# Performance review of AK regional seismic network for 2019-2021 with focus on field site telemetry and power

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# 1. Background

As of December 2021, AK regional network comprises 250 active, real-time seismic sites (not including NetQuakes and non-seismic telemetry hubs). The network is spread over a wide geographic area presenting a challenge for designing and maintaining uniform infrastructure standards. Over the years we have been developing best practices for dealing with remoteness, weather, large animals, etc. As a result, the AK instrumentation network has a large variety of telemetry methods and power options (Table 1, Figures 1&2).

About a third of our sites are on host-provided AC power (most are in urban settings such as Fairbanks and Anchorage strong motion sites and a few other population centers), while the remainder are on remote power supported via combination of lead-acid (30% of sites) or lithium batteries (28% of sites) with solar charging. Solar charging is a challenge in northern latitudes, due to limited winter daylight, and coastal areas due to large amounts of snow (tens of feet at times). A limited number of sites also have supplemental wind turbines, but early data suggest these provide very little power compared to the solar input. Three sites with heaviest snow loads do not have solar panels and work on non-rechargeable batteries,which have to be replaced every one to two years. The remainder of sites are on host provided DC power (5%) or host solar power where AEC sites are co-located with UNAVCO or AVO facilities (4 sites or 2%, Figure 1).

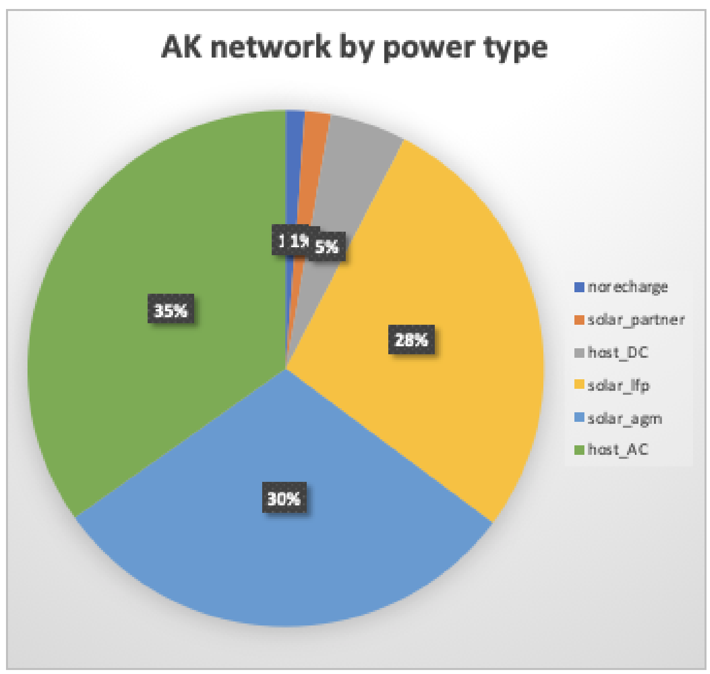



*Figure 1. AK network by site power type.*

Telemetry strategies for each site are based on the availability of existing commercial options, geographic setting and power system. Multiple methods may be involved for data leaving the site, reaching the intermediate hub and eventually arriving at our facilities in Fairbanks (Table 1, Figures 2&3). The majority of the sites use 900MHz, spread-spectrum radios to send the data out on the first leg (29%), however only four of these sites transmit the data directly to the Geophysical Institute. The rest of the radio sites are routed to data hubs, sometimes via multiple radio repeater links.

The next two largest groups of sites use either satellite communications via BGAN terminals (23%) or cell modems (15%) as the first data transmission leg (Figure 3a). We prefer cell modems over BGAN due to lower power consumption. However, cell networks in Alaska still have limited coverage. 12% of sites use the host organization's internet, which provides free internet access, but also requires unique networking strategies and extra coordination with external organizations. 6% of sites are on dedicated VSAT communications, 5% are on DSL lines, and 2% are on RBB (rural broadband). While each of these three latter categories are only a small percentage, in most cases they are the only viable option for those locations.

The remaining groups include 11 Alyeska sites which are on a dedicated T1 line that connects directly to the Geophysical Institute, eight 56K phone circuits sites that are being received directly at the UAF's Butrovich data center and data from 18 State of Alaska Telecommunications System (SATS) sites that are collected at our facility via a dedicated ACS data circuit.

Our field network communication hubs mostly use VSAT and cell communications and most are located in remote places with no other available options (Figure 3b).

With the exception of 56K, Alyeska, direct radio links and SATS (41 sites combined), data from the remaining sites (83%) travel the last leg to our acquisition facilities via public internet (Figure 3c).

