A STUDY OF SATELLITE NAVIGATION, DILUTION OF PRECISION, AND POSITIONING TECHNIQUES FOR USE ON AND AROUND THE MOON

THESIS

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Abstract
The National Aeronautics and Space Agency is examining several approaches to meet navigational requirements for spacecraft in lunar orbit, in transit to or from the moon, and for personnel on the lunar surface requiring an accurate, real-time, on-board navigation capability. This work addresses one possible solution to the navigation problem in the vicinity of the moon using a lunar satellite navigation system. Dilution of precision is the figure of merit used to determine if a candidate lunar satellite navigation system can meet accuracy specifications based on a given satellite constellation and the measurement types used. Ten satellite constellations, using two measurement types (direct ranging and time-difference-of-arrival), are analyzed for numerous user locations on the moon. Using terrestrial and Earth-orbiting assets to augment the lunar constellations is also investigated. Sensitivity analyses are accomplished to determine the effect on the position solution accuracy of additional measurements, reduced measurements, and different combinations of measurement types.

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THESIS

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John H. MacNicol

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Abstract

The National Aeronautics and Space Agency's Glenn Research Center is examining several approaches to meet navigational requirements for spacecraft in lunar orbit, in transit to or from the moon, and for personnel on the lunar surface requiring an accurate, real-time, on-board navigation capability. This work addresses one possible solution to the navigation problem in the vicinity of the moon using a lunar satellite navigation system.

Dilution of precision is the figure of merit used to determine if the system can meet accuracy specifications based on a given satellite constellation and the measurement types used. Ten satellite constellations, using two measurement types (direct ranging and time-difference-of-arrival), are analyzed for numerous user locations on the moon. Using terrestrial and Earth-orbiting assets to augment the lunar constellations is also investigated. Sensitivity analyses are accomplished to determine the effect on the position solution accuracy of additional measurements, reduced measurements, and different combinations of measurement types.

A STUDY OF SATELLITE NAVIGATION, DILUTION OF PRECISION, AND POSITIONING TECHNIQUES FOR USE ON AND AROUND THE MOON

I. Introduction

Overview

On July 20, 1969, Neil Armstrong became the first person to set foot on the moon. It was the highlight of the National Aeronautics and Space Agency's (NASA) lunar program that began with Ranger 7's intentional impact on the moon on July 31, 1964 and ended with Apollo 17's successful return, which left the moon on December 14, 1972. On July 20, 1976, NASA's unmanned Viking 1 became the first spacecraft to land successfully on the surface of Mars. Twenty years later, in 1996, NASA launched the Mars Pathfinder that both landed and deployed the remotely controlled Sojourner rover. Other successful Mars missions include the Mars Global Surveyor (still operating in orbit) and the Mars Odyssey that entered Mars orbit on October 23, 2001 [5]. With the aim of current plans to build gradually toward sustained robotic, and then human, presence farther and farther from Earth, NASA is once again turning its attention toward the moon, this time as a stepping-stone to Mars. NASA needs a system to meet the navigational requirements for spacecraft in lunar orbit, in transit to or from the moon, and for personnel on the lunar surface with an accurate, real-time, on-board capability. In future lunar missions, unmanned cargo vehicles will land in predesignated locations, followed by manned craft that will touch down nearby. Astronauts will then travel beyond sight of the landing area and return [15]. While many terrestrial navigation methods have been developed during the centuries that mankind has been traversing the Earth, few are applicable to the new, extra-terrestrial, mission requirements. However, satellite-based navigation, developed in the latter half of the 20th century, has the accuracy and ubiquity to do the job.

Satellite Navigation Background

After the launch of the first artificial satellite, Sputnik, by the Soviet Union in 1957, scientists around the world realized that position on the Earth's surface could be determined by measuring radio signals from a satellite. The first U.S. satellite navigation system, Transit, was launched by the U.S. Navy in the 1960s for use by ships and submarines. The 7-satellite system measured the Doppler shift of a satellite signal to determine the rate of change of the distance between the satellite and the ship. The two-dimensional user position was calculated based on the known satellite position, as determined from a navigation message transmitted by the satellite that provided its orbital ephemeris. The system had a reported accuracy of 25 meters [17].

The replacement for Transit was the Navstar Global Positioning System (GPS), a 24-satellite (plus operating spares), passive ranging system that provides continuous, global coverage for determining user position, velocity, and time through the use of spread-spectrum, one-way signals incorporating both ranging and Doppler measurements. One of GPS's many advantages over Transit was the increased number of satellites in the constellation. This allows users to view multiple satellites simultaneously, which provides instantaneous three-dimensional position solutions (unlike Transit that required tracking a single satellite for up to twenty minutes in order to get a position fix). Using a passive, or one-way, ranging method requires precise timing to measure the difference between the satellite signal's transmit and receive times. This requirement means that an additional satellite measurement is needed to resolve any error between the satellite and receiver clocks, resulting in a minimum of four GPS satellites to be in view to determine a user's three-dimensional position and time.

The immense benefits associated with a satellite navigation system [12, 17, 20, 21, 24] have revolutionized navigation on the Earth, taking it out of the domain of experts and placing it into the hands of the common person, with comparable accuracies. However, satellite navigation system benefits do not carry over to space applications beyond Earth orbit because the current generation of GPS satellites only point earthward. While there has been successful GPS uses out to geosynchronous altitudes [7], the signals do not propagate very far beyond that range before becoming too weak to receive.

