaysia (lat. 5° N) and Finland (lat. 60° N), to cover different satellite geometries and site environments. The test site in Malaysia had a metal sheet roof and other structures in the vicinity of the antennas. The Finland site had some metal structures in the vicinity of the antennas.

For multi-GNSS, the sounding campaigns were carried out in two locations in Finland at different latitudes (lat. 60° N and 64° N). During the tests, there was strong interference affecting especially the GPS satellites.

The combined uncertainty of measurement was estimated in different conditions and through the full radiosounding height range. The analysis follows the principles in JCGM 100:2008 [5] and is explained in more detail in the RS41 performance document [4]. Statistical analyses and radiosonde comparison results were processed using RSKOMP Radiosonde Comparison Software [7] and post calculations in Microsoft Excel. Such tools were complemented by Python scripts, used to analyze the multi-GNSS sounding campaign data and plot the reproducibility statistics.

Height

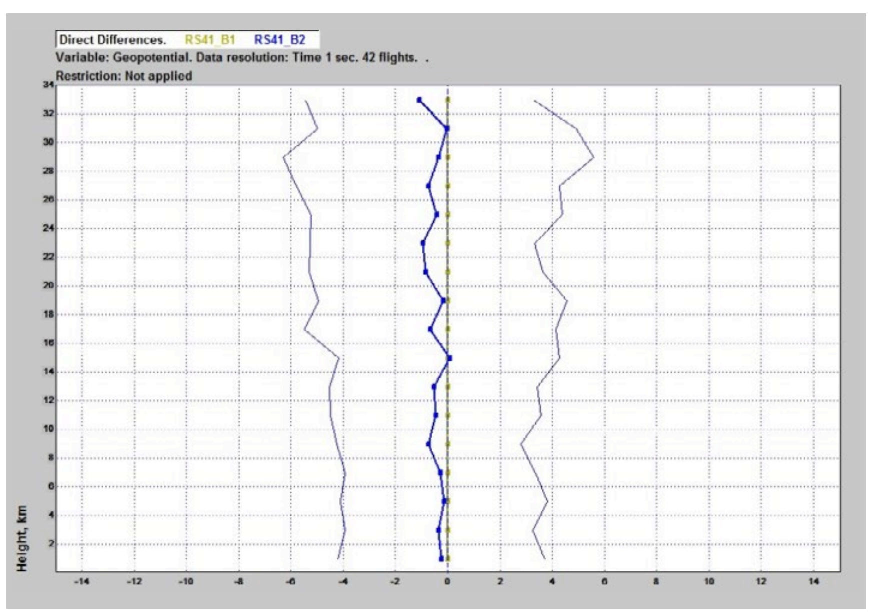
Reproducibility in DGPS soundings

Two radiosondes were flown in the same rig to assess the reproducibility of measurements. Separate GA31 local GPS antennas received the signal used for differential correction for radiosonde location. The antennas were installed an adequate distance from each other to ensure the measurements were not affected by the same multipath effects. The standard deviation of the measured differences describes the sounding reproducibility.

Figure 8 shows the geopotential height results from all soundings. Performance is uniformly good at all heights, with average differences of 0–1 gpm and standard deviations of less than 6 gpm.

Figure 9 shows the differences in heights between two RS41 radiosondes during one sounding in Finland.

Figure 8. Results of geopotential height comparison between two RS41 (DGPS) radiosondes in 42 flights. Showing average differences and standard deviation of differences (thin lines).



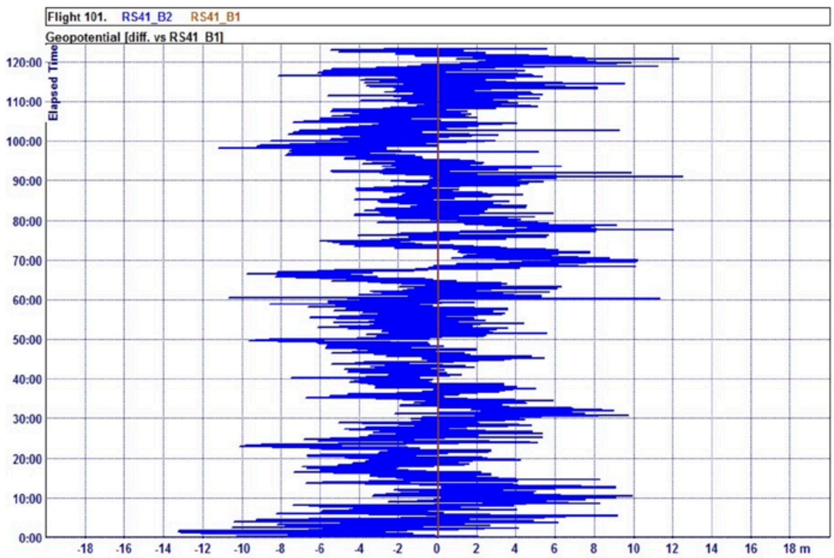


Figure 9. Example of geopotential height differences between two RS41 (DGPS) radiosondes in one sounding.

