FCC License Application Technical Attachment

Revision History

Revision	Date	Description	Editor
A	6/3/22	Initial creation from HM material	PD, HM
B	9/16/22	Incorporation of beaconing mode and frequency updates from HM	PD, HM
C	10/20/22	Split copies from original to make separate versions that are for MuSat-1 and MuSat-2/3. MuSat-1 removed all HSR references and plots.	PD
D	11/7/22	Update to include Azure locations	PD. HM
E	11/18/22	Updated to removed references to Schedule S as MuSat-1 will be an experimental application. Added information about Azure in general description.	PD
F	1/6/23	Corrected S-band uplink EIRP values for Fairbanks, Quincy.	PD

Table of Contents

1 Scope

This Technical Appendix contains technical information regarding Muon's fleet of non-geostationary orbit (NGSO) satellites, as required by Section 25.114 and other sections of the Part 25 rules. The FCC Form 442, and this Technical Appendix should be used as the complete information package where limitations in the application forms require supplemental explanation in this document.

2 Description of Applicant

Muon Space Inc. ("Muon" or "Muon Space") is a Delaware C corporation headquartered in Mountain View, CA which provides satellite mission design, construction, and deployment services as well as space-based data and analytical products. Multi-modal space-based remote sensing data will be made available commercially for commercial, civil, non-profit, and government customers.

Construction of the proposed demonstration satellite, MuSat-1, and associated facilities has begun prior to the Commission's grant of an authorization. This is necessary given the nature of satellite construction and technical requirements over long lead times.

3 General Description of Overall Facilities

The promised demonstration satellite will consist of a space segment comprised of MuSat-1 and a ground segment comprised of commercially available Earth stations provided by Kongsberg Satellite Services ("KSAT") and Microsoft Azure and located in ten locations (five for each supplier) around the globe. Each satellite is designed to receive commands from a ground station and downlink the data collected by various demonstration sensors and stored onboard the satellite, as well as the telemetry data. The sensors for the mission will vary from mission to mission in order to assess the suitability of the sensors for on-orbit earth systems data collection.

The proposed Muon Space satellite will be three-axis stabilized using an on-board closed loop control system. The satellite is based on advanced technology that allows for small, lightweight and low-cost spacecraft. MuSat-1 will operate in independent, circular, sun-synchronous orbit.

The MuSat-1 is planned to be launched as a secondary payload on the SpaceX Falcon9 Transporter ride-share mission. MuSat-1 is scheduled to be launched in April or May of 2023 on Transporter 8. The orbital parameters of the transporter launch is described further in a table later in this document.

The data collected by the sensors onboard the satellites will be processed, stored and down linked to the appropriate earth station while the satellites are visible from that particular earth station site at a five degree elevation angle or higher. The storage capacity on board each satellite is 256GB.

For the telemetry, tracking and command ("TT&C") functions, the Muon Space satellites will receive command communications from gateway earth stations using the bands described in the Frequency Plan, which is authorized in the EESS subject to such conditions as may be applied on a case-by-case basis. The proposed ground segment will consist of several earth stations around the world, the antennas at which are described in the Earth Stations section. Command signals will be issued from the mission operations center in Mountain View, California, and uplinked to the satellites via the earth stations. Telemetry data from the satellites will be received at the earth stations and relayed to the Mountain View operations center.

4 Spacecraft Overview

The MuSat-1 satellite is a demonstration spacecraft with one primary goal: to demonstrate and validate the on-orbit performance of Muon Space's in-house avionics suite.

5 Operations and Services

5.1 Orbital Parameters

The following Table shows the orbital parameters for the MuSat-1 spacecraft.

Parameter	MuSat-1
Apogee	525-575 km[1]
Perigee	N/A - circular orbit
Inclination	97-98 (sun-synchronous)
Eccentricity	0 (circular)
Orbital Period	95 minutes
LTDN	13:00-15:00[2]
Orbital Type	NGSO

[1] Altitude of injection is determined by the launch vehicle provider
[2] Final LTDN determined by launch vehicle provider

5.2 Orbital Debris

Muon Space has conducted an Orbital Debris Assessment Report ("ODAR") for the MuSat-1 in compliance with NASA-STD-8719.14, Appendix A, which is attached as a

separate exhibit. As discussed in the submitted ODAR, the MuSat-1 spacecraft is compliant with all applicable orbital debris requirements as listed in Section 25.114(d)(14).

5.3 Earth Stations

The MuSat satellites will rely on several KSAT and Microsoft Azure earth stations for commanding, telemetry and payload data downlink. The characteristics of the earth station antennas are summarized in Table 11.1 below.

Table 11.1: Ground station antenna characteristics

Parameter	S-band	X-band
Reflector Size	2.8 m (KSAT) 6.1m (Azure)	2.8 m (KSAT) 6.1m (Azure)
Downlink Frequencies	N/A	8385 MHz, 8390 MHz
G/T (20° elevation)	N/A	25.7 dB (KSAT) 30 dB (Azure)
Polarization	RHCP (KSAT) RHCP/LHCP (Azure)	RHCP (KSAT) RHCP/LHCP (Azure)
Uplink frequency	2062.5 MHz 2067.5 MHz	N/A
EIRP	44.7 dBW (KSAT) 53.5 dBW (Azure)	N/A

Muon Space will initially be using ten ground stations around the globe, with others likely to be added in the future. The full list is provided in Table 11.2

Table 11.2: Earth station locations

Provider	Name	Type	Country	Coordinates (Lat, Lon, Elev)
KSAT	Inuvik	S and X bands TTC	Canada	68.325, -133.562, 62 m
	Fairbanks	S and X bands TTC	US	64.794 -147.536, 144 m
	Svalbard	S and X bands TTC	Norway	78.227, 15.417, 498 m
	Punta Arenas	S and X bands TTC	Chile	-52.933, -70.850, 22 m
	Hartebeesthoek	S and X bands TTC	South Africa	-25.889, 27.684, 1378 m
	Awarua	S and X bands TTC	New Zealand	-46.525, 168.381, 13 m
Azure	Quincy	S and X bands TTC	US	47.23944°, -119.8849°, 418 m
	Santiago	S and X bands TTC	Chile	33.95086°, -71.40294°, 143 m
	Gavle	S and X bands TTC	Sweden	60.63622°, 16.73886°, 89 m
	Johannesburg	S and X bands TTC	South Africa	-26.07508°, 28.27717, 1640 m
	Singapore	S and X bands TTC	Singapore	1.4000° , 103.840°, 28 m

6 Frequency plan

The satellites will carry data communications equipment to support Telemetry and Commanding operations (TTC).

The EESS S-band (2025-2110 MHz) is used for TTC commanding operations, while the EESS X-band (8025-8400 MHz) for TTC telemetry and Payload data downlinks.

TTC operations will be conducted from all of the five earth station sites listed in Section 11 below (Fairbanks, Svalbard, Inuvik, Punta Arenas, Hartebeesthoek and Awarua) and potentially others in the future. The specific commanding and telemetry channels are listed in FCC Form 442 and reproduced in Tables 3, 4, and 6 below for convenience.

