Space Sciences & Engineering LLC (dba)

FCC Form 442 – Narrative Statement

Application for New or Modified Radio Station Under Part 5 of FCC Rules-

Experimental Radio Service (Other Than Broadcast)

Federal Communications Commission

445 12th Street, SW

Washington, DC 20554

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Acronyms

BCT	Blue Canyon Technologies
DAS	Debris Orbit Software
DSN	Deep Space Network
FDMA	Frequency Division Multiple Access
GNOMES	GNSS Navigation and Occultation Measurement Satellites
GNSS	Global Navigation Satellite System
ITU	International Telecommunication Union
JSPOC	Joint Space Operations Center
L1	1575.42 MHz
L2	1227.60 MHz
L5	1176.45 MHz
LEO	Low Earth Orbit
LTDN	Longitude of the Descending Node
ALB	Advanced Lightband
NWP	Numerical Weather Prediction
PFD	Power Flux Density
PSLV	Polar Satellite Launch Vehicle
RF	Radio Frequency
RO	Radio Occultation
SDR	Software-Defined Radio
SNR	Signal-to-Noise Ration
SSO	Sun-Synchronous Orbit
STK	Systems Toolkit (formerly Satellite Toolkit)
TT&C	Telemetry, Tracking, and Control

1 Narrative Statement

1.1 Introduction

Space Sciences & Engineering LLC (SSE), a subsidiary of Global Weather & Climate Solutions, Inc. and doing business as PlanetiQ, seeks authority to conduct Earth weather observation via Radio Occultation (RO) from a PlanetiQ experiment satellite and engage in market trials with the atmospheric data obtained from the experiment, as permitted under the Commission's rules.[1] Please reference the following summary:

GNOMES-1 satellite:
File No. 0011-EX-CN-2019
Granted Feb. 19, 2020
Call Sign: WK2XIU
Status: Non-operational / Satellite Bus and Payload never powered-on*

GNOMES-2 satellite:
File No. 0504-EX-CN-2020
Granted Nov 6, 2020
Call Sign: WL2XES
Status: Operational / Successful, currently on-orbit generating RO science data

*Due to the GNOMES-1 failure, the GNOMES-3 satellite will complement the GNOMES-2 satellite, in order to complete our experimental market trial efforts. The GNOMES-3 satellite build is nearly identical to GNOMES-1 and GNOMES-2; however, the different descending node time allows for more timely and comprehensive measurements of the ionosphere.

PlanetiQ plans to sell data products collected from the experimental spacecraft to government customers and a limited number (less than 100) interested commercial parties. Assessment of the market for the data products, including price and commercial interest, will inform our ability to launch and operate a commercial satellite system.

After successful demonstration of the GNOMES-2 and GNOMES-3 missions, PlanetiQ will seek an FCC Part 25 authorization for the PlanetiQ constellation of "GNSS Navigation and Occultation Measurement Satellites" (GNOMES).

GNOMES-3 will operate using the same frequency characteristics coordinated and approved for GNOMES-1 and GNOMES-2, as shown in Table 1.1-1.

Table 1.1-1. Desired frequency characteristics

	Frequency Band	**Center Frequency**	**Maximum Bandwidth**	**Data Rate**
Uplink	S-band	2.081 GHz	200 kHz	100 kbps
Downlink	X-band	8.260 GHz	20 MHz	10 Mbps

[1] 47 C.F.R. § 5.602; *see also infra* Section 1.3 (discussing the Air Force data contracts).

1.2 Background

PlanetiQ aims to significantly improve weather forecasting, numerical weather prediction (NWP) models, and space weather forecasts and analyses by dramatically increasing the number and quality of Global Navigational Satellite System (GNSS) occultations that are available to be assimilated. To achieve this vision, we have designed a new GNSS-RO instrument, Pyxis, which delivers the highest level of performance while flying on a microsatellite-style spacecraft. This approach enables a large number of satellites carrying state of the art instrumentation to be placed into and operate in low-Earth orbit (LEO) and will dramatically increase the combined quality and quantity of GNSS occultations assimilated in each NWP and space weather update cycle.