Reproducibility in multi-GNSS soundings

RS41 radiosondes with multi-GNSS were compared to radiosondes with DGPS flying in the same rig.

Figure 10 illustrates geopotential height reproducibility for the DGPS and multi-GNSS, respectively. The GNSS receivers used are similar in performance, but DGPS uses Vaisala's standard differential calculation algorithm while multi-GNSS uses the multi-constellation, chip-based positioning solution.

The GNSS-derived altitudes measured by the RS41 (multi-GNSS) were consistent with the reproducibility specifications limits of the RS41 (DGPS; <6 m, k=1).

During this trial, both the multi-GNSS and DGPS RS41 radiosondes showed good and consistent reproducibility when looking at the standard deviation of height differences measured in 1 km bins. The two methods were about equivalent up to an altitude of approximately 28 km. Above this altitude, the multi-GNSS method outperformed DGPS, when GPS interference was encountered in the upper end of the sounding profile. In such conditions, the reduced GPS satellite availability resulted in decreased precision of the DGPS method while the multi-GNSS method maintained the same level of performance observed in other parts of the sounding profile.

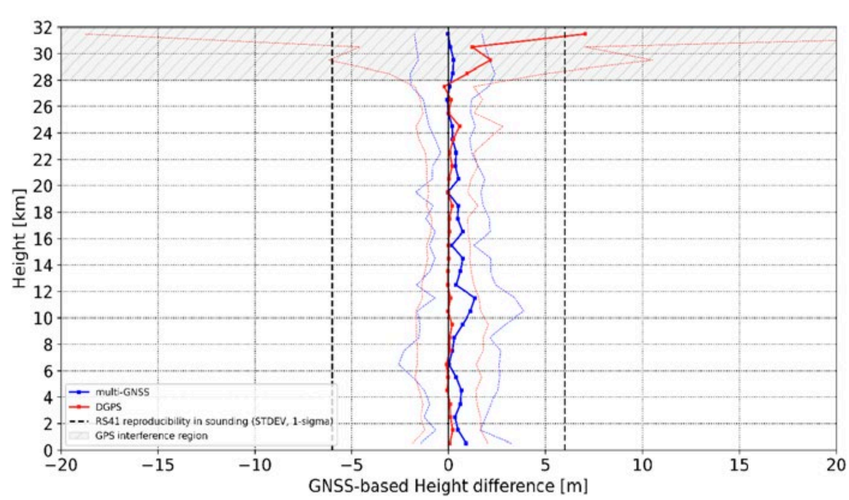
Combined uncertainty

The uncertainty analysis for geopotential height considered the following components:

- Reproducibility in soundings
- Tropospheric and ionospheric effects
- Uncertainty in station-height settings

Reproducibility tests quantified random and uncorrelated errors coming mostly from the quality of the available satellite reception, the external RF environment, and receiver noise.

Figure 10. Comparison of GNSS-based geopotential heights between the RS41 radiosonde with DGPS (red) and multi-GNSS (blue). The thick line shows average differences, and standard deviation of differences is illustrated with thin lines. Data is from 15 flights in Finland (lat. 64° N). The shaded region (grey) indicates the altitudes where GPS interference was observed.



The impact of tropospheric and ionospheric effects was estimated as the uncertainty of applied corrections. The accuracy of the station-height settings was assumed to correspond to careful measurements, for example, an accuracy of 0.3 m for the GPS antenna offset from barometer height.

Figure 11 shows the combined uncertainty along with the uncertainty components. The results were evaluated through all height ranges. The combined uncertainty is fairly constant, with a small increase at the highest heights due to atmospheric effects. The combined uncertainty results were used as a basis for the specified RS41 accuracy shown in Table 1.

The above specified combined uncertainty is still applicable for the multi-GNSS operational mode for most users. However, when evaluating the individual uncertainty components, the most remarkable difference against the DGPS mode is in the residual ionospheric and tropospheric delay compensation errors.

Relying on ground-based real-time corrections, DGPS provides better mitigation of common atmospheric propagation effects to GPS satellite signals than the broadcast corrections used in autonomous positioning, particularly in the equatorial zone and outside of the Satellite Based Augmentation System (SBAS) service areas. On the other hand, the uncertainty of local GPS antenna can be omitted as long as the sonde operates in multi-GNSS autonomous mode.