The MuSat fleet includes a mode where whenever a spacecraft enters Safe Mode (due to an anomalous event) a short transmission burst with satellite status data is sent periodically, at a rate of about 1s of transmission activity every two minutes (< 1% of duty-cycle). This beaconing operation is not active in nominal satellite operation and is expected not to be a frequent occurrence, but can happen at any orbital location.

The transmission waveform parameters of the beacon are the same as the nominal TTC X-band downlink: same carrier frequencies, same power levels, and same bandwidths.
The beacon feature is one that can be disabled from mission control.

Mission operations are conducted from the Muon Space Mission Operations Center at its headquarters in Mountain View, California.

Details on the TTC frequencies and channels are provided in the Tables below:

Table 4.1: Spacecraft frequencies

Usage	Link Direction	Frequency (MHz)
Primary TTC Uplink	Earth-to-space	2062.5
Backup TTC Uplink	Earth-to-space	2067.5
Primary TTC Downlink	Space-to-Earth	8385.0
Backup TTC Downlink	Space-to-Earth	8390.0

6.1 S-band

The following tables list the S-band TTC uplink channels planned for the MuSat satellites. This information is also provided in the accompanying Form 442 but is also included here for reference.

Table 4.2: S-band TTC Uplink frequency plan

Channel ID	Bandwidth (MHz)	Center Frequency (MHz)	Polarization
TCU1 (Primary)	3.5	2062.5	RHCP
TCU2 (Secondary)	3.5	2067.5	RHCP

6.2 X-band

The following tables lists the TTC downlink channels planned for the MuSat-1 satellite. This information is also provided in the accompanying Form 442 but is included here for completeness.

Table 4.3: X-band TTC Downlink frequency plan

Channel ID	Bandwidth (MHz)	Center Frequency (MHz)	Polarization
TCD1 (primary)	3.5	8385.0 MHz	RHCP
TCD2 (secondary)	3.5	8390.0 MHz	RHCP

7 Frequency Tolerance

The frequency tolerance requirements of Section 25.202(e) that the carrier frequency of each space station transmitter be maintained within 0.002% of the reference frequency will be met (20 ppm).

The frequency tolerance specification for all MuSat emissions is expected to be better than 2 ppm.

8 Out of Band Emissions

The out-of-band emission limits of Section 47 CFR 25.202(f)(1), (2), and (3) will be met, as well as the limits specified by:

Recommendation ITU-R SM.1541-6 (08/2015): Unwanted emissions in the out-of-band domain (annex 2 and annex 5)
https://www.itu.int/dms_pubrec/itu-r/rec/sm/R-REC-SM.1541-6-201508-I!!PDF-E.pdf

Recommendation ITU-R SM.329-12 (09/2012): Unwanted emissions in the spurious domain
https://www.itu.int/dms_pubrec/itu-r/rec/sm/R-REC-SM.329-12-201209-I!!PDF-E.pdf

9 Cessation of Emissions

All downlink transmissions can be turned on and off by ground commands, thereby achieving cessation of emissions from the satellite, as required by Section 25.207 of the FCC rules.

10 Power Flux Density (PFD) Analysis

This section provides required PFD analyses for the target operational orbit of 550 km.

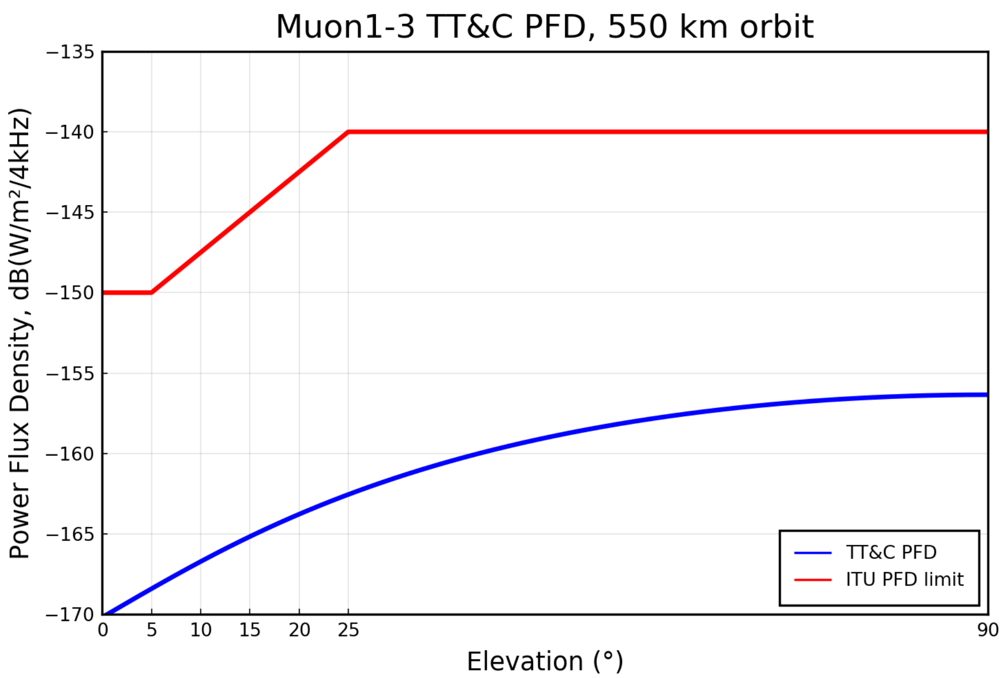
10.1 PFD at the surface of the Earth in the 8025-8400 MHz band

Table 21-4 of the ITU Radio Regulations establishes that the PFD at the Earth's surface produced by emissions from an EESS space station in the 8025–8400 MHz band, including emissions from a reflecting satellite, for all conditions and for all methods of modulation, must not exceed the following values:

- -150 dB(W/m²) in any 4 kHz band for angles of arrival between 0 and 5° above the horizontal plane;

- -150 + 0.5(δ – 5) dB(W/m²) in any 4 kHz band for angles of arrival δ (in degrees) between 5° and 25° above the horizontal plane; and
- -140 dB(W/m²) in any 4 kHz band for angles of arrival between 25° and 90° above the horizontal plane.

These limits relate to the PFD that would be obtained under free-space propagation conditions. As shown in Figure 8.1 below, the PFDs at the Earth's surface produced by the MuSat's data transmissions satisfy the PFD limits in the ITU Radio Regulations for all angles of arrival. In addition, the transmit power for all transmitters is adjustable on orbit in case any reduction of the PFD level becomes necessary.



10.2 PFD at the surface of the Earth in the 8400-8450 MHz Deep Space Research Band

Recommendation ITU-R SA-1157 specifies a maximum allowable interference power spectral flux-density level at the Earth's surface of -255.1 dB(W/m²/Hz) in the 8400–8450 MHz to protect ground receivers in the deep-space research band (DSN). MuSat-1 uses a combination of baseband digital filtering (root-raised cosine) and transmitter output bandpass and notch filtering to achieve the ITU recommended protection level for the 8400-8450 MHz band. Additionally, the

TTC channels with center frequency at 8385 and 8390 MHz are furthest away from the X-band DSN allocation, providing plenty of spacing for proper spectrum decay of the TTC channels.