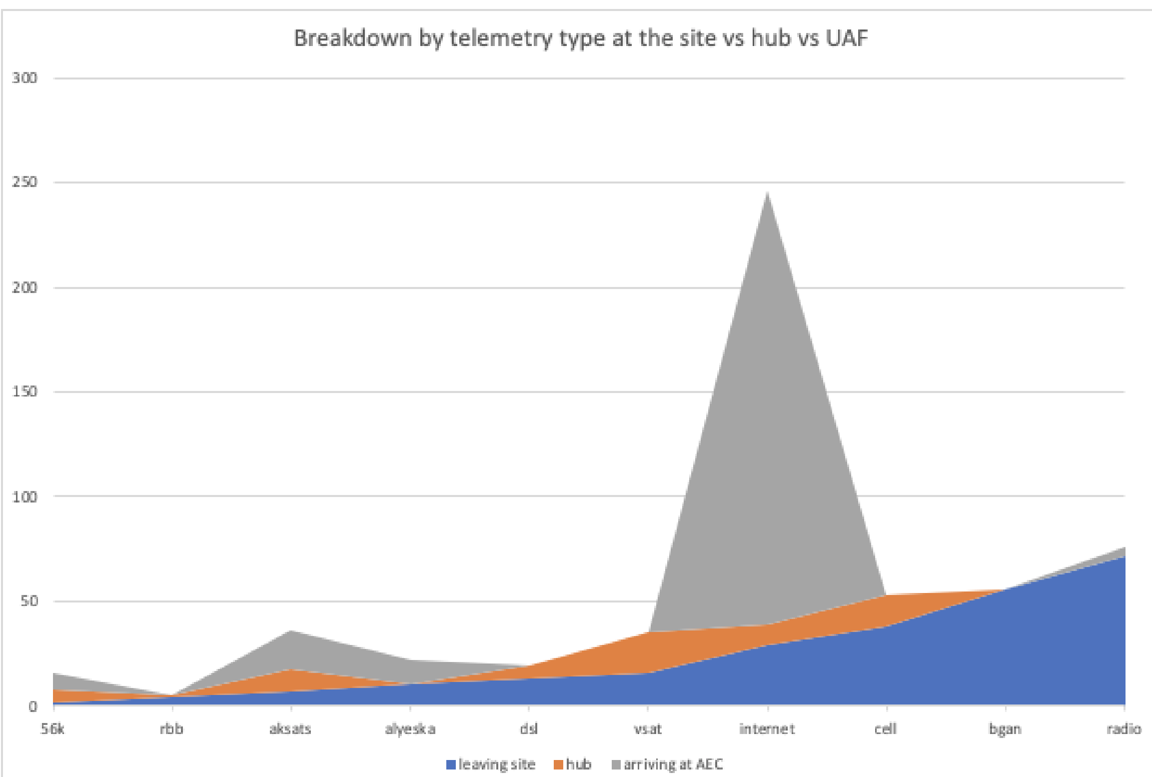
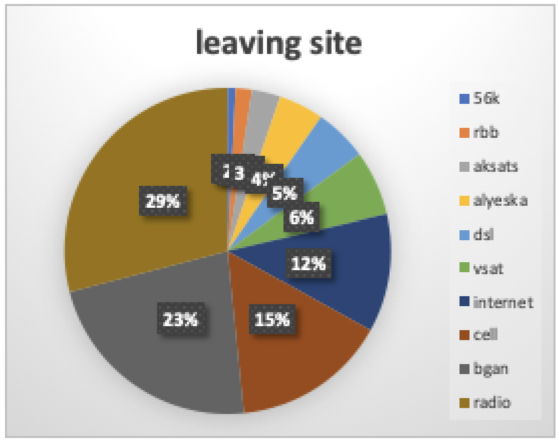



*Figure 2. AK network by telemetry type.*

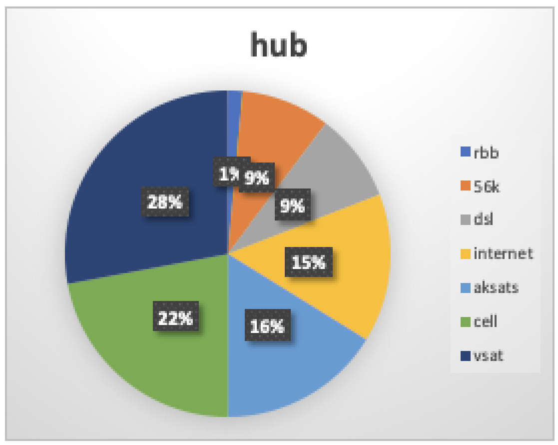
Table 1. AK network telemetry type at the site, at the hub, and arriving at the AEC facility.

| telemetry type | leaving site | hub | arriving at AEC | leaving site2 | hub2 | arriving at AEC2 |
|---|---|---|---|---|---|---|
| internet | | | 207 | | | 83% |
| 56k | 2 | 6 | 8 | 1% | 9% | 3% |
| rbb | 4 | 1 | 0 | 2% | | |
| aksats | 7 | 11 | 18 | 3% | 16% | 7% |
| alyeska | 11 | | 11 | 4% | | 4% |
| dsl | 13 | 6 | | 5% | 9% | |
| vsat | 16 | 19 | | 6% | 28% | |
| host | 29 | 10 | | 12% | 15% | |
| cell | 38 | 15 | | 15% | 22% | |
| bgan | 56 | | | 23% | | |
| radio | 72 | | 4 | 29% | | 2% |
| Total | 248 | 68 | 248 | | | |

(a)




(b)




(c)

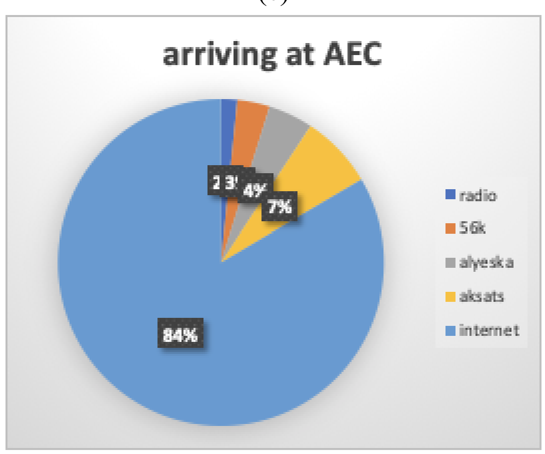



*Figure 3. AK network by telemetry: (a) leaving the site, (b) at the data hub, and (c) arriving at AEC.*

# 2. Analysis

We analyzed the time period between October 2019 and September 2021 for data completeness and acquisition latencies. For both metrics, we used ObsPy to read day-long segments of data for each station directly from our waveform archives. For the data completeness metric, we calculate a simple percentage by dividing the total number of samples at each station by the expected number of samples. For data latency, we utilize a peak finding algorithm to extract only the peaks in the data latency channel recorded by Q330 dataloggers (QDL). We do this because the QDL data increase linearly with time until a data packet is received at the AEC, indicating that a connection between the station and our servers has been made. This results in the QDL data having a sawtooth shape, but the important part of that data stream is when the data packet is received. After extracting the peaks, we calculated the mean, median, and max of the daily QDL peaks. For the figures in this report, we are showing results of the median metric because it best represents the usual behavior of the station for each day.

To organize our site telemetry analysis, we created a comprehensive table that, for each site, summarizes the telemetry methods, network manager organizations(s), internet gateway owner, type of power system, funding sources, and dependencies on other sites (e.g., dependency on a radio repeater or communications hub site). We could then import the table entries in the analysis scripts to quickly compare telemetry performance between the criteria listed above. Moving forward, we plan to continue to develop the summary table to include sensor housing environment (e.g. vault or borehole), sensor types, environmental factors, and other site characteristics that influence data quality and return.