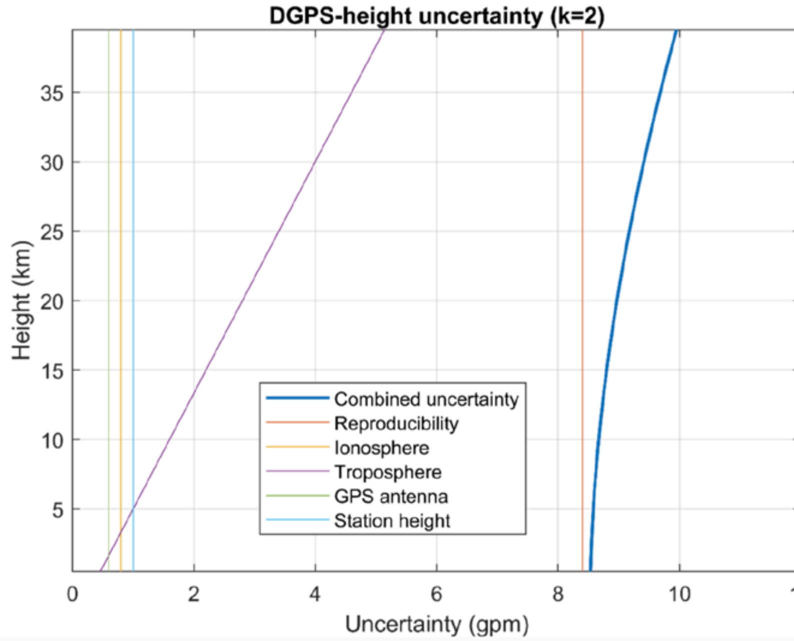


Figure 11. Combined uncertainty (k=2) and main uncertainty components for DGPS-based geopotential height measurements in the RS41 radiosonde.

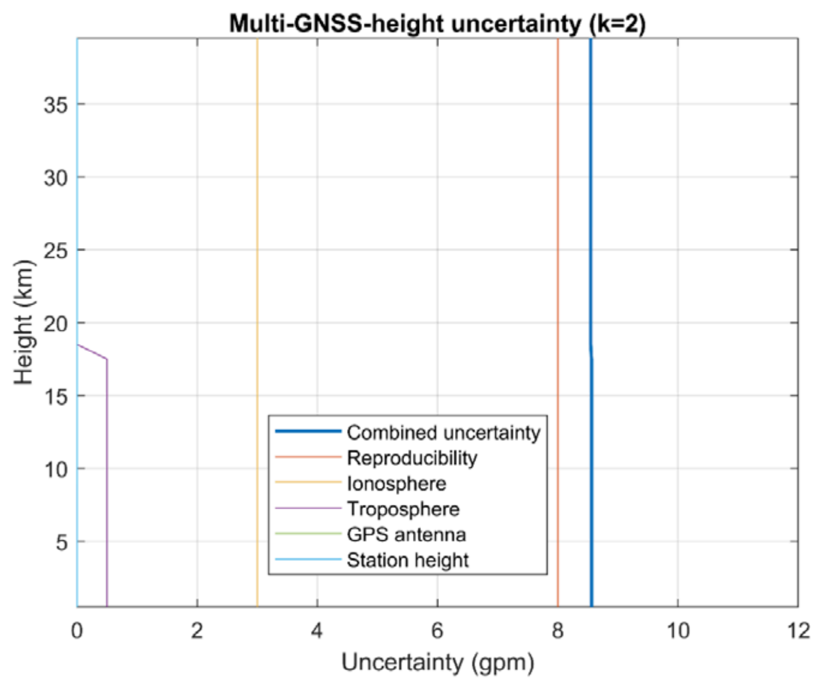


Figure 12. Combined uncertainty (k=2) and main uncertainty components for multi-GNSS-based geopotential height measurements in the RS41 radiosonde.

An estimate of the typical multi-GNSS-based height combined uncertainty is shown in Figure 12.

GNSS-based pressure

Reproducibility in DGPS soundings

Figure 13 shows the reproducibility of DGPS-based pressure measurements between two radiosondes. The results agree with the reproducibility of geopotential height, which is the dominant factor in pressure accuracy. The random differences decrease rapidly as a function of altitude, following the exponential decrease in atmospheric pressure. Observed standard deviations were 0.4 hPa near ground and <0.04 hPa at above 30 km.