10.3 PFD at the Geostationary Satellite Orbit in the 8025-8400 MHz Band

ITU Radio Regulation No. 22.5 specifies that in the 8025–8400 MHz frequency band, which the EESS using non-geostationary satellites shares with the fixed-satellite service (Earth-to-space), the maximum PFD produced at the geostationary satellite orbit (GSO) by any EESS space station shall not exceed -174 dB(W/m²) in any 4 kHz band.

The calculation below shows that the PFD produced by transmissions from the MuSat satellites does not exceed ITU limits even in a worst-case analysis.

The PFD at the GSO produced by the MuSat transmission is:

PFD [dB(W/m² / 4 kHz)] = EIRP [dBW] – 71 – 20log10(D) – 10log10(BW) – 24, where:

- EIRP is the maximum EIRP of the transmission, in dBW;
- D is distance between the MuSat satellite and the GSO, in km; and
- BW is the symbol bandwidth of the transmission, in MHz.

The minimum possible distance between a MuSat satellite and the GSO is 35,786 - 550 = 35,236 km.

Under a hypothetical assumption that the MuSat satellite antenna is radiating at its peak EIRP directly toward the GSO, the PFD and the geosynchronous orbit is:

- TTC PFD at the GSO:
  -2.0 dBW - 71 - 20log10(35,236) - 10log10(3.5) - 24 = -193.4 dB(W/m²/4 kHz)

11 X-band Interference Analysis

Interference between the MuSat satellite downlinks and those of other EESS systems is very infrequent because EESS systems operating in the 8025–8400 MHz band normally transmit only in short periods of time while visible from the dedicated receiving earth stations. For interference to happen, satellites belonging to different systems would have to travel through the antenna beam of the receiving earth station and transmit at the same time. In the event of a precise alignment, interference can be avoided by coordinating the satellite transmissions so that they do not occur simultaneously.

In addition, Muon Space will maintain coordination agreements with NASA that protect governmental space missions against harmful interference from operations of its MuSat constellations in this band. Muon Space also maintains coordination agreements for foreign earth stations if required by the responsible foreign administration or local authorized users of the frequency bands. MuSat will apprise NASA of this application and coordinate the proposed X-band operations.

Sections 10.1 and 10.3, above, demonstrate that the MuSat satellite transmissions will meet the limits specified by the ITU for protection of the Fixed Service in the 8025–8400 MHz band,

Section 10.2 above demonstrates that the protection criterion recommended by the ITU for deep-space research in the 8400-8450 MHz band is met.

12 Satellite Antennas

The space station antenna patterns are provided in Attachment A. The FCC Form 442 portion of this Application describes in detail the technical characteristics of the proposed beams. The following provides a summary of the proposed radio frequency parameters for each MuSat antenna.

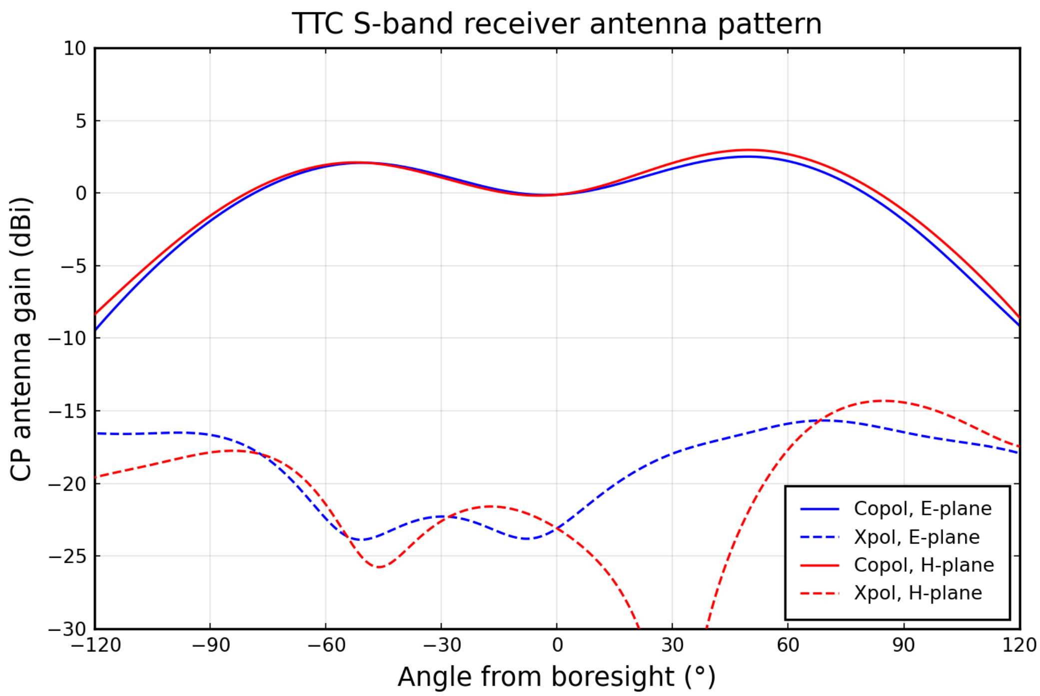
12.1 S-band TTC receiver antennas

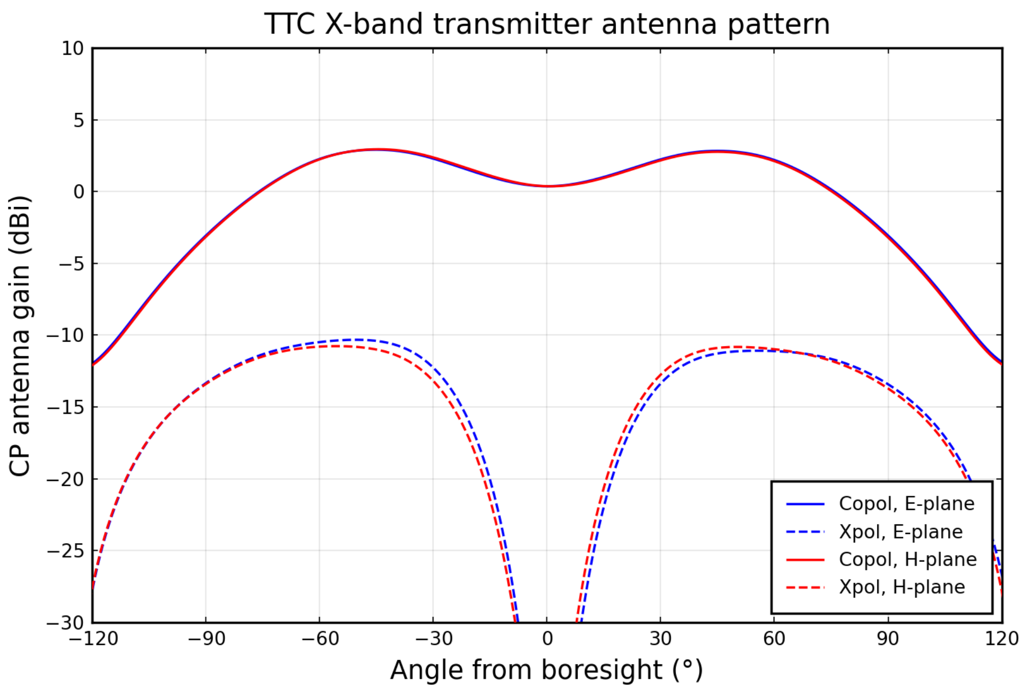
- Type: Quadrifilar Helical
- Frequency: 2025 – 2110 MHz
- Gain: 2.0 dBi, RHCP
- 3-dB beamwidth: 160°
- Location: On both nadir and zenith sides