The GNOMES-3 spacecraft will carry a Pyxis instrument. GNOMES-3 will be launched into the following orbit:

LTAN / LTDN: 11:00 pm / 11:00 am (+/-15 mins)
Parking/transfer orbit range: Apogee: 500-600 km; Perigee: 500-600 km (+/- 20km)
Nominal operational case: Apogee: 650 km; Perigee: 650 km (+/- 20km)
Inclination: Sun-synchronous inclination: 97.5 degrees at launch, 98.0 degrees operational

The nominal orbit configuration is a sun-synchronous orbit (SSO) at 650 km altitude to provide pole to pole Earth coverage; however, the satellite design is capable of operation at other inclinations and altitudes. The satellite's solar panel delivers power sufficient to acquire all RO acquisition opportunities continuously and downlink at every opportunity to globally distributed commercial ground stations. The satellite carries a propulsion system to maintain altitude, optimal phasing between satellites, and accelerated de-orbit at end of mission.

1.3 Government Contract

With regard to Section 4 of FCC Form 442, this application is to be used to fulfill the following government contracts:

Government Project: GNSS-RO data buy under the BAA Commercial Weather Data Pilot-2, as a data supplier to ASTRA, to evaluate our on orbit high Signal to Noise data
Agency: U.S. Air Force
Contract Number: USAF BAA Contract # FA8730-19C-0044 (Subcontract number 242-01 to PlanetiQ)

2 Mission Description

2.1 Mission Expectations

On-board scheduling and orbit determination for the GNOMES-3 are performed by a navigation engine primarily using GPS observations (Galileo, if needed). The Pyxis science instrument onboard GNOMES-3 tracks dual-frequency signals from GPS, Galileo, GLONASS, and BeiDou GNSS satellites. [Note: Reference section 2.4.5 for additional information on foreign signals of opportunity] Pyxis tracks both rising and setting occultations to double the number of soundings (see Table 2.1-1 for the signal sources from each constellation). All signals collected are freely available to civil users. With our design for a future operational system, the

GNOMES aim to track with a 100% duty cycle, each and every orbit, as all operational weather satellites do.

Table 2.1-1. RO signal source for each constellation

	GPS	GLONASS	Galileo	BeiDou
1st frequency	L1C/A	L1OF	E1	B1C
2nd frequency	L2C	L2OF	E5b	B2a

GNOMES-3 is scheduled to launch as a rideshare through Space Exploration Technologies Corp. in Q1 2022. The initial injection orbit altitude is 525 km, with a nominal operational altitude of 650 km, as shown in Figure 2.1-1a. The final, operational constellation will consist of twenty GNOMES, in sun-synchronous or a combination of sun-synchronous and lower inclined orbits, shown in Figure 2.1-1b. A Part 25 authorization will be sought after at the appropriate time for the subsequent 18 GNOMES satellites.

