Site guidelines for multi-purpose GNSS reflectometry stations

The following guidelines are meant for station operators interested in sharing their station installations for multiple purposes, including GNSS reflectometry (GNSS-R). They complement the International GNSS Service (IGS) Site Guidelines. It was started during the 2015-2019 term of the Working Group 4.3.9 on GNSS Reflectometry (GNSS-R), International Association of Geodesy (IAG).

1. For sea level monitoring and similar applications, the antenna does not need to be installed directly over the body of water, i.e., the antenna may be sheltered from the sea waves at a distance, as the sensing occurs at slant direction.
2. There should be unobstructed view from the antenna down to the surface (water, soil, snow, etc.), for reflected signal reception, especially between 5 and 35 degrees below the horizon (i.e., between zenith angles of 90 and 125 degrees).
3. There should be unobstructed view from the antenna up to the satellites in the sky, for direct signal reception, especially between 5 and 35 degrees above the horizon (i.e., between zenith angles of 55 and 85 degrees).
4. Trees and buildings should be sufficiently distant in the azimuths of interest; as a rule of thumb, the vertical-to-horizontal distance ratio, Z/D, between antenna and obstructions, shall be smaller than 10% for a 5-degree elevation mask: $Z/D < \tan(e \approx 5°) \approx 0.1$.
5. Visibility should span an azimuthal sector as large as possible, at least 90 degrees wide
6. In the region of interest, the reflecting surface should be as flat as possible; mild slopes and gentle undulations are acceptable.
7. Minimize surface roughness, such as rocks over ground and breaking waves on water, as it may restrict the range of useful satellite elevation angles, due to loss of radio-wave coherence.
8. For soil moisture and snow depth sensing, vegetation should be as sparse and as short as possible, preferably grass or even bare ground.
9. For roof-top installations, give preference to side walls and corners, avoiding the middle of the roof.
10. For roof-top installations, raise the antenna, using a pedestal or mount, at least half meter above the building roof, to minimize near-field effects (strong reflections, edge diffraction, snow accumulation, etc.).
11. For ground-based installations, raise the antenna, using a tripod or other monumentation, at least 1.5 m above the ground, to allow the recording of enough SNR oscillation cycles.
12. In snow-prone regions, make the antenna 1.5 meter taller than the highest expected snow depth accumulation.
13. When there is the need for a fence or enclosure around a GNSS site for security or safety reasons, keep it as far as possible and make wires widely spaced, avoiding narrow metal meshes as they may block the propagation of radio waves.
14. The GNSS sampling interval should be inversely proportional to the height of the antenna above the surface; a rule of thumb is: 30 seconds for 2 meters, 10 seconds for 5 meters, 1 second for 10 meters (the exact answer depends on the station latitude, as it affects the satellite trajectory in the sky).
15. Avoid objects (such as masts, sensors, and other antennas) protruding within a 1.5-m radius around the GNSS antenna.
16. Ancillary equipment (solar panels, gear box, etc.) deployed around the antenna should be placed towards the nearest geographical pole (e.g., northern azimuth for an antenna in northern latitudes), to take advantage of a hole in the sky satellite coverage (35 degrees around the celestial pole) caused by the orbit inclination (55 degrees w.r.t. the equator).
17. An upright antenna (boresight facing zenith) works well for GNSS-R and can be shared with other applications.

18. Antennas with multipath mitigation technology (e.g., choke rings or resistive plane) work well for GNSS-R, as reflections off grazing incidence have similar direction of arrival and polarization compared to the direct propagation wave.
19. Intermittent campaigns are discouraged; continuously operating installations are to be preferred.
20. Disable tracking elevation mask, setting it to zero or even minus 5 degrees, as the low elevation angles are most useful for Reflectometry; furthermore, positioning applications can always apply a higher mask in post-processing.
21. Record other GNSS in addition to GPS if possible, such as GLONASS, etc.
22. Record modernized GPS signals (L2C, L5, L1C) in addition to legacy ones.
23. RINEX files should contain SNR observables, not just signal strength indicators, or else raw binary files should be kept.
24. Version 3 of the RINEX format is strongly recommended, as it stores separately the SNR of each GNSS signal (e.g., S2X vs. S2W or S1C vs. S1P) – version 2 allows only one SNR observable per carrier frequency.
25. Take photographs of the antenna surroundings, at least every 45 degrees in azimuth, as these will guide the definition of a valid reflection mask; consider taking stitched panoramic images or using the Dioptra app for photos annotated with azimuth/elevation information.

Further information:
- The horizontal distance to the specular reflection point is given by $H/\tan(e)$, in terms of the height of the antenna above the surface (H) and the satellite elevation angle (e).
- The reflection footprint may be approximated by the first Fresnel zone, an ellipse whose major and minor diameters depend on the carrier wavelength L (Larson & Nievinski, 2013; https://doi.org/10.1007/s10291-012-0259-7): $a = b/\sin(e)$, $b = (2HL/\sin(e) + L^2/\sin^2(e))^{0.5}$.
- Open source software for SNR-based GNSS-R is available from:
https://github.com/fgnievinski/mpsim
https://github.com/kristinemlarson

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