12.2 X-band TTC transmitter antenna

- Type: Quadrifilar Helical
- Frequency: 8025 – 8400 MHz
- Gain: 2.0 dBi, RHCP
- 3-dB beamwidth: 160°
- Location: On both nadir and zenith sides

Attachment A
Space Station Antenna Radiation Patterns




TTC X-band transmitter antenna pattern
CP antenna gain (dBi)
Angle from boresight (°)
10
5
0
−5
−10
−15
−20
−25
−30
−120
−90
−60
−30
0
30
60
90
120
Copol, E-plane
Xpol, E-plane
Copol, H-plane
Xpol, H-plane

Attachment B
Predicted Gain Contours

Consistent with 47 C.F.R. § 25.114(c)(4)(vi)(B), below, Muon Space provides predicted antenna gain contours depicted on the surface of the earth at the anticipated initial earth station locations.

47 C.F.R. § 25.114(c)(4)(vi)(B): *For space stations in non-geostationary orbits, specify for each unique orbital plane the predicted antenna gain contour(s) for each transmit and receive antenna beam for one space station if all space stations are identical in the constellation. If individual space stations in the constellation have different antenna beam configurations, specify the predicted antenna gain contours for each transmit and receive beam for each space station type and orbit or orbital plane requested. The contours should be plotted on an area map with the beam depicted on the surface of the earth with the space stations' peak antenna gain pointed at nadir to a latitude and longitude within the proposed service area. The contour(s) should be plotted at 2 dB intervals down to 10 dB below the peak gain and at 5 dB intervals between 10 dB and 20 dB below the peak gain. For intersatellite links, specify the peak antenna gain and 3 dB beamwidth.*

The following are the contour plots for all antennas on the spacecraft:

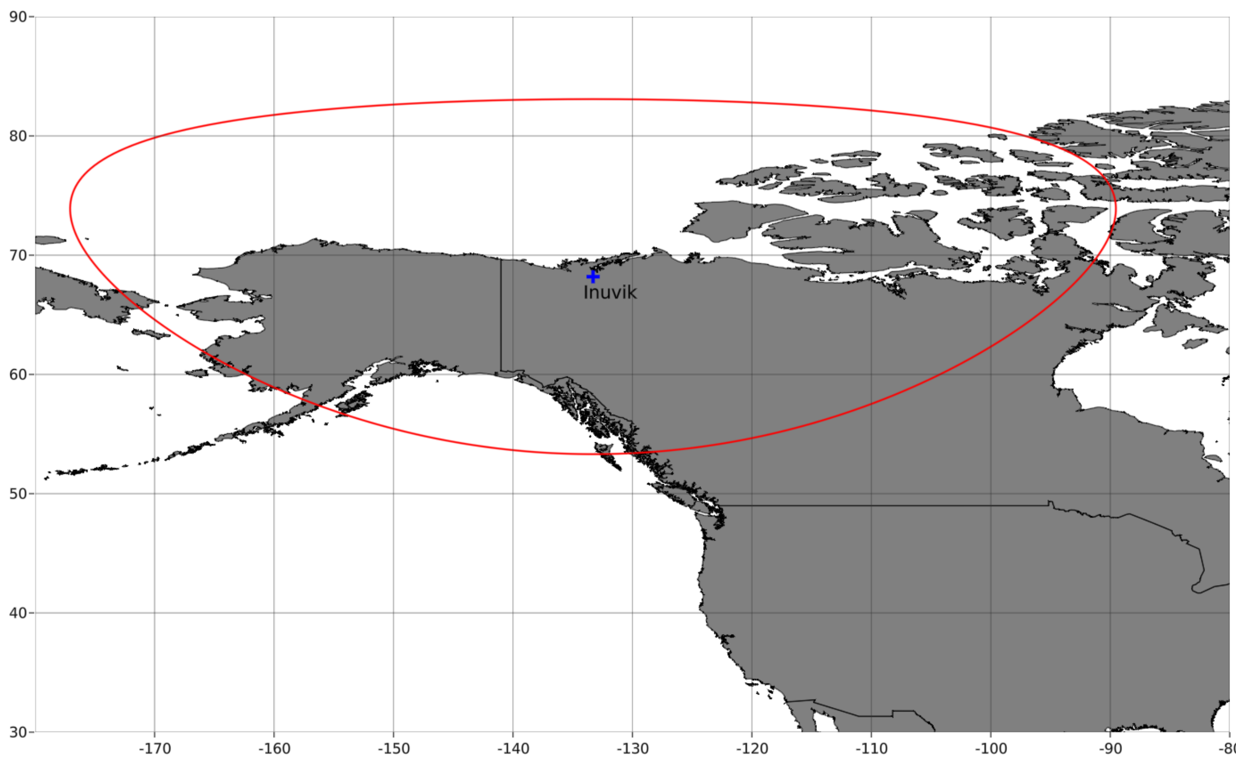
- TTC widebeam Tx and Rx antennas

Since the TTC widebeam antennas have a < 2dB gain variation in the visible region footprint, only that footprint is displayed (loci of Earth points with 0° elevation).

The axis ticks are numbered in degrees of Longitude and Latitude.

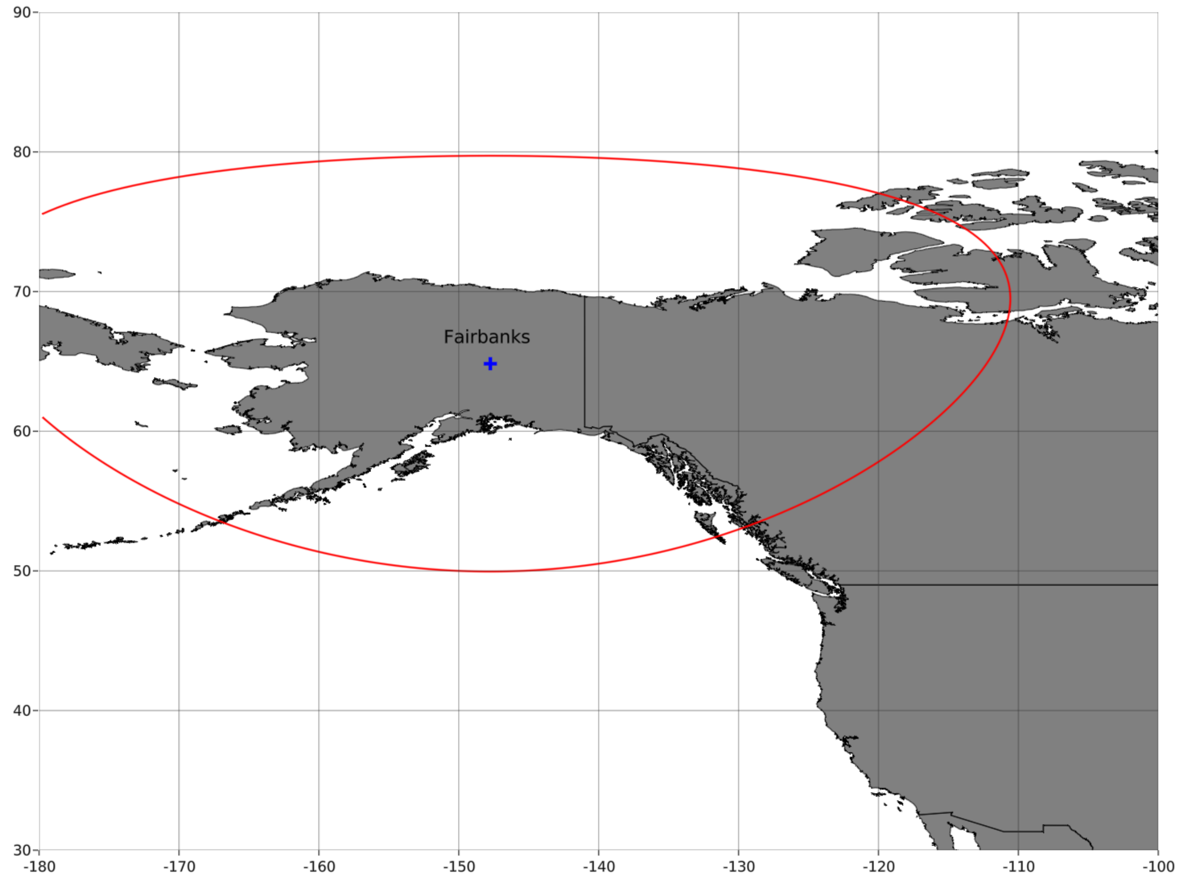
12.4 TTC Tx and Rx antenna footprints
Inuvik station at nadir