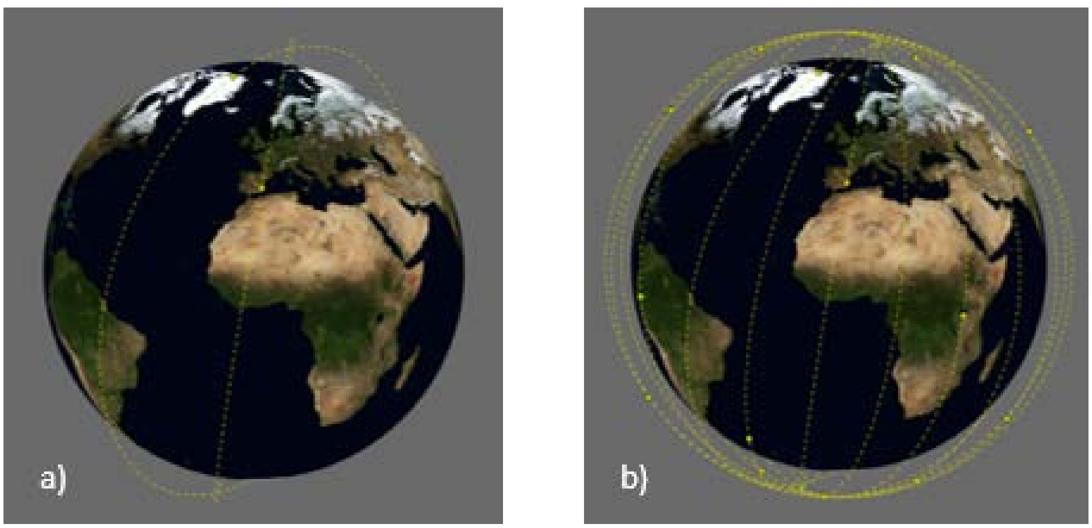

Figure 2.1-1. PlanetiQ satellite orbit configuration for a) the first two satellites registered under the Part 5 license and b) the final twenty-satellite constellation under the eventual Part 25 license(s)

2.2 Theory of Operations

To achieve global coverage for full atmospheric and ionospheric sampling, our target orbit for the GNOMES-2 spacecraft is at 650 km altitude. The spacecraft will be launched to an orbital plane dictated by the primary's launch characteristics: LDTN of 11:00 am, 525 km sun-synchronous. The on-board ion propulsion system allows for adjustments to altitude, inclination, and right ascension of the ascending node to diversify coverage and for station keeping. Further analysis of the possible orbital characteristics and their implications to de-orbit operations can be found in Exhibit A - Orbital Debris Assessment Report.

As GNOMES-3 is a secondary payload onboard the SpaceX Falcon 9, the injection altitude and inclination may not be equivalent to the planned final orbit. PlanetiQ plans to perform system commissioning and RO data collection at the injection altitude, then shift to its operational altitude at 650 km SSO. The commissioning period is expected to be less than 18 months. GNOMES-3 will perform altitude and inclination change maneuvers with its propulsion system for approximately four months to reach 650 km altitude, with periodic satellite telemetry check-ups during the orbit maneuvers. The satellite will resume data collection and transfer to the ground after the orbit transition. The satellite contains sufficient propulsion for orbit change, inclination adjustments, station keeping, and deorbit operations (details described in Exhibit A - Orbital Debris Assessment Report).

Table 2.2-1. shows the orbit lifetime of GNOMES-3 for injection and operational orbit scenarios. GNOMES-3 will carry propulsion to adjust to a 650 km circular orbit, and to allow for perigee lowering to accelerate deorbit by atmospheric reentry. The propulsion system on GNOMES-2 will carry heritage from the GNOMES-2 mission.

Table 2.2-1. Injection and operational orbit characteristics and planned mission lifetime. The orbital altitude and inclination will be maintained by the onboard propulsion system.

Mission	**Altitude (Perigee x Apogee)**	**Inclination**	**LTDN**	**Lifetime**
GNOMES-3	Injection: 525 km x 525 km	97.5°	11:00 am	<18 months
	Operational: 650 km x 650 km	98.0°		3 yrs.

Because data latency is vital for the value of the atmospheric measurements, frequent data downloads to the ground are necessary. Occultation observation data from GNOMES-3 will be downlinked via X-band radio at a nominal rate of 10 Mbps and maximum output power of 2.0 Watts. This data will be transmitted to globally distributed ground stations. Commands and software updates will be uplinked via S-band radio from a subset of ground-stations at a rate of 100 kbps.

Consistent with GNOMES-2 (0504-EX-CN-2020), PlanetiQ is applying for center frequencies of 8.260 GHz (downlink) and 2.081 GHz (uplink). GNOMES-3 will transmit in a single 20 MHz channel for downlink and another single 200 kHz channel for uplink. Telemetry, tracking and command (TT&C) will also be provided within those frequency bands.