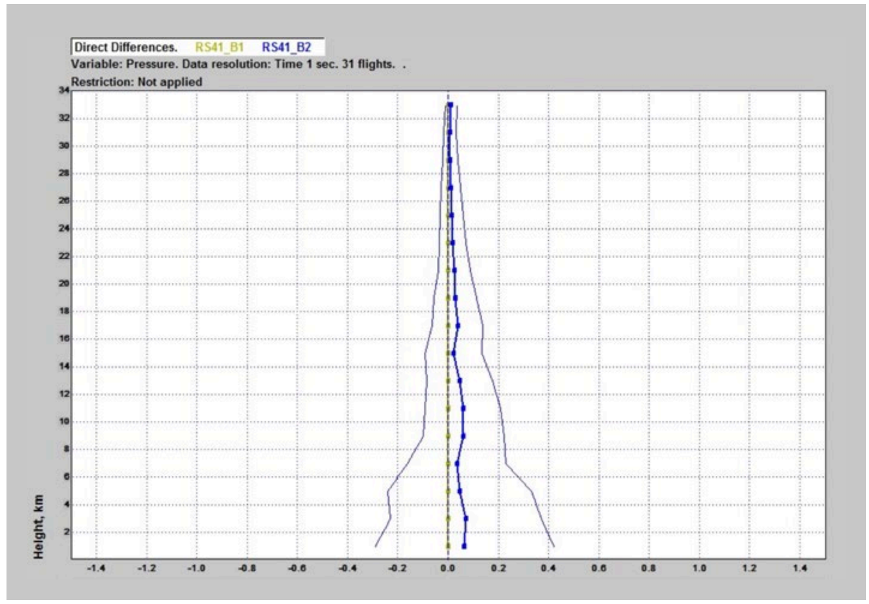


Figure 13. Results of pressure comparison between two RS41 (DGPS) radiosondes in 31 flights. Showing average differences and standard deviation of differences (thin lines).

Comparison between DGPS-based and sensor pressure

RS41-SGP provides both sensor and GNSS-based measurements of pressure. The DGPS-based results were used as a set of independent reference measurements in the sounding campaigns.

An example of differences between sensor and DGPS-based measurements of pressure during one sounding in Finland is shown in Figure 14. The variability in differences in the lower heights is mostly due to noise in DGPS height measurements.

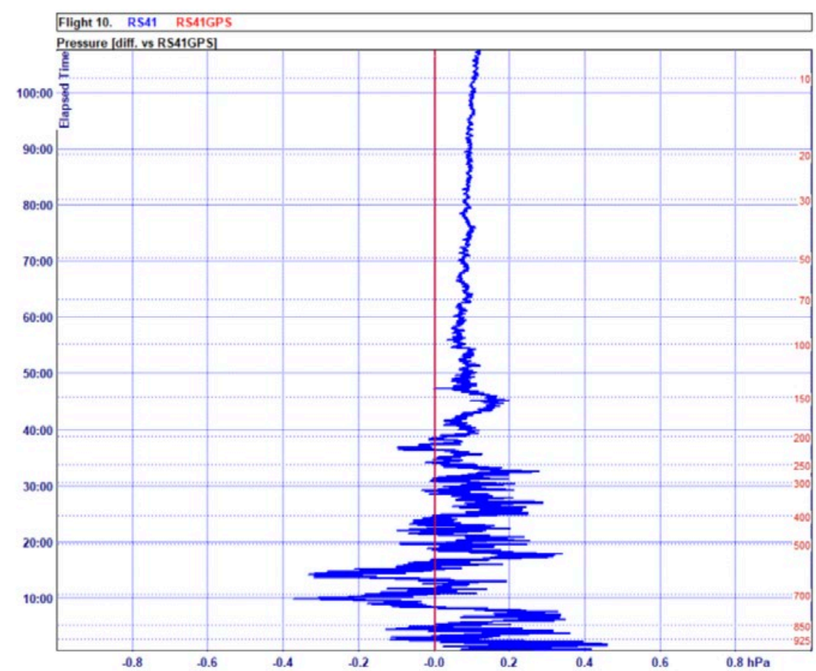


Figure 14. An example of differences between measurements of sensor pressure (RS41) and DGPS-based pressure (RS41GPS) from an RS41-SGP in one sounding.

Figure 15 shows statistical results of comparison between sensor and DGPS methods from a set of 32 soundings. The average differences were within 0.15 hPa in both locations in Malaysia and Finland.