(visible footprint displayed since antenna gain variation < 2dB in that region)



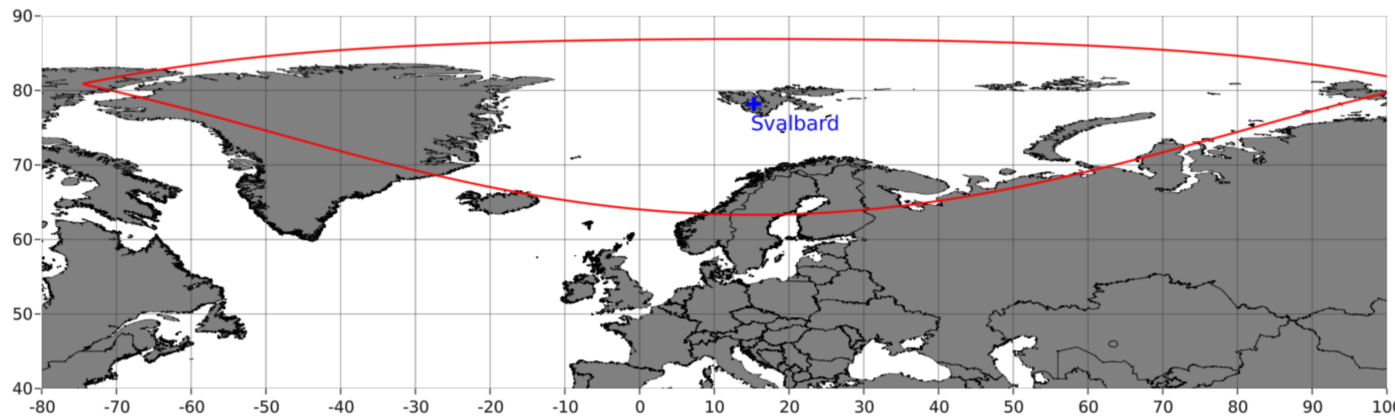
12.5 TTC Tx and Rx antenna footprints
Fairbanks station at nadir

(visible footprint displayed since antenna gain variation < 2dB in that region)



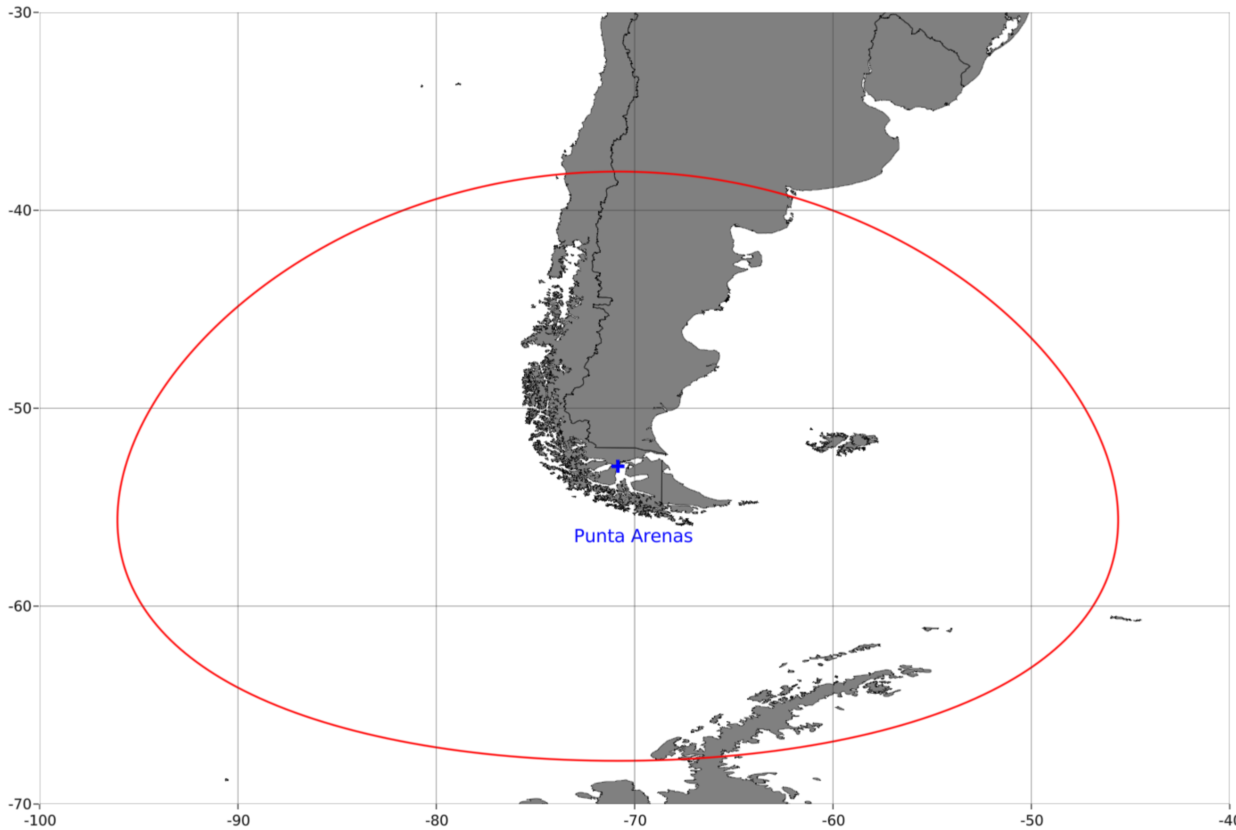
12.6 TTC Tx and Rx antenna footprints Svalbard station at nadir