The Pyxis-RO instruments are designed to receive the publicly available GNSS signals from the GPS (L1 at 1575.42 MHz and L2 at 1227.6 MHz), Galileo (E1 at 1575.42 and E5 at 1207.14 MHz), GLONASS (FDMA signals centered at L1 at 1602 MHz and L2 at 1246 MHz), and BeiDou (B1 at 1575.42 MHz and B2 at 1207.14 MHz) constellations, as shown previously in Table 2.1-1. Dual-frequency measurements from each occulting satellite are necessary to resolve the ionospheric contribution to the signal path delay. Additionally, the reception of multiple GNSS signals will allow PlanetiQ to cross-check and validate the accuracy of its data observations.

Observations of GNSS signal Doppler frequency and carrier phase amplitude will be collected and stored on-board before periodic transfer to the ground for further processing. Linking the observations to post-processed orbital geometry information will identify the bending angle unique to each occultation event, which is then translated to a vertical refractivity profile at a given location. The use of post-processed orbits also ensures that the weather products are not derived from spoofed or inaccurate signals, especially from the foreign GNSS satellites. Further discussion of reception of foreign GNSS signals is found in Section 2.4.5.

2.3 Spacecraft Description

The GNOMES are a microsatellite-style satellite that are installed on the Planetary Systems Corporation's 8-inch Advanced Lightband (ALB) separation system for launch[2]. See Figure 2.3-1 for a conceptual drawing of the satellite's deployed configuration. Once separated from the launch vehicle, the satellite will deploy the solar panel and specialized Pyxis-RO antennas. The spacecraft are three-axis stabilized and nadir following.