Space Navigation Challenges

Kachmar and Wood [11] outline the three space navigation system objectives: to provide the spacecraft state (position and velocity) estimate, to provide the state estimate within a specified time period (latency), and to provide the estimate with a specified degree of reliability. For manned missions, the real-time, on-board navigation requirements are the most important, so that guidance decisions can be made quickly if a problem develops or if communications with Earth are lost. Historically, the post-processed navigation solution, accomplished on the ground with larger computers and more measurement data, has provided more accurate state information. This has been used to verify real-time navigation performance and improve experimental data accuracy. However, all Earth-based systems incur larger navigation errors as the distance from the Earth increases. For this reason, space vehicles use a combination of Earth-based and on-board navigation sensors when operating close to, or landing on, another planet. However, even these sensors will not provide a navigation capability to the astronauts operating on a planet's surface.

One solution is to put navigation satellites in orbit around the destination planet to provide a navigation capability for spacecraft and personnel in orbit or on the surface. With advances in computing power and memory storage, combined with a destination-based navigation system, the real-time, on-board solution accuracy could exceed that of the current Earth-based, post-processed solutions.

Problem Statement

Space travel requires space vehicle navigation and guidance during the various mission phases. Navigation applies to the determination of the spacecraft's position and velocity in relation to a relevant coordinate system, while guidance determines the necessary control inputs to place the spacecraft in a desired location or orbit. McDonald and Stern [14] discuss the three phases of space travel as the parking phase, transitional phase, and the midcourse phase. A spacecraft in orbit around a planet is in the parking phase, during which the dominant force acting on the vehicle is the gravitational pull of the planet and the forces of other planets and the sun cause small perturbations in the orbit. The transitional phase occurs when the spacecraft leaves or approaches a celestial body. The

body is still the dominant force acting on the vehicle; however, the distinction from the parking phase is the vehicle's increased energy. In the transitional phase, the spacecraft has enough energy to escape the pull of the body. In the midcourse phase, the spacecraft is far enough away from any planet that the major gravitational influence is the sun. In this phase the vehicle is in orbit around the sun. Generally, a spacecraft's position is in reference to a coordinate system centered on the dominant gravitational body.

This thesis addresses one possible solution to the navigation problem in the moon's vicinity during the transitional and parking phases, as well as during descent/ascent and surface operations, using a lunar satellite navigation system based on a moon-centered, moon-fixed (MCMF) coordinate frame. The mission requirement for accurate, real-time, on-board navigation will be challenging to meet within cost, schedule, and performance constraints. Metrics will be needed to determine if initial designs can meet mission requirements [9]. Two satellite navigation system aspects that directly relate performance to cost are the satellite constellation geometry, in relation to the user, and the type of navigation measurements used. With greater satellite numbers comes greater accuracy and availability, but also greater cost. Direct ranging with a transponder allows the user to measure the distance to a satellite directly. The time-difference-of-arrival method (TDOA) measures the difference between the time an Earth-based signal arrives at the user position directly and after being relayed through a satellite. TDOA measurements can provide more navigation information without additional satellites, as long as the relay satellite and the user are both in view of the Earth station sending the signal. Dilution of precision (DOP) is a figure of merit used to determine if the system can meet accuracy specifications based on a given satellite configuration and the measurement types used.

This thesis analyzes lunar satellite constellations under consideration by NASA for navigational use during future missions to the moon by determining the effects of geometry and positioning method on the position solution accuracy. Geometric effects are quantified by calculation of DOP for each constellation based on using direct ranging and TDOA measurements in determining the user position. Sensitivity analyses are accomplished to determine the effect on the position solution accuracy for additional measurements, reduced measurements, and different combinations of measurement types, according to

mission scenarios that determine which satellites and measurements are available. DOP versus time graphs for each scenario are generated and analyzed to detect gaps in coverage, unfavorable geometries, and constellation sensitivities to satellite or measurement outages.

Assumptions

For this thesis, the following assumptions are made:

1. White, Gaussian noise is used in the development of the conditional density function. The user position states are represented by wide-band Gaussian noise, where the noise bandwidth is greater than the system bandwidth.
2. The user position states are independent of (and thus uncorrelated with) measurement noise.
3. The user, satellites, and Earth stations can communicate if they have an unimpeded line of sight.
4. The measurements for each epoch are independent of (and thus uncorrelated with) each other. Therefore, the calculation of DOP is accomplished on an epoch-by-epoch basis.
5. Direct ranging and time-difference-of-arrival measurements will be available (the methods to generate such measurements are not discussed in this thesis).
6. All satellite, Earth station, and user positions are known in order to determine the user-satellite geometry for each epoch.
7. The random errors occurring in both measurement types are zero-mean and identically distributed, thus all measurements have the same covariance.

II. Background

Candidate Constellations

NASA has chosen several satellite constellations for possible use in future lunar missions for navigation and communications [15, 18], including:

- Low-altitude lunar constellation
- Medium-altitude lunar constellation
- Earth-Moon Lagrange constellations (L1 and L1/L2)
- Earth-ground and Earth-satellite augmentation of L1 constellations

Initial requirements assume operations in two main regions – at the lunar south pole and the lunar equator. Although not necessarily in use at the same time, both regions will require navigation coverage utilizing the minimum number of satellites possible. Accuracy requirements may vary for different phases of operations. However, high levels of accuracy and availability of the navigation solution must be assured during critical phases of operations, such as landing. Possible methods to meet these requirements include using a "hot spare" satellite to minimize the risk of coverage outages or moving the satellites within their orbits to improve availability over a particular region.