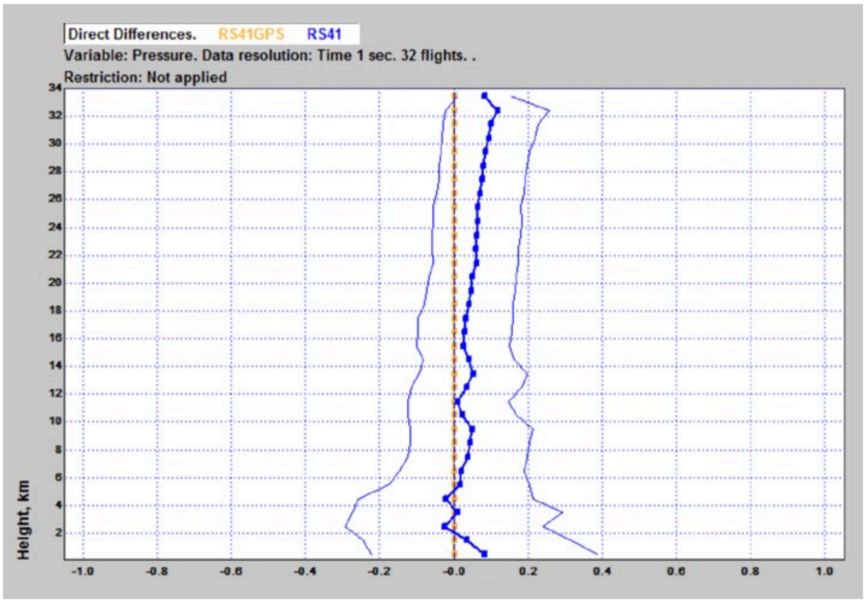


Figure 15. Comparison of sensor pressure (RS41) and DGPS-based pressure (RS41GPS) from RS41-SGP in 32 flights, using DGPS-based pressure as the reference. Average differences are indicated by the bold line, and standard deviation of differences by thin lines.

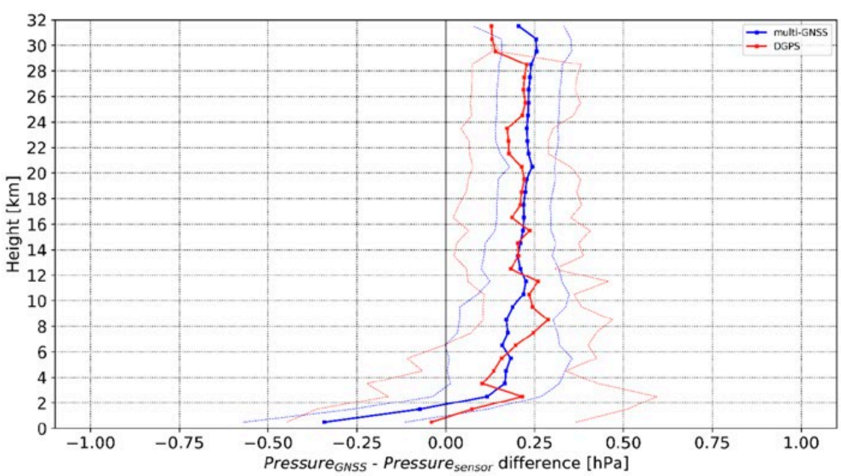


Figure 16. Comparison between sensor pressure and GNSS-based pressure. The results for DGPS mode and multi-GNSS mode are shown by red and blue lines, respectively. Average differences are indicated by the bold lines, and standard deviation of differences by thin lines.

Comparison between multi-GNSS-based and sensor pressure

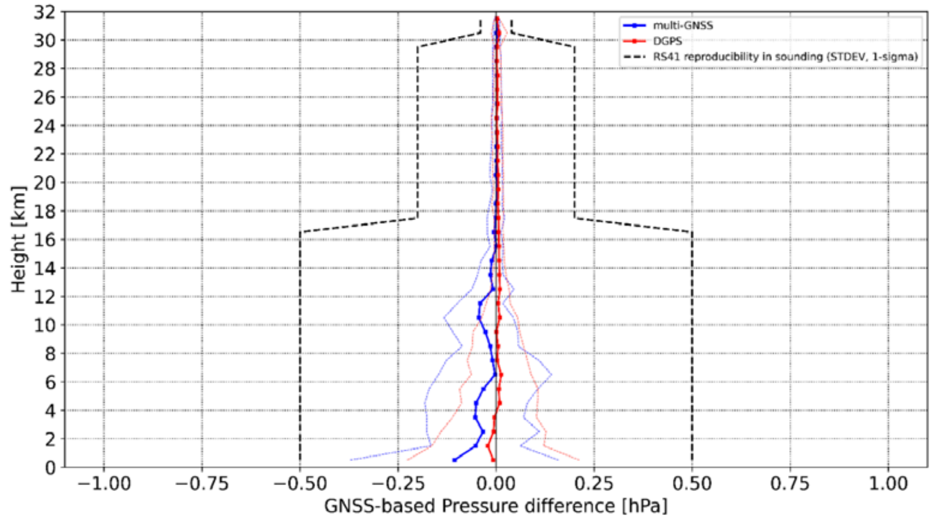
Figure 16 shows the statistical results in 1 km bins of comparison between the sensor and both DGPS- and multi-GNSS-based methods from a set of 6 soundings done in Finland. The average differences were within ±0.3 hPa for both the multi-GNSS and DGPS methods and consistent throughout the altitude profile. The maximum deviation between the multi-GNSS and the DGPS methods during this trial is seen at the lowest altitude level (0-1 km), but the standard deviation of the differences for the multi-GNSS RS41 indicates, generally, less dispersion in the results.