We chose to concentrate on longer term trends and use six-month time periods to capture telemetry performance in the winter (October-March) and summer (April-September) or annual time periods to compare year performance from year to year. We did not investigate and attribute causes of specific outages or latencies, which could be due to issues at the site, repeaters, or data/internet hubs. Types of failures could involve site power problems, site and network communication device complications, or ancillary equipment malfunctions.

For data completeness analysis we classify performance into 4 categories: 0-49% (poor), 50-69% (intermediate), 70-89% (good), and 90-100% (excellent). ANSS standard for data completeness is defined as 90%. For data latencies we classify performance into 4 categories: <1 minute (excellent), 1 minute to 1 hour (great), 1 hour to 1 day (good), >1 day (poor).

## 2.1. Data completeness vs power type

Figure 4 shows a breakdown for each type of power into 4 performance categories (0-49%, 50-69%, 70-89%, and 90-100%) separately for 4 seasons (winter 2019-2020, summer 2020, winter 2020-2021, and summer 2021). Figure 5 shows combined data for the two winters and two summers for the worst performing group of sites (0-69%).

Not surprisingly, sites on host power, either AC or DC, consistently outperform other sites both in winter and summer seasons (Figure 4). On the other side of the spectrum, sites on solar and AGM battery power consistently underperform both in winter and summer time, these are traditional AK network sites.


*Figure 4. AK network performance by power type for (a) October 2019 - March 2020, (b) April 2020 - September 2020, (c) October 2020 - March 2021, and (d) April 2021 - September 2021. Data in each figure is sorted from best performers on the right to worst on the left.*

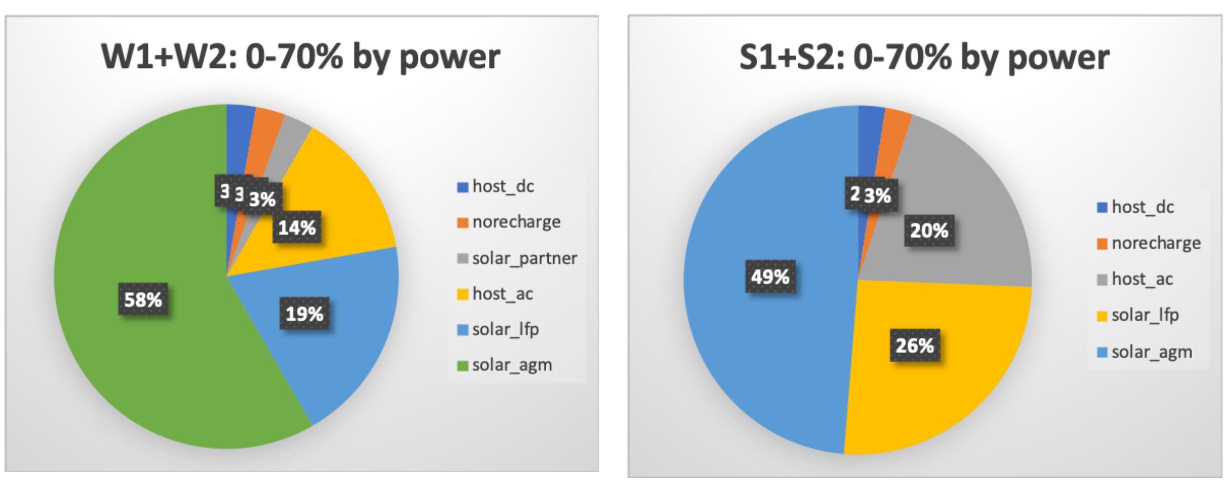



*Figure 5. Worst (0-70% data availability) performers by site power for winters 2019-2020 and 2020-2021 (left) and summers 2020 and 2021 (right).*

Sites on solar and LFP (lithium iron phosphate) battery power indicate more variability in performance between the two winters and in summer time. These are adopted USArray sites, most of which came under the AK umbrella in fall of 2020. Therefore, the majority solar_lfp sites in winter 1 were under IRIS maintenance at the time, but those adopted with the Southern Tier project in fall of 2019 were under AEC's maintenance. The LFP sites show significant improvement in data availability in summer time compared to winter months. This indicates that these sites have the capacity to recover almost fully and quickly with enough sunlight. Also, there is a somewhat significant difference in data availability for the sites between 2019-20 and 2020-21 winters with the 2nd winter performance being notably worse.

Sites on cell airs ("norecharge") are also in the group of underperformers, but since there are only 3 such sites even partial outage of one site would skew the statistics significantly.

Overall, three-quarters of the sites with poor and intermediate data return rates are on solar charging (Figure 5), with the sites on solar AGM being the largest contributor. However, often the communications for these sites are dependent on one or more repeater sites, which are also subject to power and telemetry failures, and so poor returns for the solar AGM sites are not necessarily due to power problems at the sites themselves. In addition, while host_ac and host_dc sites are also on the list of worst performers, most likely the culprit is not the power source but rather other factors, such as failed telecommunications.

## 2.2. Data completeness vs internet type

For analysis by telemetry type, we organize the categories by the internet connection method used at the communication hubs since the hub sites are where the most significant interruptions occur. Figure 6 shows the breakdown for each internet type into 4 performance categories (0-49%, 50-69%, 70-89%, and 90-100%) separately for 4 seasons (winter 2019-2020, summer 2020, winter 2020-2021, and summer 2021). Figure 7 shows combined data for the two winters and two summers for the worst performing group of sites (0-69%).

Not surprisingly, Alyeska sites rank consistently as the best performers for all evaluated time periods. The next best performance comes from the SATS sites. Both groups are on dedicated data paths that bypass the public internet.

BGAN sites show bi-modal performance degrading in winter time and significantly improving in summer time. This is related to undersized power systems that have to use power cycling in winter months, due to the lack of sunlight, and sometimes do not stay online for the entire winter season due to low battery voltage.

On the other side of the spectrum, the worst performing group are sites and hubs on VSAT systems. These account for third to half of underperformers (Figure 7) showing consistently poor performance in all seasons. Cell sites are the next largest group on the list of sites with poor and intermediate performance.