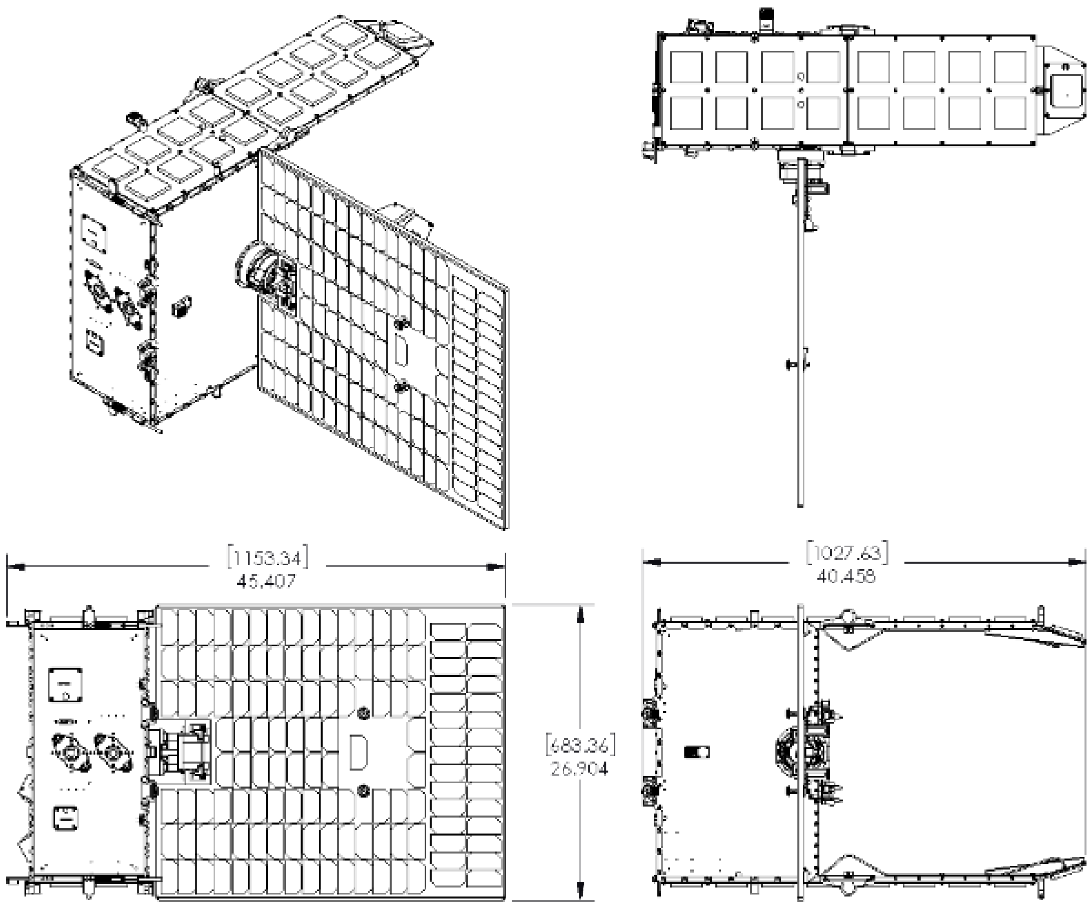

Figure 2.3-1. The GNOMES spacecraft in its deployed state

The on-board ion propulsion system will allow for precise orbit insertion after launch vehicle separation, with sufficient fuel to lower the satellite perigee and accelerate de-orbit after end of mission. Further description of re-entry disposal, orbital debris mitigation plan, and

[2] Further information on the ALB can be found at http://www.planetarysystemscorp.com/product/advanced-lightband/

specialized thruster can be found in a separate exhibit: Exhibit A - Orbital Debris Assessment Report[3].

2.4 Data Transfer

2.4.1 Space Stations

GNOMES-3 will carry a single X-band transmitter to downlink data and conduct telemetry, tracking, and command (space-to-Earth). This transmitter is the SDR-X model supplied by Blue Canyon Technologies (BCT), with transmission characteristics described by Table 2.4-1 and in Form 442.

Table 2.4-1. BCT SDR-X X-band transmitter description

	Non-geostationary
Action frequency	8.260 GHz
Maximum output power	2.0 W
ERP	3.85 W
Mean/Peak	Peak
Frequency Tolerance	4 ppm
Emission Designator	20M0G1D
Modulating signal	10000000 baud OQPSK

The X-band and S-band antennas are designed and supplied by Haigh-Farr Inc. Both are nearly hemispherical in their gain patterns and are nadir-pointed. For both antennas, the gain is generally constant and varies between 0 and 5 dBi over Earth coverage angles.

A link budget can be formed from the transmitter characteristics shown in Table 2.4-1 and the expected X-band antenna coverage. The power flux density (PFD) at the maximum gain (5 dB) is calculated to be -119.2 dB(W/m^2) over the total bandwidth of the transmitter at the injection altitude of 525 km and -120.5 dB(W/m^2) at the nominal operational altitude of 650 km. Therefore, the largest PFD resulting from the X-band transmitter on GNOMES-3 will be -132.3 dB(W/m^2·MHz) at the sub-satellite point from 650 km, a value that is well below the recommendation given by the ITU[4].

The ITU also recommends the following limits of PFD from space stations as received at the Earth's surface[5]. These limits relate to the PFD obtained only under free-space path loss conditions and a 4 kHz bandwidth.

[3] Information regarding the on-orbit performance of the propulsion system is found in: Krejci, David & Reissner, Alexander & Seifert, Bernhard & Jelem, David & Hörbe, Thomas & Friedhoff, Pete & Lai, Steve. (2018). DEMONSTRATION OF THE IFM NANO FEEP THRUSTER IN LOW EARTH ORBIT.
[4] Rec. ITU-R SA.1810
[5] ITU Radio Regulations Table 21-4

Table 2.4-2. ITU PFD limits at the Earth's surface

Frequency band	Service	Limit in dB(W/m²) for angles of arrival (δ) above the horizontal plane			Reference bandwidth
		0°-5°	5°-25°	25°-90°	
8025-8500 MHz	Earth exploration satellite (space-to-Earth) Space research (space-to-Earth)	-150	-150 + 0.5(δ-5)	-140	4 kHz

Table 2.4-3 GNOMES-2 Peak Power Flux Density from 650km to Earth, and from 650km to GSO (if pointing up, vs. pointing to the Earth).