On the other hand, GPS interference present during the soundings at upper altitude (approx. above 28 km) affected the DGPS performance, preventing the height and pressure measurement up to the balloon burst altitude.

Reproducibility of pressure with DGPS and multi-GNSS

The reproducibility from 15 flights between DGPS and multi-GNSS based pressure is shown in Figure 17. The GNSS derived pressure measured by the RS41 (multi-GNSS) was consistent with the reproducibility specifications limits of the RS41 (DGPS), when looking at the standard deviation of height differences measured in 1 km bins.

Figure 17. Comparison of reproducibility of DGPS (red) and multi-GNSS (blue) based pressure. The thick line shows average differences, and standard deviation of differences is illustrated with thin lines. Data is from 15 flights in Finland (lat. 64° N).



Combined uncertainty

The uncertainty analysis for pressure considered the following components:

- GNSS-based geopotential height
- Radiosonde temperature and humidity measurements
- Accuracy of surface pressure measurements

The impact of these factors was modeled using custom analysis software that uses different atmospheric models, and even different scenarios of solar angles, to estimate the pressure uncertainty through all heights.

The effect of environmental conditions was small as geopotential height is the dominant factor.

Figure 18 shows the combined uncertainty along with the uncertainty components. The uncertainty decreases as a function of altitude, corresponding to the exponential decrease in atmospheric pressure. The combined uncertainty results were used as a basis for the specified RS41 accuracy shown in Table 1.

When evaluating the combined uncertainty for multi-GNSS-based pressure, the geopotential height is still the dominant factor. For most users and conditions, the multi-GNSS attains about the same level of combined uncertainty as for DGPS (Figure 19).

In the more challenging ionospheric conditions that are generally found in the equatorial zone (approx. ±15° Lat.), depending on the actual time of the sounding and the dynamic state of the ionosphere, the overall combined uncertainty for multi-GNSS pressure may increase with respect to DGPS, as a direct consequence of the increased geopotential height uncertainty in such specific conditions.

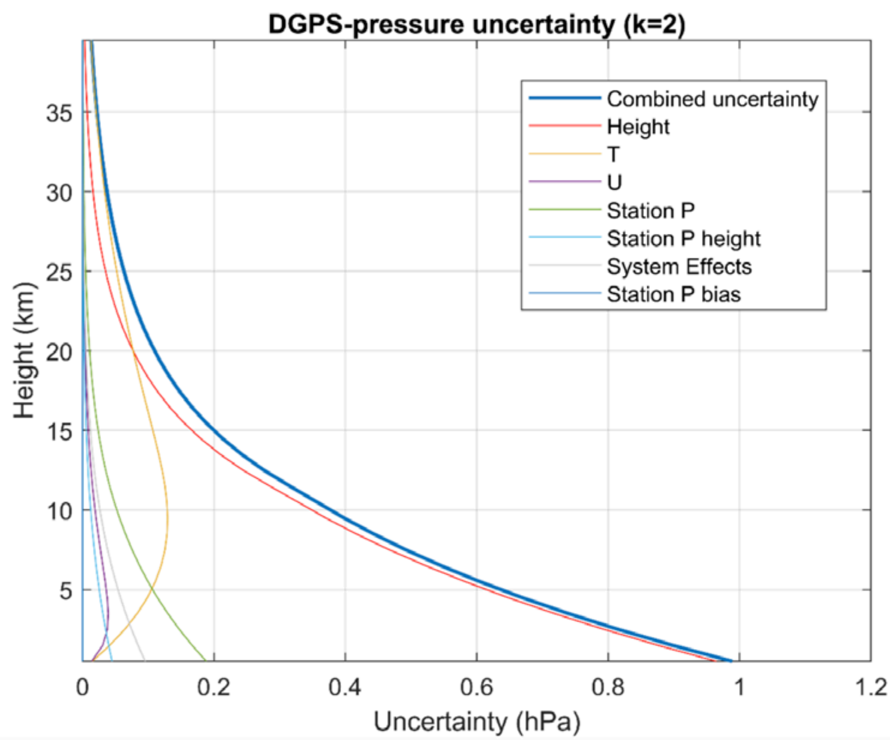


Figure 18. Combined uncertainty (k=2) and main uncertainty components for DGPS-based pressure measurements in the RS41 radiosonde evaluated assuming the ISA standard atmosphere for pressure and temperature.