Low-Altitude Lunar Constellation. The low-altitude constellation consists of 30 100-kg satellites, at a minimum altitude of 200 km, in five 90-degree inclined, circular, polar orbits that are evenly spaced with respect to each other. The six satellites in each orbit are evenly distributed around the orbit.

Medium-Altitude Lunar Constellation. The medium-altitude constellation, shown in Figure 2.1, consists of either six or eight 1,000-kg satellites, at a minimum altitude of 2,000 km, divided equally between two 90-degree inclined, circular, polar orbits that are rotated 90-degrees with respect to each other. The satellites are evenly distributed in each orbit.

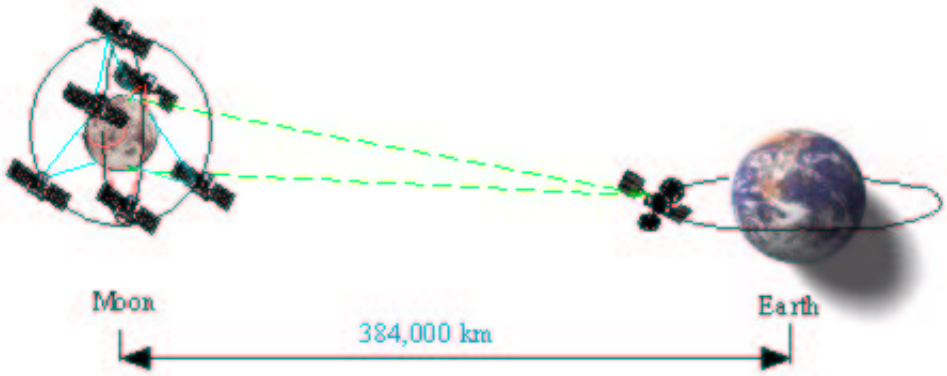

Figure 2.1 Medium Satellite Lunar Constellation

Earth-Moon Lagrange Constellation. The Earth and Moon form a two-body gravitational system which contains libration points where the competing gravitational fields and centripetal forces balance one another, as first described by Count Joseph Louis Lagrange (1736-1813), French mathematician and astronomer [3]. There are five libration points in the Earth-Moon system; however, only points L1 and L2 exist closely enough to the moon for use by a lunar navigation system. An object at one of the libration points remains in a "fixed" relative position with respect to the Earth and Moon, as shown in Figure 2.2, from Johnson and Holbrow [10]:

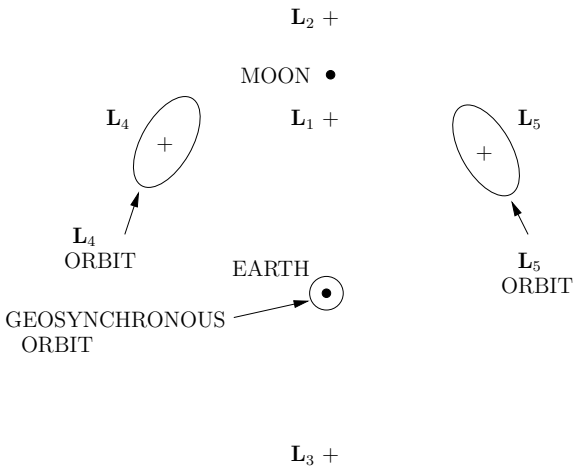

Figure 2.2 Lagrange Libration Points

The L1, L2, and L3 points are stable in directions perpendicular to the Earth-Moon axis, but unstable along the axis, so a vehicle at these points exhibits an unstable equilibrium. A spacecraft can occupy or orbit around these points with active control to maintain along-axis position using minimal fuel. However, the fuel required to recapture position after a significant orbital disturbance is proportional to the distance from the libration point. The L4 and L5 points are located at equal distances from both the Earth and Moon. They are not precise locations in space, but large regions of stable equilibrium. The libration point orbits are not circular, but rather oval or kidney-shaped. The L1 and L2 orbits used in computer simulations for this thesis assume circular orbits as a first order approximation to the true orbits. [4]

The Lagrange constellation, shown in Figure 2.3, uses two to four 1,000-kilogram satellites in orbit around either L1 alone or both L1 and L2, at either a low orbital radius (3,478 km) or a high orbital radius (17,374 km), in counter-rotating orbits. L1 lies between the Earth and moon, approximately 58,000 km from the center of the moon and 326,000 km from the center of the earth. L2 lies outside the moon's orbit, approximately 64,000 km from moon-center and 448,000 km from earth-center. This provides coverage of the poles and lunar "far side", even in the event of a satellite failure, because the satellites are not in orbit around the moon, but around the libration point.