(visible footprint displayed since antenna gain variation < 2dB in that region)



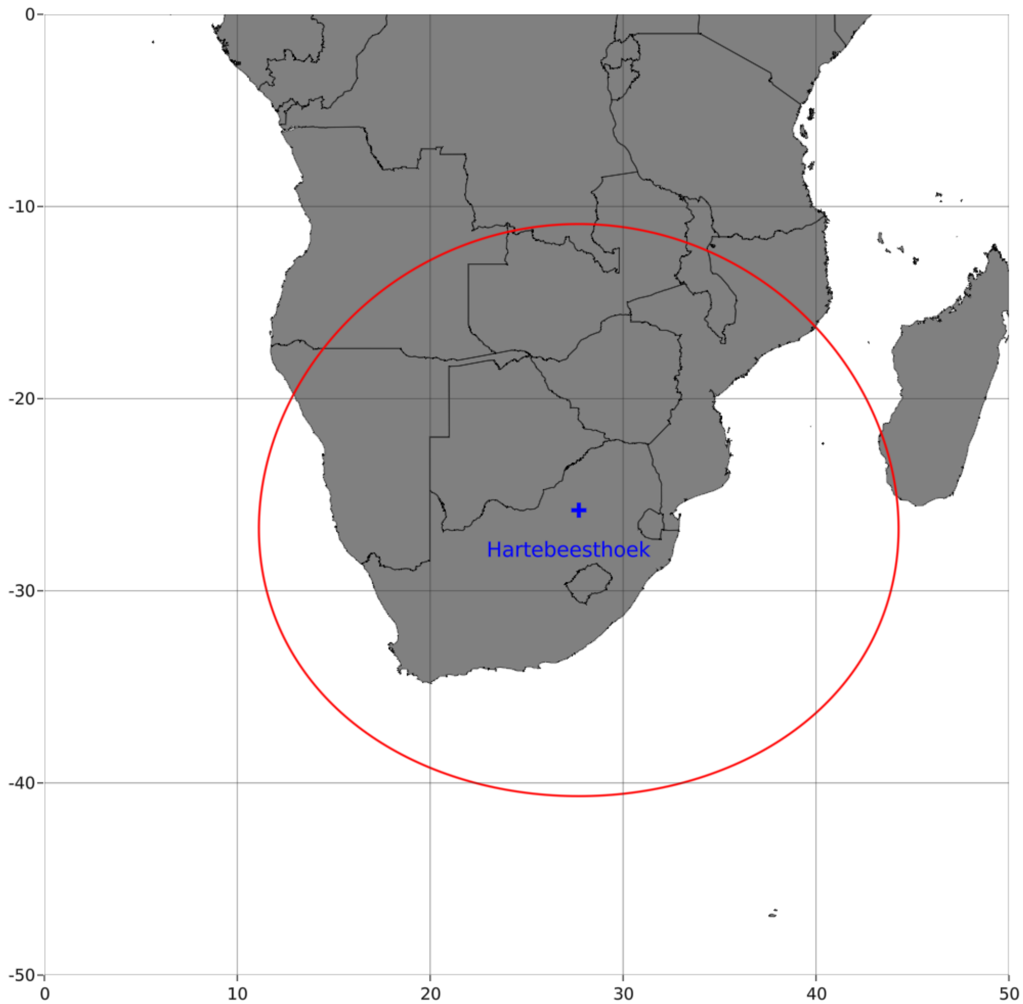
12.7 TTC Tx and Rx antenna footprints Punta Arenas station at nadir

(visible footprint displayed since antenna gain variation < 2dB in that region)



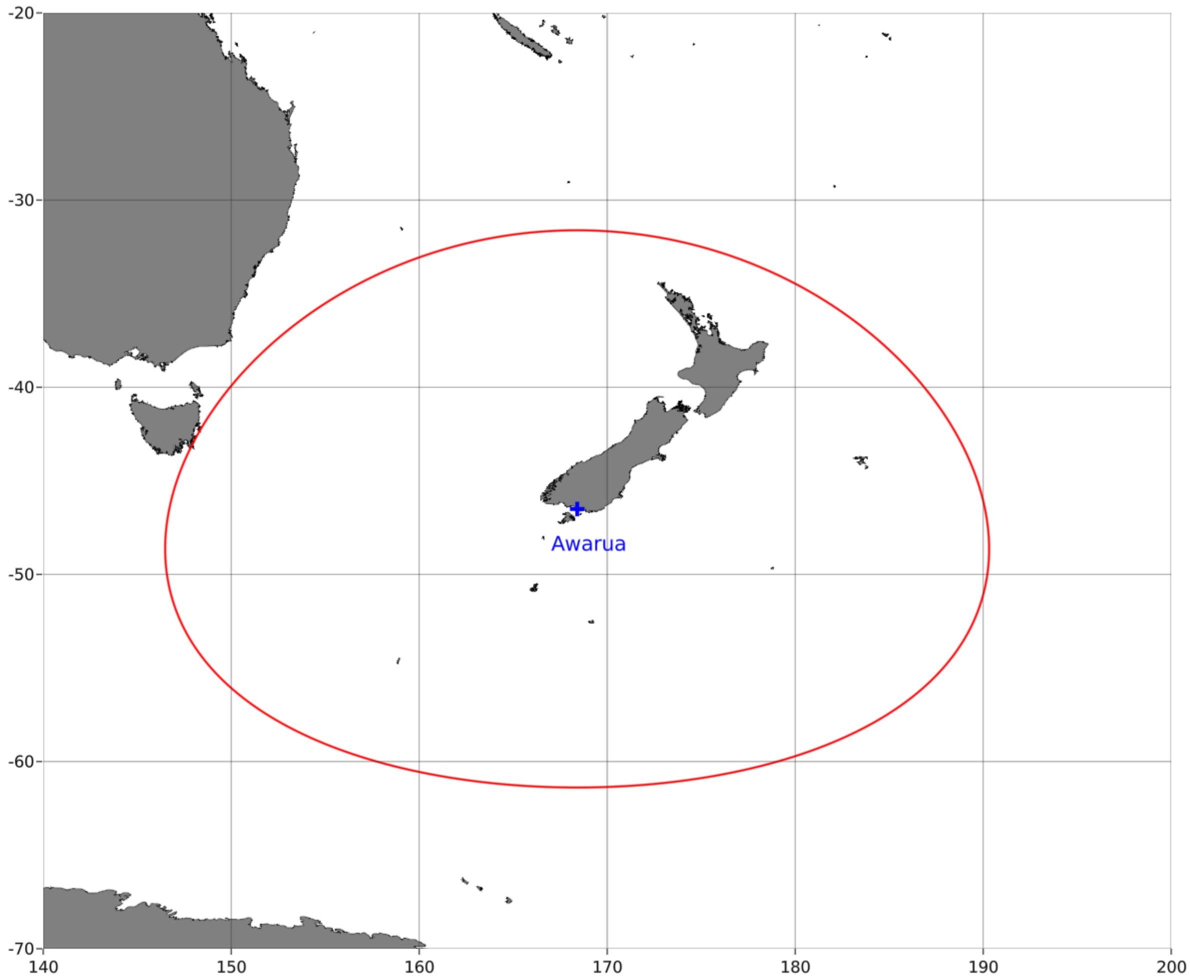
12.8 TTC Tx and Rx antenna footprints Hartebeesthoek station at nadir