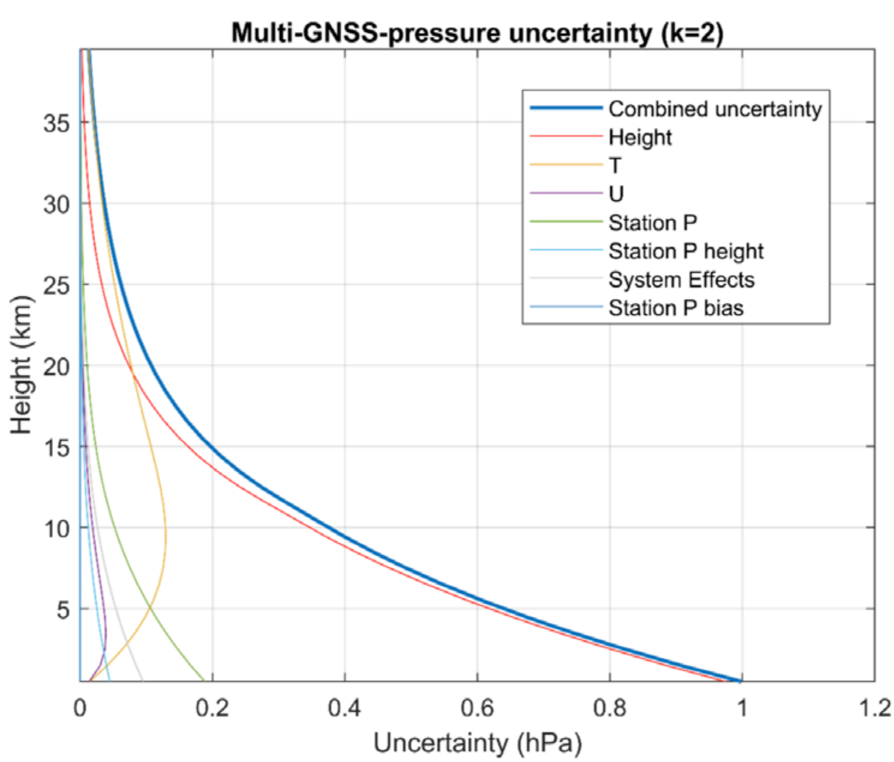


Figure 19. Combined uncertainty (k=2) and main uncertainty components for the RS41 multi-GNSS-based pressure measurements.

CHAPTER 5

Comparison of GNSS-Based and Sensor-Based Pressure Measurements

Pressure sensor measurement method

The conventional method of determining atmospheric pressure is to equip the radiosonde with an electronic pressure sensor that measures the physical weight of the atmosphere. Beginning with the RS90 series, Vaisala radiosondes have used the proven Vaisala silicon pressure sensor. The sensor combines two powerful techniques for barometric pressure measurement: single crystal silicon as a sensor material, and capacitive measurement. The main advantages are excellent stability, repeatability, a wide dynamic range, and low temperature dependence.

Height and geopotential height can be obtained from pressure sensor measurements using the hydrostatic equation and ideal gas law. The calculation procedure is analogous to the calculation of pressure from GPS height [8].

Comparison of measurement methods

GNSS-based and sensor-based measurements of atmospheric pressure have been extensively compared, for example, in WMO sounding campaigns. Despite the differences in measurement techniques, the agreement between the methods has been within the required accuracy limits. The following sections discuss conditions where performance differences may arise due to the different measurement principles used.