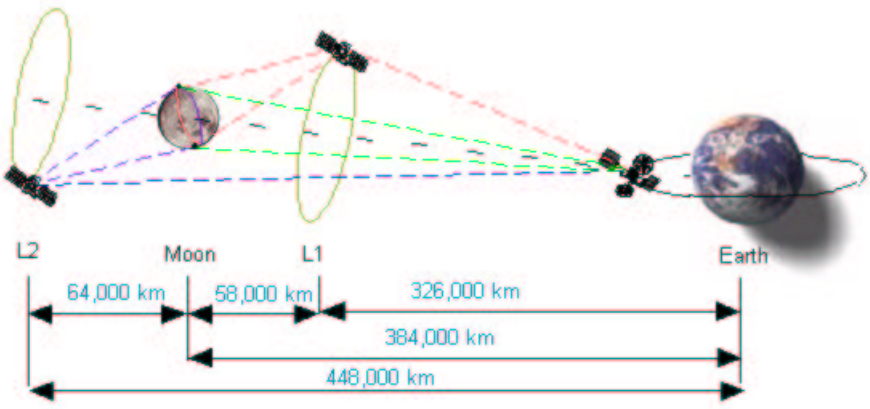

Figure 2.3 Earth-Moon Lagrange Constellation

Earth-ground and Earth-satellite augmentation of L1 constellations. The L1 constellation provides fewer satellites than the low or medium polar constellations. In order to increase the number of measurements available to the user, it was assumed that measurements could be taken from the Earth-based Deep Space Network (DSN) stations, Earth-orbiting geosynchronous satellites, or Earth-orbiting satellites at twice the geosynchronous altitude, as shown in Figure 2.4. The three DSN stations are located in Goldstone, California, U.S. (35 N, 117 W); Madrid, Spain (40 N, 4 W); and Canberra, Australia (36 S, 150 E). Three satellites, phased 120 degrees apart, are used in both the geosynchronous and twice-geosynchronous orbits. The geosynchronous satellites were placed over 179 degrees West, 59 degrees West, and 61 degrees East latitudes. The twice geosynchronous satellites were placed over the same positions at the start of epoch, 3 December 2003.

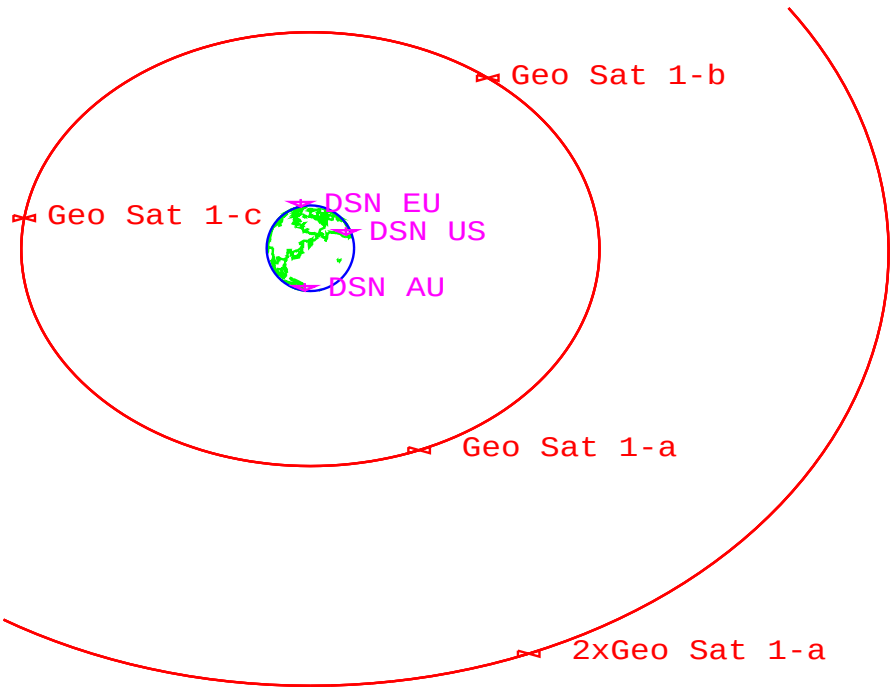

Figure 2.4 Earth-based Deep Space Network Stations with Geosynchronous and Twice-Geosynchronous Satellites

III. Analysis Procedure

Bayesian Derivation of the Geometry Matrix

A random variable, such as the three dimensional user position, $\mathbf{x}_u$, given here in moon-centered, moon-fixed Cartesian coordinates, can be described through its probability density function. This generally requires an infinite number of statistical moments to characterize the density function completely, unless it is a Gaussian distribution, in which case only the first two central moments, the mean and covariance, are needed. Furthermore, Bayes' rule [23] can be used to define the conditional density function for two random variables, describing how one variable's realization affects the other's density function. The approach used here follows Maybeck [13] to show how a user position estimate (indicated by a hat over the variable), $\hat{\mathbf{x}}_u$, can be determined from the range measurement values, $\mathbf{z}$, by using the conditional density function, $f_{\mathbf{x}|\mathbf{z}}(\xi|\zeta)$. In this notation, ξ and ζ are dummy variables that act as place-holders for actual values, while the subscripts indicate that the variable of interest is $\mathbf{x}$ as it is 'affected by', or conditioned on, the variable $\mathbf{z}$. The vertical bar indicates that the density function is conditional, rather than joint. A joint density would be indicated by a comma between the subscript variables, rather than a vertical bar. A full discussion of statistics, including density functions, can be found in Maybeck, Papoulis, or Stark and Woods [13, 19, 23].