56K and RBB sites are consistently on the lower side of performance characteristics, but since both are small groups they tend to fluctuate a lot even due to short lived outages.

Sites on host internet are in the middle of the pack, not very bad but not super good either. These tend to be one-offs and at times difficult to troubleshoot due to unresponsiveness of the (human) hosts.

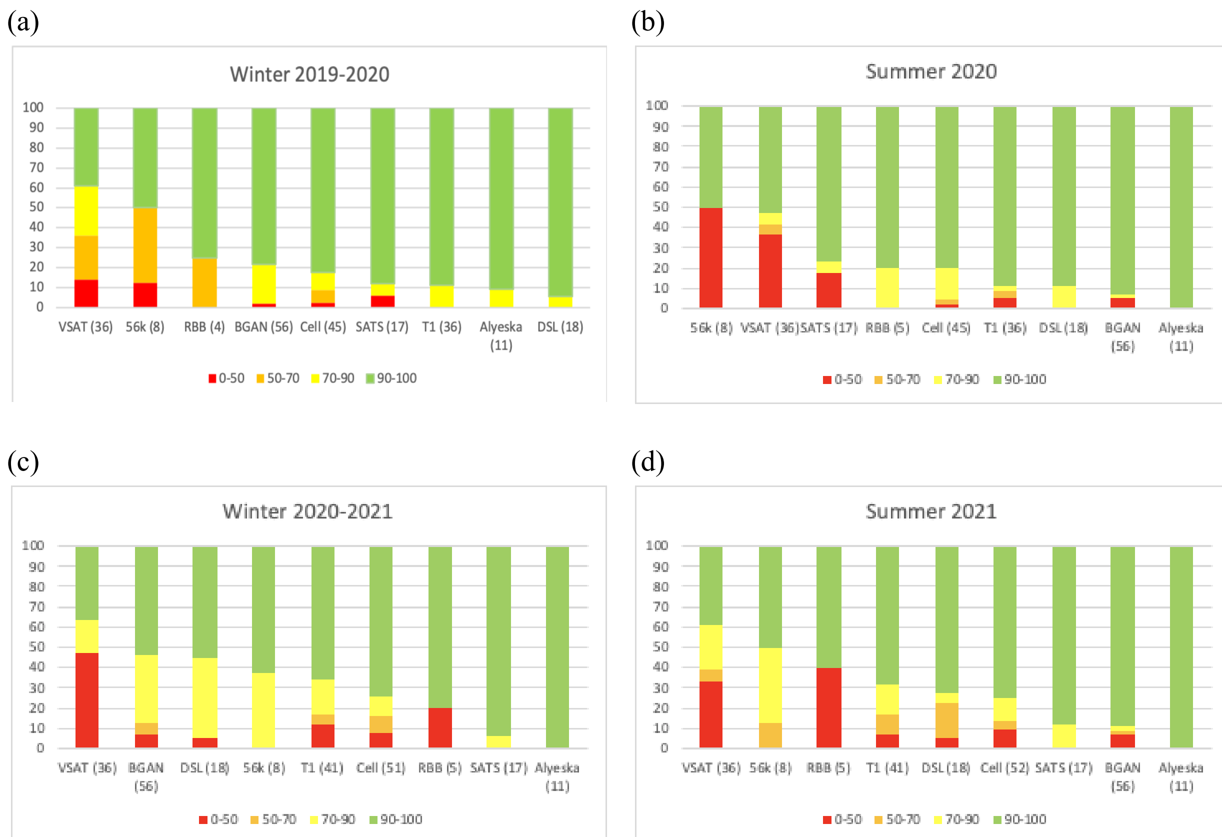



*Figure 6. Network performance by internet type at the data hub (a) October 2019 - March 2020, (b) April 2020 - September 2020, (c) October 2020 - March 2021, and (d) April 2021 - September 2021. Data in each figure is sorted from best performers on the right to worst on the left.*

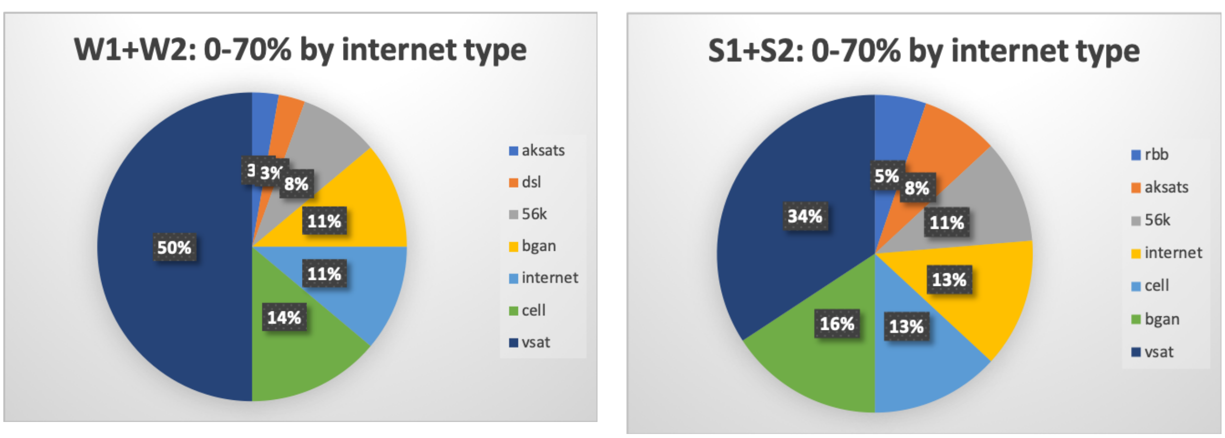



*Figure 7. Worst (0-70% data availability) performance by internet type at the data hub for 019-2020 and 2020-2021 (left) and summers 2020 and 2021 (right).*

## 2.3. Data latencies vs power type and internet type

Figure 8 shows a breakdown for each category of internet type and power into 4 performance categories (< 1 minute, 1 minute to 1 hour, 1 hour to 1 day, and > 1 day), divided into winter and summer seasons. Figure 9 shows combined data for the two winters and two summers for the best and worst performing group of sites by power. Figure 10 shows combined data for the two winters and two summers for the best and worst performing group of sites by internet type. Pie charts of all four performance categories for the winter and summer can be found in the appendix.