Hydrostatic and non-hydrostatic situations

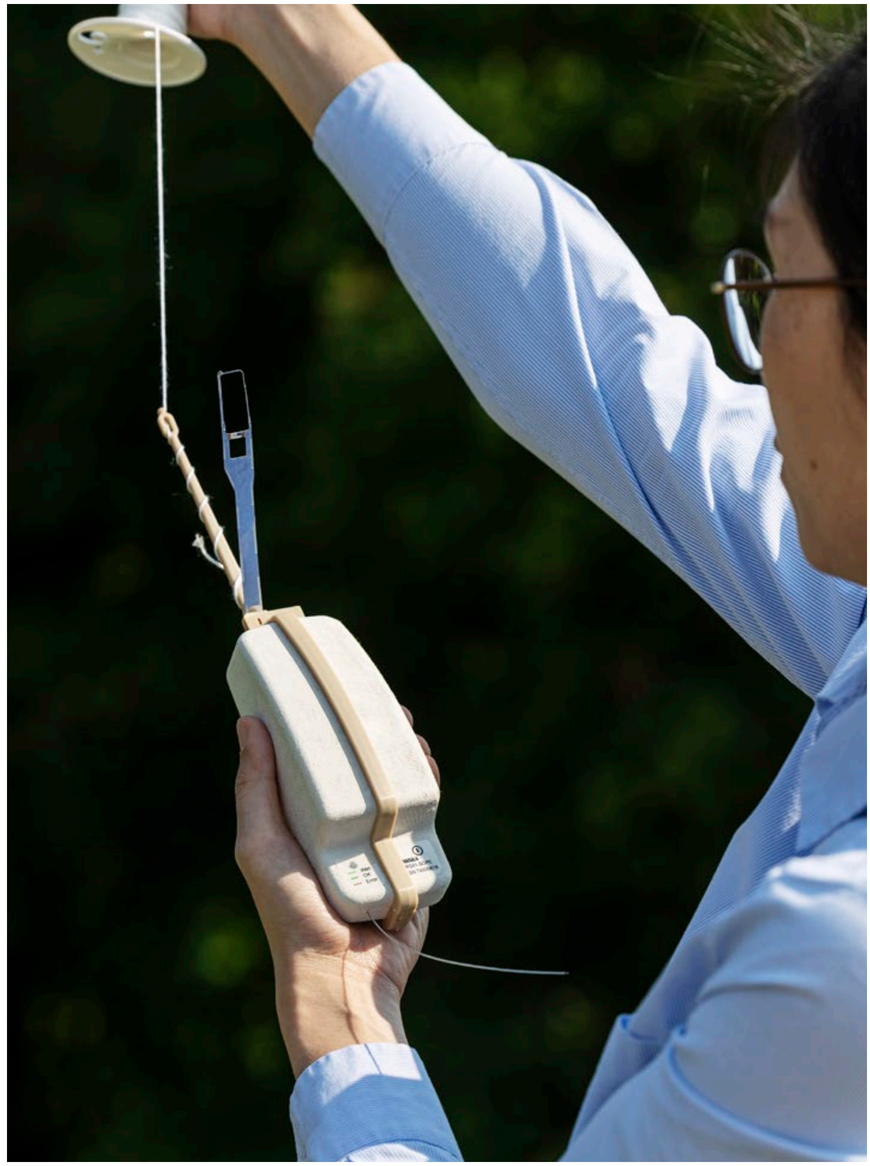
The GNSS-based measurement method assumes hydrostatic equilibrium in the atmosphere. A small deviation from pressure sensor measurements could be detected in non-hydrostatic conditions, such as near frontal zones, urban turbulence, or local storms.

The hydrostatic assumption used in GNSS-based pressure measurements is a good approximation for most radiosonde applications, including numerical weather prediction.

Horizontal inhomogeneity

The station pressure value used in the GNSS calculation represents the atmospheric conditions at the time and location of the start of the sounding, while a pressure sensor measures conditions along the flight time and path. Horizontal pressure gradients could produce minor deviations when comparing GNSS-based and pressure sensor measurements. These differences are a result of the different measurement principles and are generally minor compared with the accuracy of the measurement.

Horizontal inhomogeneity may also include precipitating weather systems along the radiosonde's flight path. The pressure sensor measures the sum of the weights of air and hydrometeors in the air column above the sensor. The contribution of the hydrometeors may not be detected by the GNSS method if the precipitation area is local. This difference is negligible compared with the accuracy of the measurement.



Other effects

Pressure sensor measurement accuracy is typically better than the GNSS method at the lowest heights. GNSS-based pressure accuracy improves quickly when the radiosonde ascends higher above the ground and above possible multipath reflections from the surroundings. At high altitudes, the geopotential height values may differ by up to a few hundred meters (gpm) due to the higher performance of the GNSS method in low pressures.

The relative accuracy of the pressure sensor decreases in the low end of the measurement range of 1080–3 hPa, while the relative accuracy of the GNSS method remains almost constant.

Any comparison of the two measurement methods requires accurate station height parameters and the correct use of a calibrated barometer. This is also essential for good climatological continuity at the measurement station.

Recommendations

When to select GNSS-based pressure measurement

Atmospheric pressure measurement using the GNSS principle is a high-quality measurement technique that is suitable for operational sounding applications. It is the recommended option for providing data for numerical weather prediction.

Multi-GNSS is the preferred choice to secure accurate weather forecast. The use of GPS, Galileo, and BeiDou constellations provides an increased number of satellites. This leads to better reproducibility in soundings. In addition, in areas where GPS interference is experienced and causes early sounding termination, multi-GNSS offers resilience against GPS interference so that targeted heights can be reached.

When to select pressure sensor measurement

A properly calibrated pressure sensor is the recommended choice for research applications where accurate observations of non-hydrostatic pressure profiles are required. A pressure sensor also provides the highest obtainable measurement accuracy at the lowest flight altitudes.

Some sounding sites may experience persistent external RF interference or suffer from poor satellite reception. A barometric pressure measurement is an alternative. These situations are unusual and should be considered on a case-by-case basis, following the manufacturer's recommendations.

1. WMO Intercomparison of High Quality Radiosonde Systems, Vacoas, Mauritius, 2-25 February 2005
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