(visible footprint displayed since antenna gain variation < 2dB in that region)



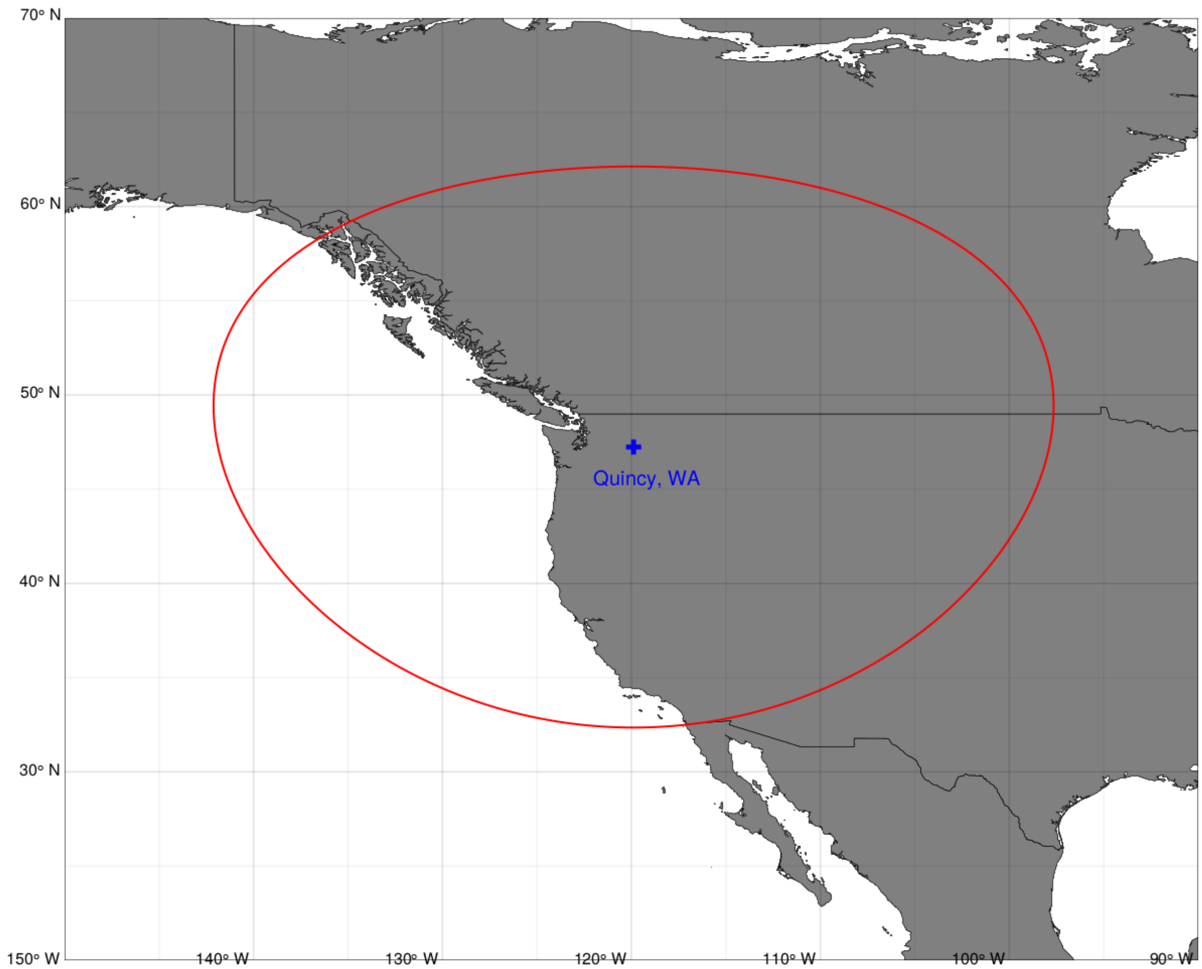
12.9 TTC Tx and Rx antenna footprints
Awarua station at nadir

(visible footprint displayed since antenna gain variation < 2dB in that region)



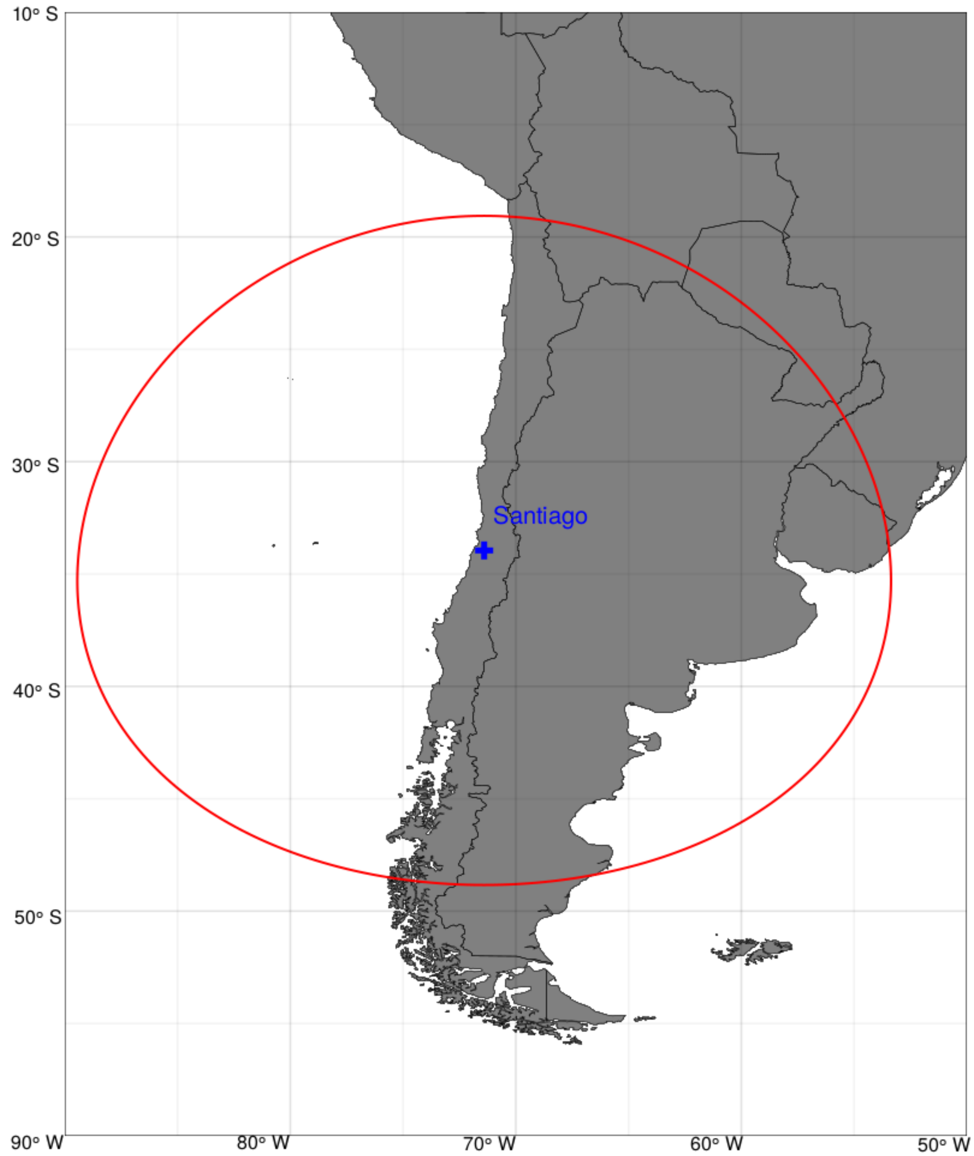
12.10 TTC Tx and Rx antenna footprints
Quincy station at nadir