In the winter, the best performing sites by power type use locally hosted AC/DC power, and the worst performing sites are on solar power or batteries alone (Figure 8, right panel). This is certainly expected, as the lack of sun, particularly in the northern latitudes, prevents sufficient battery recharge. For the northernmost sites, the November/December time frame is when we take steps to mitigate these power issues by significantly increasing (up to 10 hours) the delay before a station attempts to send data packets back to the AEC. This is done in an attempt to preserve battery life by prioritizing data completeness over data latency, so we expect data latency to suffer at these sites in the winter.

In the summer, the best performing sites by power type are still the locally hosted power group (Figure 9). Solar powered stations with LFP batteries have significantly better latencies in the summer than in the winter, which reflects the intentional communication device power cycling used for the northern-most solar LFP sites. Solar powered stations with AGM batteries show similar performance in the summer and winter. Lastly, stations without solar power do not show significant differences in performance between the winter and summer seasons.

Unsurprisingly, the best performing sites by internet type are from the Alyeska group, with excellent performance in both winter and summer seasons. DSL and SATS stations also have excellent performance year round.

BGAN sites are the only telemetry method that shows significant differences between winter and summer seasons, with significantly better performance during the summer. BGAN sites account for 13% of our excellent performance sites in the summer, but 0% of our excellent performance sites in the winter (Figure 10). Similar to the LFP battery discussion above, the poorer winter performance of BGAN sites is related to the winter power cycling that's necessary to preserve the site power through the winter. At sites where the BGAN terminal is power cycled, the data is mostly recorded and buffered on site and then transmitted to our processing facility in bursts every 4-10 hours.

The 56K and VSAT sites are the other poorly performing groups, both in summer and winter seasons (Figure 8, left panel). Sites with VSAT internet type (either at the site or at the hub) are the largest segment of the poor performance group (Figure 10, left panel). The poor performance of VSAT sites in Alaska is a combination of the extremely low altitude angle of geosynchronous satellites which leaves much of Alaska at the fringe or outside of the satellites' official geographic coverage and high power consumption which often results in winter outages of these sites.

Cell modem sites are in the middle of the pack and represent a significant portion of both performance end groups, poor and excellent (Figure 10). This suggests that cell modems are not inherently bad performers and other factors may be at play, such as power systems or other network device failures, when the data transmission from those sites fails. Some of the poorly performing cell sites are at locations where we are forced to rely on 2G cell networks (the best available in the area) where harsh weather conditions regularly impact the quality of the cell signal or even cause the entire cell network in the region to go offline.

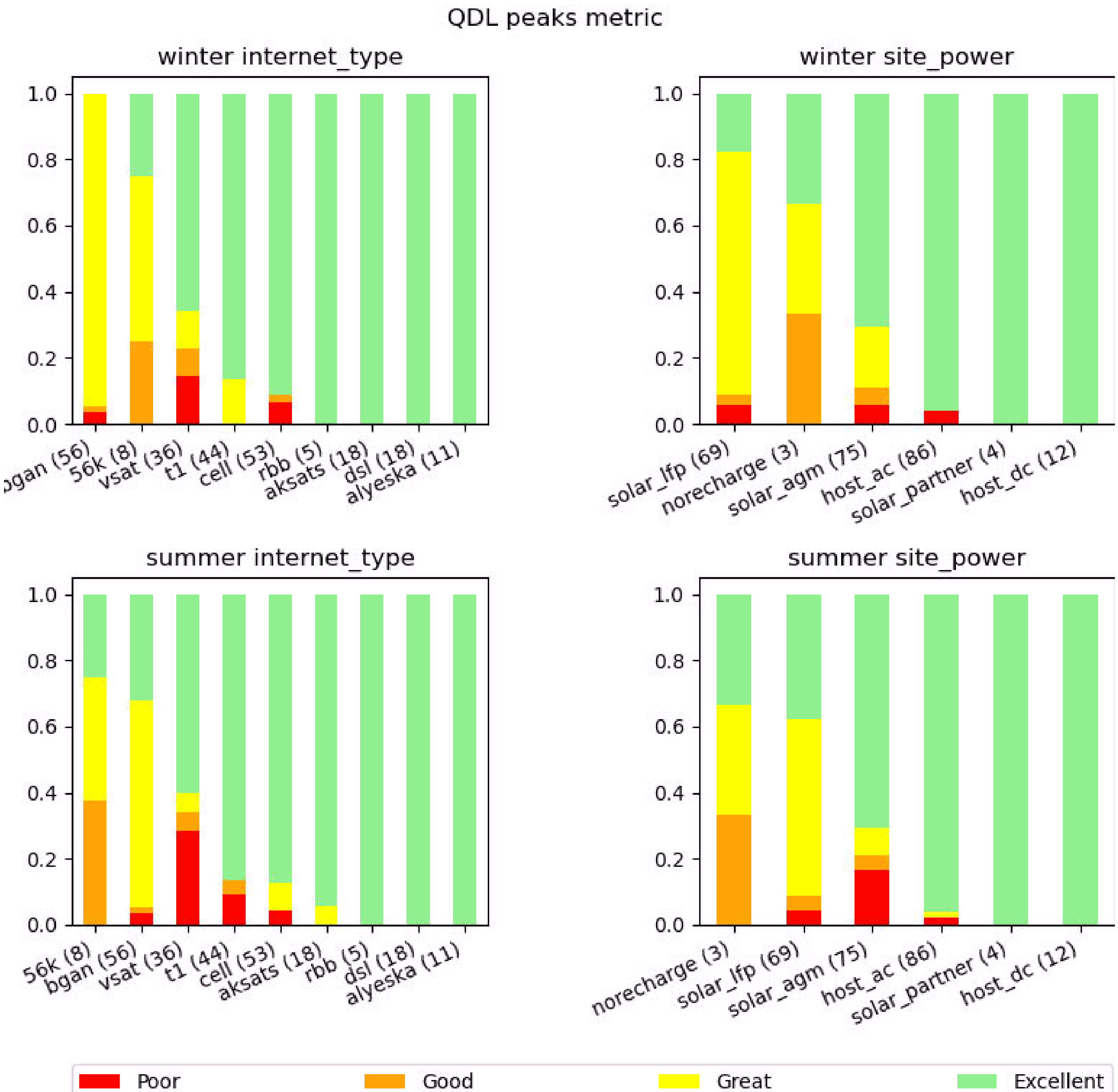



*Figure 8. Station latencies for winter (top) and summer (bottom) by internet type (left) and site power (right). Data in each figure is sorted from best performers on the right to worst on the left.*