The conditional density function's second central moment is the conditional covariance, $\mathbf{P}_{x|z}$, which can be determined from the *joint* covariance matrix elements, $\mathbf{P}_{x,z}$, of the joint density function, $f_{\mathbf{x},\mathbf{z}}(\xi,\zeta)$, by using Equation (3.1), as derived by Maybeck [13] for jointly Gaussian random variables. The double subscripts on the right hand side of Equation (3.1) indicate the joint covariance matrix partitions. From the conditional covariance matrix, the geometry matrix can be determined, from which the dilution of precision (DOP) can be calculated.

$$\mathbf{P}_{x|z} = \mathbf{P}_{xx} - \mathbf{P}_{xz}\mathbf{P}_{zz}^{-1}\mathbf{P}_{zx} \tag{3.1}$$

Two things are needed to apply Equation (3.1). First, it must be demonstrated that $\mathbf{x}_u$ and $\mathbf{z}$ are jointly Gaussian. This is done by showing that $\mathbf{x}_u$ is Gaussian, and then that $\mathbf{z}$ is a linear combination of $\mathbf{x}_u$. Second, the elements of the joint covariance for $\mathbf{x}_u$ and $\mathbf{z}$ must be determined. Equation (3.2) relates $\mathbf{z}$ and $\mathbf{x}_u$, where $\mathbf{H}$ is a linear operator and $\mathbf{v}$ represents measurement noise.

$$\mathbf{z} = \mathbf{H}\mathbf{x}_u + \mathbf{v} \tag{3.2}$$

The Central Limit Theorem can be used to show that the distribution of a sum of random variables which are independent and identically distributed will approximate a Gaussian distribution in the limit as the number of random variables in the set being summed increases infinitely. However, for practical purposes, the approximation to a Gaussian distribution is sufficient for numbers of random variables much smaller than infinity. Papoulis [19] shows that the sum of uniformly distributed random variables will closely approximate a Gaussian random variable with as few as three uniformly distributed variables in the summation. Therefore, since the user position realizations are considered independently for each measurement epoch, and the errors in the measurements are assumed to be identically distributed (the measurement error standard deviation is the same for each individual measurement), the unknown, true state vector distribution, $\mathbf{x}_u$, is assumed to be adequately described by a Gaussian distribution's mean and covariance. The measurement noise, $\mathbf{v}$, is defined as white Gaussian noise for the types of measurements being considered and is assumed to be independent of the user position. This assumption is more valid in space and near the moon, where there is no atmospheric interference, than on or near the Earth.

Since $\mathbf{x}_u$ and $\mathbf{v}$ are each Gaussian and independent, they are jointly Gaussian. To show $\mathbf{x}_u$ and $\mathbf{z}$ are jointly Gaussian, an augmented vector $\mathbf{a}$ is defined as shown in Equation (3.3) for $\mathbf{x}_u$ and $\mathbf{v}$.

$$\mathbf{a} = \begin{bmatrix} \mathbf{x}_u \\ -- \\ \mathbf{v} \end{bmatrix} \tag{3.3}$$

Then the joint density function for $\mathbf{x}_u$ and $\mathbf{v}$, $f_{\mathbf{x},\mathbf{v}}(\xi,\eta)$, can be written as the density function of $\mathbf{a}$, $f_{\mathbf{a}}(\alpha)$, which is also Gaussian and is described by the mean, $\mathbf{m}_a$, and covariance, $\mathbf{P}_a$, shown in Equations (3.4) and (3.5), where $\mathbf{R}$ is the covariance of the measurement noise and $\mathbf{P}_x$ is the covariance of the unconditional, *a priori* density function of the user position, $f_{\mathbf{x}}(\xi)$.

$$\mathbf{m}_a = \begin{bmatrix} \hat{\mathbf{x}}_u \\ -- \\ \mathbf{0} \end{bmatrix} \tag{3.4}$$

$$\mathbf{P}_a = \begin{bmatrix} \mathbf{P}_x & | & \mathbf{0} \\ -- & + & -- \\ \mathbf{0} & | & \mathbf{R} \end{bmatrix} \tag{3.5}$$

Since a linear transformation on a Gaussian variable is also Gaussian, a new random variable, $\mathbf{w}$, can be formed by premultiplying $\mathbf{a}$ by the matrix $\mathbf{B}$, as shown in Equations (3.6) and (3.7).

$$\mathbf{B} = \begin{bmatrix} \mathbf{I} & | & \mathbf{0} \\ -- & + & -- \\ \mathbf{H} & | & \mathbf{I} \end{bmatrix} \tag{3.6}$$

$$\mathbf{w} = \left[\begin{array}{c|c} \mathbf{I} & \mathbf{0} \\ -- & -- \\ \mathbf{H} & \mathbf{I} \end{array}\right] \left[\begin{array}{c} \mathbf{x}_u \\ -- \\ \mathbf{v} \end{array}\right] = \left[\begin{array}{c} \mathbf{x}_u \\ --- \\ \mathbf{H}\mathbf{x}_u + \mathbf{v} \end{array}\right] = \left[\begin{array}{c} \mathbf{x}_u \\ --- \\ \mathbf{z} \end{array}\right] \tag{3.7}$$