	650km to Earth	**650km to GSO**
Peak Power Density/Hz	1.925E-07W/Hz	1.925E-07W/Hz
Peak Power Density/4kHz	0.00077W/4kHz	0.00077W/4kHz
Peak Power Flux Density (4kHz)	-158.4 dBW/m**2	-193.05 dBW/m**2
Peak Power Flux Density (20MHz bandwidth)	-121.6 dBW/m**2	-156.06dBW/m**2

Note: Reference Appendix 1 for equations and data used

The PFD produced by GNOMES-3 satisfies the ITU PFD limits at all angles of arrival and possible altitudes, with over 10 dB of margin. In addition, the BCT X-band radio is adjustable on orbit, allowing PlanetiQ to control the PFD levels during all phases of the mission.

Finally, the ITU specifies a maximum allowable interference power spectral flux-density at Earth's surface of -255.1 dB(W/m^2·Hz) to protect earth-station receivers in the deep-space research band of 8.40-8.45 GHz[6]. The chosen data rate and center frequency for the X-band transmission on GNOMES-3 should guarantee that no close-in side lobes are within the deep space band. Additionally, the chosen ground stations, described in Section 2.4.2, are sufficiently far from Deep Space Network (DSN) stations that GNOMES-3 can avoid downlink operations while within sight of a DSN station (see Figure 2.4-2).

[6] ITU-R SA-1157

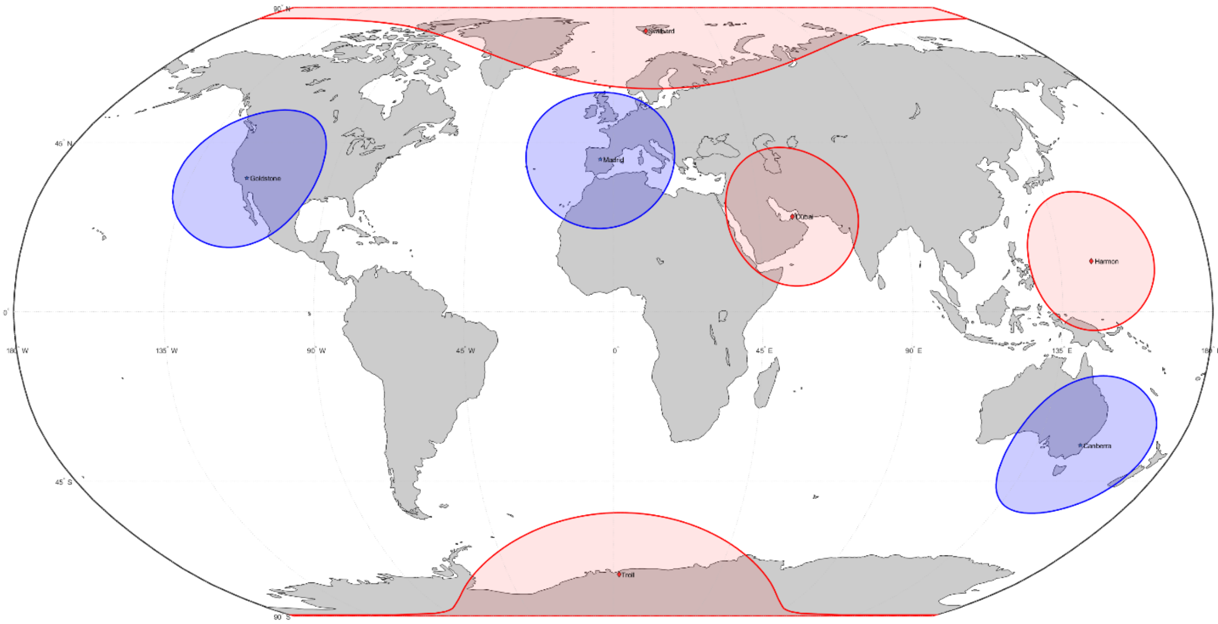

Figure 2.4-1. Transmission footprints for the possible ground stations for GNOMES-2 (in red) showing no overlap with DSN station (in blue).