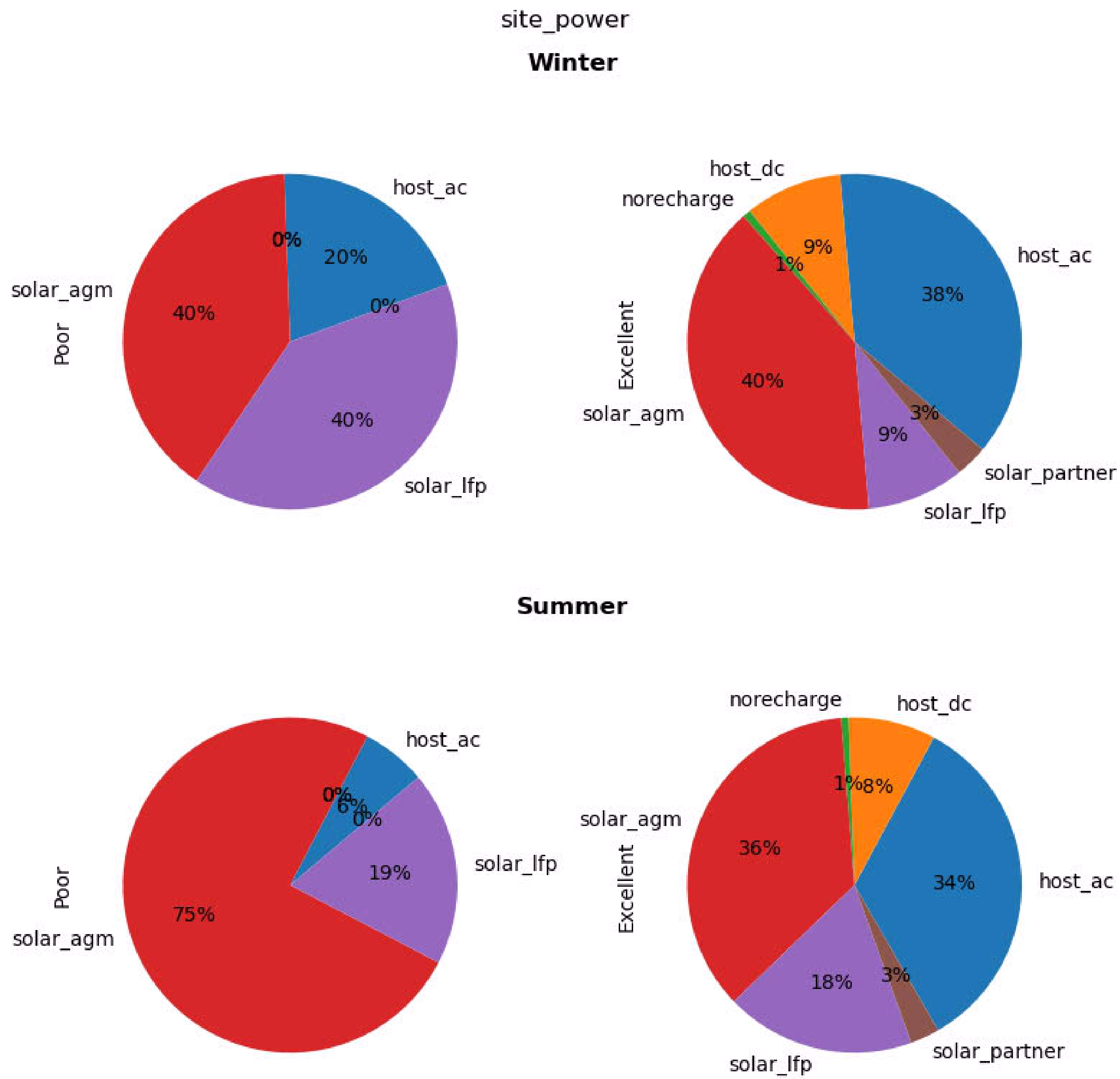



*Figure 9. Best (right ) and worst (left) performers in winter (top) and summer (bottom) by power type at the site.*