$\mathbf{w}$ is a Gaussian random variable, therefore, $\mathbf{x}_u$ and $\mathbf{z}$ are jointly Gaussian, where $f_{\mathbf{w}}(\omega) = f_{\mathbf{x},\mathbf{z}}(\xi, \zeta)$. The mean and covariance of the joint density function for $\mathbf{x}_u$ and $\mathbf{z}$ are given by Equations (3.8) and (3.9), respectively:

$$\mathbf{m}_w = \mathbf{m}_{x,z} = \left[\begin{array}{c|c} \mathbf{I} & \mathbf{0} \\ -- & -- \\ \mathbf{H} & \mathbf{I} \end{array}\right] \left[\begin{array}{c} \hat{\mathbf{x}}_u \\ -- \\ \mathbf{0} \end{array}\right] = \left[\begin{array}{c} \hat{\mathbf{x}}_u \\ --- \\ \mathbf{H}\hat{\mathbf{x}}_\mathbf{u} \end{array}\right] \tag{3.8}$$

$$\mathbf{P}_w = \mathbf{P}_{x,z} = \left[\begin{array}{c|c} \mathbf{I} & \mathbf{0} \\ -- & -- \\ \mathbf{H} & \mathbf{I} \end{array}\right] \left[\begin{array}{c|c} \mathbf{P}_x & \mathbf{0} \\ -- & -- \\ \mathbf{0} & \mathbf{R} \end{array}\right] \left[\begin{array}{c|c} \mathbf{I} & \mathbf{H}^T \\ -- & -- \\ \mathbf{0} & \mathbf{I} \end{array}\right]$$

$$\mathbf{P}_{x,z} = \left[\begin{array}{c|c} \mathbf{P}_x & \mathbf{P}_x\mathbf{H}^T \\ --- & ------- \\ \mathbf{H}\mathbf{P}_x & \mathbf{H}\mathbf{P}_x\mathbf{H}^T + \mathbf{R} \end{array}\right] \tag{3.9}$$

Substituting the partitions on the right hand side of Equation (3.9) into Equation (3.1) results in Equation (3.10):

$$\mathbf{P}_{x|z} = \mathbf{P}_x - [\mathbf{P}_x\mathbf{H}^T][\mathbf{H}\mathbf{P}_x\mathbf{H}^T + \mathbf{R}]^{-1}[\mathbf{H}\mathbf{P}_x] \tag{3.10}$$

Using the Matrix Inversion Lemma (Appendix B) to simplify Equations (3.10) results in Equation (3.11):

$$\mathbf{P}_{x|z} = [(\mathbf{P}_x)^{-1} + \mathbf{H}^T\mathbf{R}^{-1}\mathbf{H}]^{-1} \tag{3.11}$$

To determine the effect of a particular user-satellite geometry on the accuracy of the position solution, the available measurements making up $\mathbf{z}$ for a given time epoch are treated simultaneously, while each epoch is analyzed independently. Therefore, there is no *a priori* information available about the user position. This is modelled by setting the covariance of the user position to infinity, $\mathbf{P}_x = \infty\mathbf{I}$, or by its inverse, $(\mathbf{P}_x)^{-1} = \mathbf{0}$. Substituting the latter into Equation (3.11) results in Equation (3.12):

$$\mathbf{P}_{x|z} = [\mathbf{H}^T\mathbf{R}^{-1}\mathbf{H}]^{-1} \tag{3.12}$$

It is assumed that the measurements are independent from each other, and therefore uncorrelated, as well as being identically distributed. The latter means that all measurements have the same covariance. Since the measurement covariances are a function of the measurement type, it is possible for the direct ranging and TDOA measurements to have different covariances, however, it is assumed for this thesis that both measurement types share the same covariance, denoted σ^2. Therefore, $\mathbf{R} = \sigma^2\mathbf{I}$, where $\mathbf{I}$ is the identity matrix. This further simplifies Equation (3.12), resulting in Equations (3.13) and (3.14), where $\mathbf{H}$ is referred to in the literature as the geometry or measurement matrix [17, 24]:

$$\mathbf{P}_{x|z} = \sigma^2[\mathbf{H}^T\mathbf{H}]^{-1} = \sigma^2\mathbf{G} \tag{3.13}$$

$$\mathbf{G} = [\mathbf{H}^T\mathbf{H}]^{-1} \tag{3.14}$$

In a Cartesian coordinate system, the dilution of precision for each axis is the square root of the diagonal element for the appropriate row of the $\mathbf{G}$ matrix. DOP is dimensionless because the units for the covariance in Equation (3.13) are carried in the σ^2 term. To determine the three-dimensional Geometric dilution of precision (GDOP), the root-sum-square of the diagonal elements is calculated by taking the square root of the trace (the sum of the diagonal elements) of $\mathbf{G}$, as shown in Equation (3.15) [12, 17, 20, 21]. Several different

types of DOP are defined using various elements and coordinate systems. If the positioning system is either uniquely determined or overdetermined (the number of measurements equals or exceeds the number of states), then $\mathbf{G}$ will be a square matrix of size equal to the number of states. If it is underdetermined (there are fewer measurements than states), $\mathbf{H}^T\mathbf{H}$ will not have full rank and will be non-invertible, and $\mathbf{G}$ will be undefined. For lunar satellite constellation analysis, $\mathbf{G}$ is three by three. Unlike GPS, the satellite navigation system under investigation does not use spread spectrum signals, thus eliminating the need for a fourth dimension in the $\mathbf{G}$ matrix to account for user clock error. By using a direction cosine matrix to rotate the MCMF Cartesian coordinates (X,Y,Z) into a local level frame (East North Up) [24], the DOP for the three-dimensional position (PDOP), the two-dimensional horizontal (HDOP), and one-dimensional vertical (VDOP) accuracies can be determined as shown in Equations (3.16) through (3.18). In this application, GDOP and PDOP are equivalent. For spread-spectrum and other one-way ranging systems, including GPS, the $\mathbf{G}$ matrix and the GDOP equation contain a fourth term to account for user clock error.