Under contingency operations, the downlink data rate for GNOMES-3 will drop to 200 kbps, causing the power spectral flux density to approach the interference protection level of -255.1 dB(W/m^2·Hz) at the closest possible slant ranges to the DSN stations. Under these uncommon conditions, PlanetiQ plans to lower the X-band radio transmit power to abide by ITU recommendations.

2.4.2 Ground Stations

The atmospheric soundings measured by the GNOMES will be downlinked via commercial ground station networks. PlanetiQ has contracts with Kongsberg Satellite Services (KSAT) and ATLAS Space Operations for use of their ground station network as specified in Table 2.4-3. For S-band uplink and X-band downlink, KSAT supplies a network of 3.7-meter antenna dishes[7], while ATLAS maintains a network of ground stations of various sizes (3.4 m to 9.1 m).

The ground stations shown in Table 2.4-3 and Table 2.4-4 represent a superset of possible ground stations under consideration from KSAT and ATLAS. Currently, PlanetiQ plans to operate at the Svalbard, Troll, Harmon, and Dubai stations for GNOMES-2. Combinations of these ground stations allow for at least 27 opportunities for data transfer per day for each of the GNOMES. Further information regarding the transmission and reception characteristics for all antennas to be used by PlanetiQ can be found in Exhibit B – National Telecommunications and Information Administration Space Record Data Form.

[7] https://www.ksat.no/en/news/2016/january/ksat%20lite-network/

Table 2.4-4. KSAT ground station locations (uplink and downlink)

	Svalbard, Norway	Troll, Antarctica
Latitude	78°13'46"N	72°00'40"S
Longitude	15°24'28"E	2°33'14"E
Elevation above sea level	480 m	1365 m

Table 2.4-5. ATLAS ground station locations (uplink and downlink)

	Harmon, Guam	Dubai, United Arab Emirates[8]
Latitude	13°30'45"N	24° 56' 32"N
Longitude	144°49'29"E	55° 20' 52"E
Elevation above sea level	45 m	65 m

PlanetiQ and its subcontracted ground station suppliers will seek the appropriate licenses for all ground stations communicating with GNOMES-3 under the agreements with the ground station providers. PlanetiQ may subscribe to other ground stations within the KSAT and ATLAS networks, as needed, to decrease latency and avoid transmission overlap with other missions and will amend this application and coordinate all such operations, as necessary.

2.4.3 Ground Station Access

To facilitate with spectrum use coordination, the technical capabilities of the GNOMES system are described here. GNOMES-3 carries the SDR-X X-band transmitter/S-band receiver, produced by BCT. The radios are software defined, and have an adjustable data rate up to a maximum 25 Mbps. PlanetiQ plans to use 10 Mbps for nominal operations. During a station pass, GNOMES-3 will downlink the accumulated atmospheric measurements from the previous fraction of an orbit. With the broad distribution of ground stations around the Earth, the GNOMES will have frequent telecommunications opportunities. We have baselined a 5-minute contact time for each station pass to conduct commanding and downlink operations, although with our 10 Mbps data rate, the necessary communication time is likely less.

A simulation of GNOMES-3 in its anticipated orbit was conducted using the orbital software package Systems Tool Kit (STK) from Analytical Graphics, Inc. The length of time of the line-of-sight radio access between GNOMES-3 and the set of anticipated ground stations was recorded for one year’s worth of orbits at the nominal operational altitude of 650 km. An elevation mask of 5 degrees was be imposed at each of the ground stations to limit data transfer to elevations above the surrounding foliage and structures, as well as to ensure our link budget supports our data rates.

The distribution of pass times is shown in Figure 2.4-3 for GNOMES-3. The majority of GNOMES-3 pass times for data transfer are well over 300 seconds.