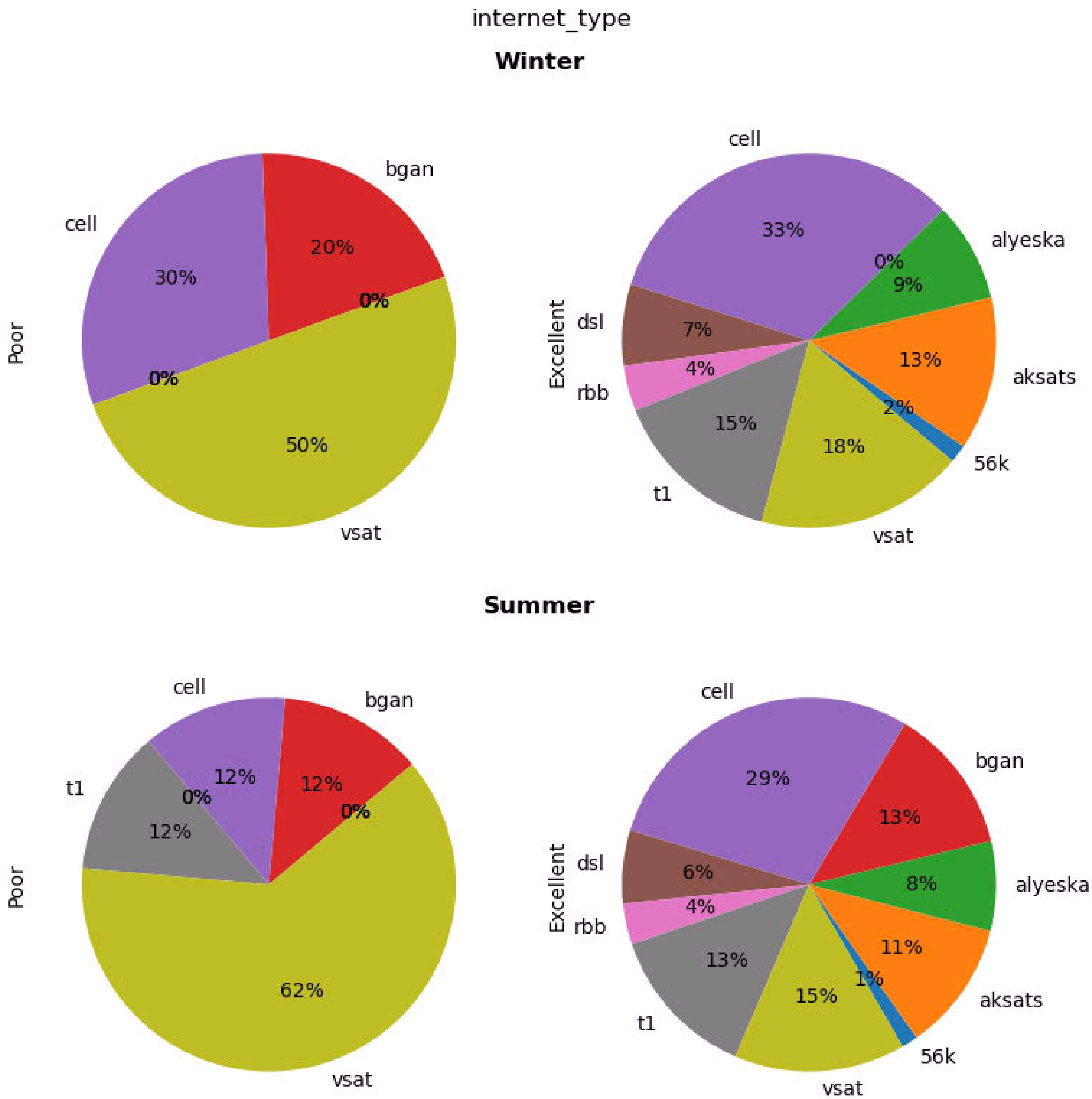



*Figure 10. Best (right ) and worst (left) performers in winter (top) and summer (bottom) by internet type at the data hub.*

## 2.5. Data completeness by project

We also evaluated data completeness by project. The projects are not equal to each other, with the number of sites under a project ranging from one station (Nikiski) to nearly 100 stations (ANSS). Some have standardized design requirements (Alyeska, AON) and some have a wide variety of equipment and design options (ANSS, Fairbanks and Anchorage Strong Motion networks). Despite the inconsistent number of stations in these groups, we found these to be worthwhile comparisons based on general similarities in the ages and configurations of sites in some projects.

Projects that have delivered over 90% of data over the course of the reporting period are: Nikiski, Greely, Alyeska, Fairbanks and Anchorage SM networks. Nearly all sites under these projects are on host-provided power and use either host internet, dedicated T1 line, or DLS and cell modems. These are the groups that have been identified as better performers in our analysis overall.

Projects that on average delivered less than 90% of data over the reporting period belong to ANSS, Southern Tier and AON projects. The common thread for these sites are solar power and a combination of telemetry options, with all of our BGAN and VSAT sites (the worst performing telemetry types) distributed amongst them.

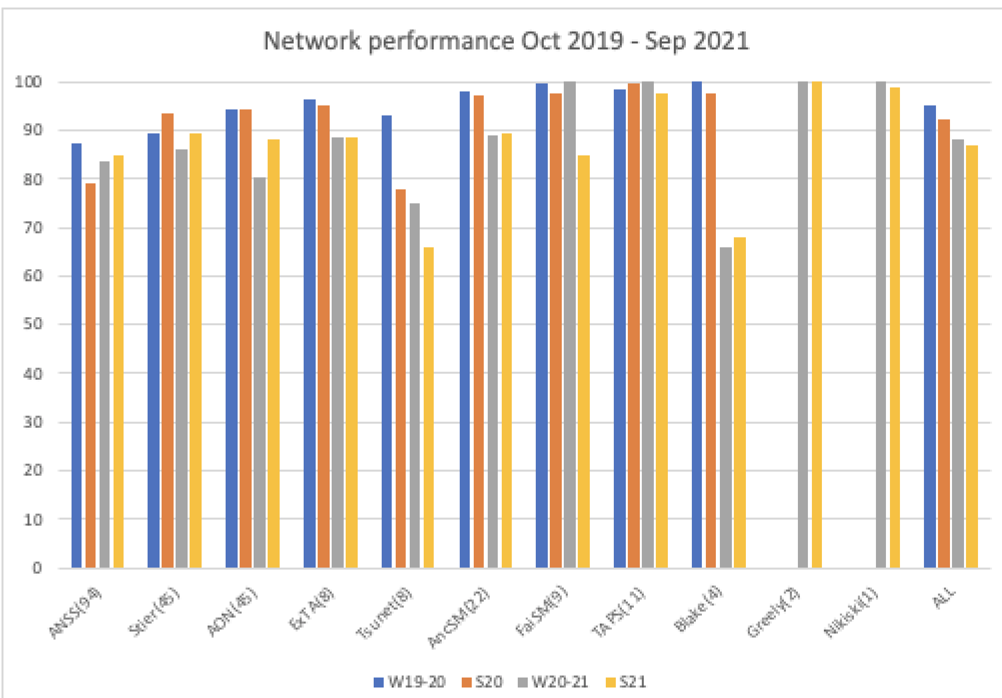



*Figure 11. Data completeness by project, divided into 4 seasons: W1 - October 2019 to March 2020, S1 - April to September 2020, W2 - October 2020 to March 2021, and S2 - April to September, 2021.*

# 3. Conclusions

We analyzed data completeness and acquisition latencies based on power type at the field site and internet type either at the site itself, if it is being acquired directly, or at its data hub. We concentrated on long term trends and seasonal variations rather than short-term daily or weekly changes.

The best performing sites by both metrics belong to the Alyeska and SATS groups, which are on host power and dedicated data acquisition paths not dependent on public internet options. Both groups are rather small and only constitute 7% of all sites.