$$Geometric\ DOP = \sqrt{\mathbf{G}_{11} + \mathbf{G}_{22} + \mathbf{G}_{33}} \tag{3.15}$$

$$Position\ DOP = \sqrt{\mathbf{G}_{east} + \mathbf{G}_{north} + \mathbf{G}_{up}} \tag{3.16}$$

$$Horizontal\ DOP = \sqrt{\mathbf{G}_{east} + \mathbf{G}_{north}} \tag{3.17}$$

$$Vertical\ DOP = \sqrt{\mathbf{G}_{up}} \tag{3.18}$$

Linearization of the Geometry matrix. The derivation given above uses the linear mathematical model $\mathbf{z} = \mathbf{H}\mathbf{x}_u + \mathbf{v}$ to describe the relationship between the user position coordinates and the measurements. However, this relationship is non-linear, described by the root-mean-square (RMS) distance. A linear approximation to the non-linear relationship, $\mathbf{z} = \boldsymbol{h}(\mathbf{x}_u, t) + \mathbf{v}$, can be determined by using a truncated Taylor series [22], linearized about a nominal value of $\mathbf{x}_u$, such as the current estimate of user position, $\hat{\mathbf{x}}_u$, as shown in Equation (3.19). Truncating the series at the first derivative term results in Equation (3.20). In this case, reference to time as a dependent variable has been removed since each epoch of measurements and their user-geometry are considered independently.

$$\mathbf{z} \;=\; [\boldsymbol{h}(\hat{\mathbf{x}}_u) + \frac{\partial \boldsymbol{h}(\hat{\mathbf{x}}_u)}{\partial \mathbf{x}_u}\,(\mathbf{x}_u - \hat{\mathbf{x}}_u) + \;\textit{higher order terms}\,] + \mathbf{v} \tag{3.19}$$

$$\mathbf{z} \cong [\boldsymbol{h}(\hat{\mathbf{x}}_u) + \frac{\partial \boldsymbol{h}(\hat{\mathbf{x}}_u)}{\partial \mathbf{x}_u}\,(\mathbf{x}_u - \hat{\mathbf{x}}_u)] \;+ \mathbf{v} \tag{3.20}$$

Defining the error in the measurement vector as shown in Equation (3.21), then solving for $\mathbf{z}$, and defining the error in the user position vector as shown in Equation (3.22), results in Equation (3.23), after substitution into Equation (3.20):

$$\delta\hat{\mathbf{z}} = \mathbf{z} - \hat{\mathbf{z}} \tag{3.21}$$

$$\delta\hat{\mathbf{x}}_u = \mathbf{x}_u - \hat{\mathbf{x}}_u \tag{3.22}$$

$$\hat{\mathbf{z}} + \delta\hat{\mathbf{z}} = \boldsymbol{h}(\hat{\mathbf{x}}_u) + \frac{\partial \boldsymbol{h}(\hat{\mathbf{x}}_u)}{\partial \mathbf{x}_u}\,\delta\hat{\mathbf{x}}_u + \mathbf{v} \tag{3.23}$$

Noting that $\hat{\mathbf{z}} = \boldsymbol{h}(\hat{\mathbf{x}}_u)$ and equating both sides, results in Equations (3.24) and (3.25):

$$\delta\hat{\mathbf{z}} = \frac{\partial \boldsymbol{h}(\hat{\mathbf{x}}_u)}{\partial \mathbf{x}_u}\,\delta\hat{\mathbf{x}}_u + \mathbf{v} = \mathbf{H}\delta\hat{\mathbf{x}}_u + \mathbf{v} \tag{3.24}$$

$$\frac{\partial \boldsymbol{h}(\hat{\mathbf{x}}_u)}{\partial \mathbf{x}_u} \;= \mathbf{H} \tag{3.25}$$

where $\mathbf{H}$ is the linearized approximation to the function $\boldsymbol{h}(\mathbf{x}_u)$, which is seen to be its first derivative with respect to the user position, $\mathbf{x}_u$, evaluated at $\hat{\mathbf{x}}_u$.

The measurement relationship from the i^{th} satellite, (sv_i), to the user position coordinates is given, for a scalar measurement, in Equation (3.26), where the subscript u indicates the user position vector components and the subscript sv indicates the satellite

position vector components.

$$z = \sqrt{(x_{sv_i} - x_u)^2 + (y_{sv_i} - y_u)^2 + (z_{sv_i} - z_u)^2} \; + v \tag{3.26}$$

This is of the form $z = h(\mathbf{x}_u) + v$, where

$$h(\mathbf{x}_u) = \sqrt{(x_{sv_i} - x_u)^2 + (y_{sv_i} - y_u)^2 + (z_{sv_i} - z_u)^2} \tag{3.27}$$