[8] Expected availability in Q4 2021

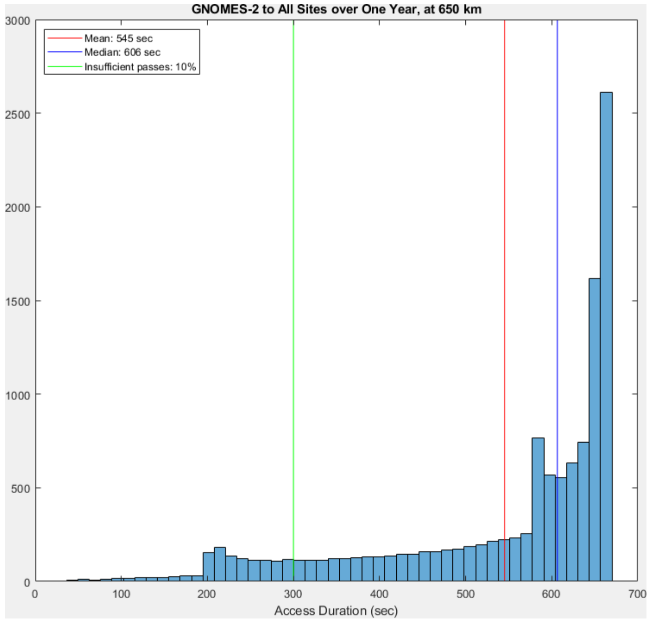

Figure 2.4-2. Pass lengths for GNOMES-3 at 650 km sun-synchronous orbit.

With a data downlink rate of 10 Mbps, there is temporal flexibility within the satellite-station pass for data downlink for the majority of passes. The ground stations within the KSAT and ATLAS networks, shown in Table 2.4-3 and Table 2.4-4, also give geographic diversity for downlink opportunities. GNOMES-3 also will have on-board data storage sufficient for multiple passes without downlink.

2.4.4 Potential Interference

PlanetiQ has already commenced pre-coordination activities with other S-band/X-band spectrum users, including Federal operators, to avoid potential interference during transmission.

2.4.5 Receipt of Foreign GNSS Signals

As stated in the application(s) for GNOMES-1 (WK2XIU) and GNOMES-2 (WL2XES), the GNOMES-3 primary payload “Pyxis” receiver performs on-board scheduling and orbit determination by a navigation engine using primarily GPS observations (Galileo, if needed). For science data products, the Pyxis is designed to detect dual-frequency signals from the four major GNSS constellations: GPS, GLONASS, Galileo, and BeiDou. Because of the necessary post-processing of the GNSS orbits and blocks to derive the atmospheric characteristics, any deliberate falsification or spoofing of the foreign GNSS signals will be detected by GNOMES-3 and known well before PlanetiQ releases any weather data products. The GNOMES satellites have no 'dependencies' on foreign signals of opportunity, however the system would just see a significant reduction in science data if all GNSS signals are measured. This scenario which would result in a need for additional satellites to obtain the same amount of data.

Appendix 1 – Equations and Data used

Power Densities at transmit antenna

At the Source: PD = Power/Occupied Bandwidth (per Hz)

PD(Hz) = 3.85 watts /20,000,000 Hz = 1.925E-07 watts/Hz

PD(4kHz) = 1.925E-07 * 4000 = 0.00077W/(4kHz)

Power Flux Densities

Power Flux Density (PFD) (650km) =

PFD = Power at Transmit antenna /(4*pi*distance**2) in watts/m**2

PFD = 3.85W/(4*pi*650km*650km) = 6.969 E-13 W/m**2 or -121.6 dBW/m**2

(Note, convert km to meters)

Power Flux Density 4 kHz (650km) = -158.4 dBW/m**2

Worst Cast PFD at GSO, is if we pitch up and point our downlink antenna up to point at GSO's

Power Flux Density GSO (35135.9 km above 650km)

PFD (20MHz@GSO) =3.85W/(4*pi*35135.9km*35135.9km)

Power Flux Density 20MHz = -156.06 dBW/m**2

Power Flux Density 4kHz = -193.05 dBW/m**2