As far as site power, unsurprisingly both AC and DC host options provide better data recovery and latencies regardless of the season. From the solar powered sites, both AGM and LFP based systems perform poorly in winter time, but LFP sites recover more quickly in summer months. This could be due to age of the sites (they are newer) or higher energy density of the batteries.

From the telemetry stand point, poorly performing VSAT systems contribute towards large data losses and latencies. This may be both due to technical challenges of poor signal strength in Alaska overall, dish mis-orientations, seasonal icing as well as high power consumption and undersized power systems.

BGAN sites are the only telemetry method that shows significant differences between winter and summer seasons, with significantly better performance during the summer. It is related to the winter power cycling of these sites that's necessary to preserve the site power through the winter.

Cell modem sites indicate variable performance, which may be attributed more to the other infrastructure problems and not inherently problems with the modems themselves, especially after we upgraded to the newer modem types.

# Appendix A

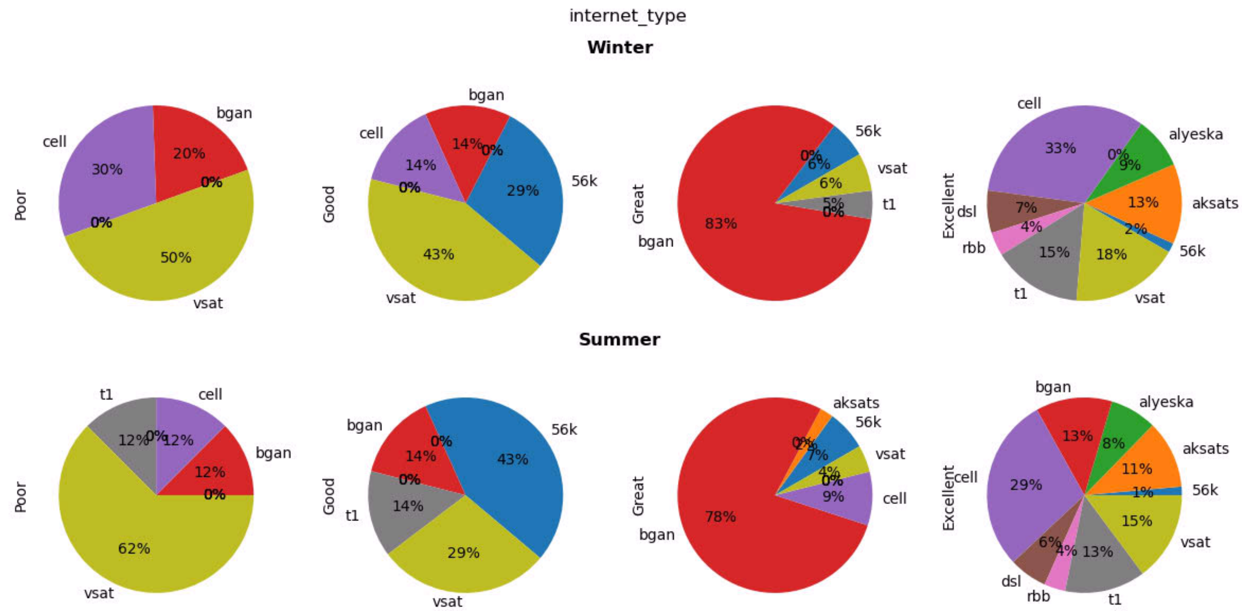



Figure A1. Pie charts for 4 performance categories by internet type at the hub: <1 minute (excellent), 1 minute to 1 hour (great), 1 hour to 1 day (good), >1 day (poor).

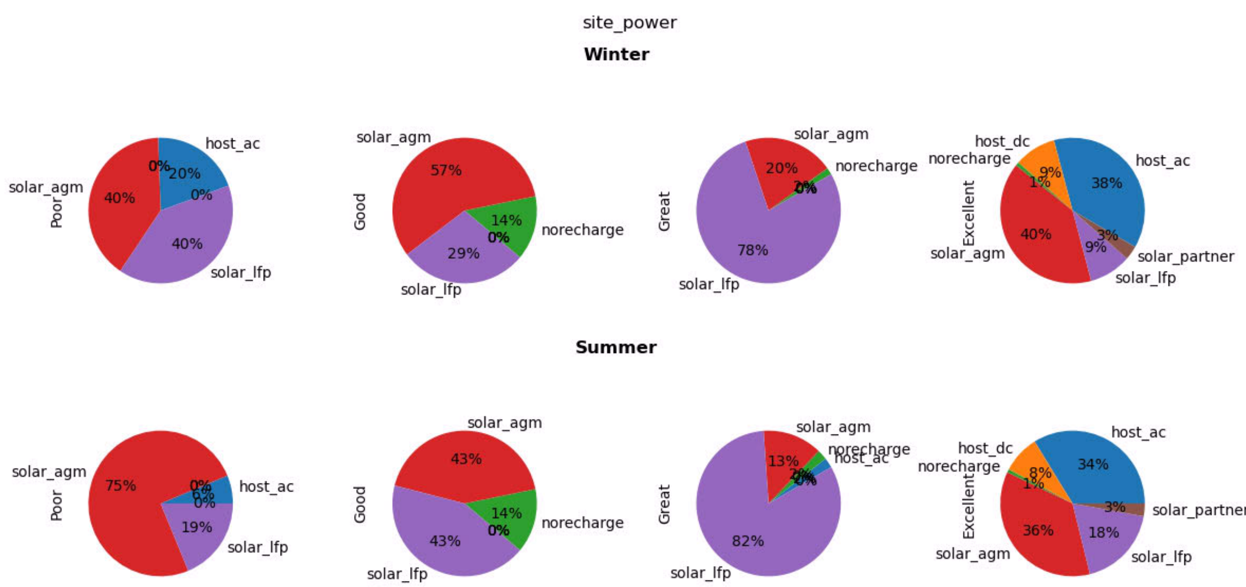



Figure A2. Pie charts for 4 performance categories by power type at the site: <1 minute (excellent), 1 minute to 1 hour (great), 1 hour to 1 day (good), >1 day (poor).