(visible footprint displayed since antenna gain variation < 2dB in that region)



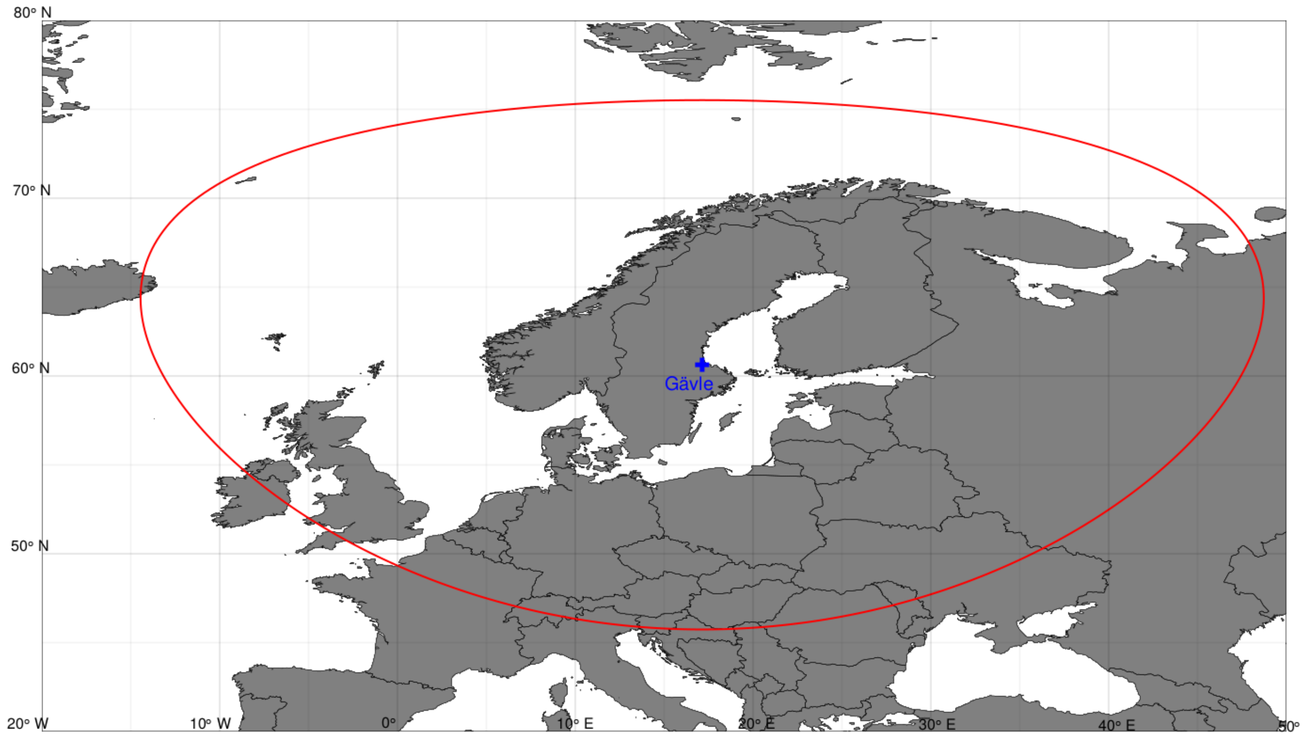
12.11 TTC Tx and Rx antenna footprints Santiago station at nadir

(visible footprint displayed since antenna gain variation < 2dB in that region)



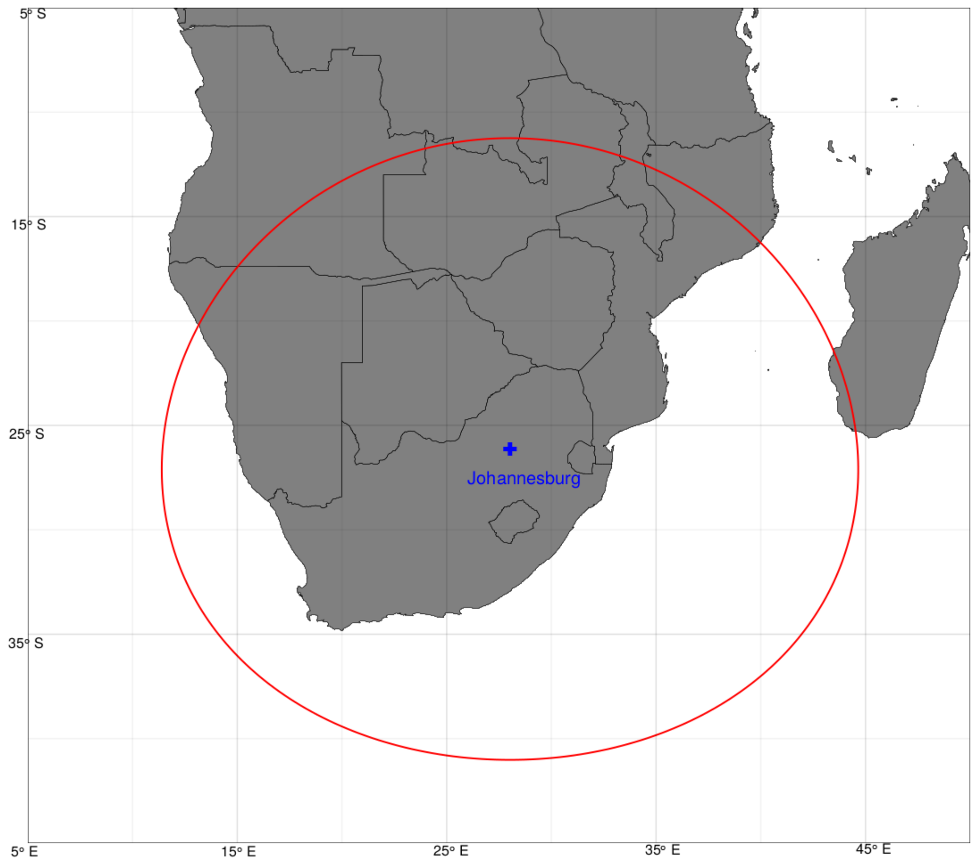
12.12 TTC Tx and Rx antenna footprints Gävle station at nadir

(visible footprint displayed since antenna gain variation < 2dB in that region)



12.13 TTC Tx and Rx antenna footprints Johannesburg station at nadir

(visible footprint displayed since antenna gain variation < 2dB in that region)



12.14 TTC Tx and Rx antenna footprints Singapore station at nadir

(visible footprint displayed since antenna gain variation < 2dB in that region)