Taking the derivative of the measurement with respect to the user position vector, $\mathbf{x}_u$, yields

$$\frac{\partial h(\mathbf{x}_u)}{\partial x_u} = \frac{x_{sv_i} - x_u}{\sqrt{(x_{sv_i} - x_u)^2 + (y_{sv_i} - y_u)^2 + (z_{sv_i} - z_u)^2}} = e_{xi} \tag{3.28}$$

$$\frac{\partial h(\mathbf{x}_u)}{\partial y_u} = \frac{y_{sv_i} - y_u}{\sqrt{(x_{sv_i} - x_u)^2 + (y_{sv_i} - y_u)^2 + (z_{sv_i} - z_u)^2}} = e_{yi} \tag{3.29}$$

$$\frac{\partial h(\mathbf{x}_u)}{\partial z_u} = \frac{z_{sv_i} - z_u}{\sqrt{(x_{sv_i} - x_u)^2 + (y_{sv_i} - y_u)^2 + (z_{sv_i} - z_u)^2}} = e_{zi} \tag{3.30}$$

These are the components of a row of the **H** matrix and represent the unit line-of-sight vector, $\mathbf{e}^i$, from the user to the i^{th} satellite, as described by Equation (3.31):

$$\mathbf{e}^i = [e_x^i \; e_y^i \; e_z^i] \tag{3.31}$$

The Geometry Matrix Range-Difference Element Derivation. The previous section derived the elements of the **H** matrix for the direct range measurements of the distance from the user to the lunar navigation satellites. The other type of measurement available is the range difference, which is derived from the time-difference-of-arrival for a signal sent from the earth to the user. It is assumed that the Deep Space Network (DSN) transmitters operated by NASA will be used to send the TDOA signal. The difference between the arrival time of the direct signal and the arrival time of the same signal passed through a navigation satellite provides a time-difference, which is converted to a range-difference between the lengths of the the two paths taken by the signal, by multiplying the time-difference by the speed of light. Since the signal is measured at only one location (the

user's position), there is no issue of synchronization between multiple receivers [16]. The geometric relationship between the signal paths is shown in Figure 3.1 and Equations (3.32) and (3.33), where $\mathbf{N}_j$ is a position vector and r_j is the corresponding range ($r_j = \| \mathbf{N}_j \|$). $\mathbf{N}_d$ is the DSN-to-user vector, $\mathbf{N}_a$ is the DSN-to-Satellite$_j$ vector, and $\mathbf{N}_j$ is the Satellite$_j$-to-user vector.

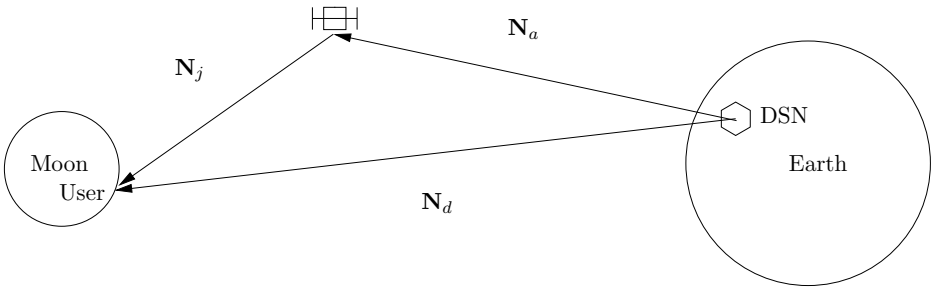

Figure 3.1 Paths of TDOA Signal

$$\mathbf{N}_d = \mathbf{N}_j + \mathbf{N}_a \tag{3.32}$$

$$z_{\delta r} = z_{tdoa} \cdot c = [(r_a + r_j) - r_d] \tag{3.33}$$

The time-difference-of-arrival measurement has been converted to a range difference measurement, denoted $z_{\delta r}$, by multiplying by c (the speed of light). The relationship between the range difference measurement and the user position is similar to the direct measurement relationship [8], with the rows of the H matrix corresponding to the derivative of the range difference measurement, shown in Equation (3.34), with respect to the user position, $\mathbf{x}_u$, as shown in Equations (3.35) through (3.39). The second term in Equation (3.34) does not depend on the user position and so its derivative goes to zero in Equations (3.35) through (3.37).

$$\begin{aligned} z_{\delta r} &= \sqrt{(x_{sv_j} - x_u)^2 + (y_{sv_j} - y_u)^2 + (z_{sv_j} - z_u)^2} \\ &+ \sqrt{(x_{dsn} - x_{sv_j})^2 + (y_{dsn} - y_{sv_j})^2 + (z_{dsn} - z_{sv_j})^2} \\ &- \sqrt{(x_{dsn} - x_u)^2 + (y_{dsn} - y_u)^2 + (z_{dsn} - z_u)^2} \; + v_{\delta r} \end{aligned} \tag{3.34}$$

The result, shown in Equation (3.38), is the difference of two unit line-of-sight vectors from the user-to-satellite and the user-to-DSN, respectively. It is denoted as $E^j_{\delta r}$, where the superscript indicates which satellite is used for the range difference measurement.

$$\frac{\partial z_{\delta r}}{\partial x_u} = \frac{(x_{sv_j} - x_u)}{\|\mathbf{N}_j\|} - \frac{(x_{dsn} - x_u)}{\|\mathbf{N}_d\|} = e^j_x - e_{x(dsn)} = x^j_{\delta r} \tag{3.35}$$

$$\frac{\partial z_{\delta r}}{\partial y_u} = \frac{(y_{sv_j} - y_u)}{\|\mathbf{N}_j\|} - \frac{(y_{dsn} - y_u)}{\|\mathbf{N}_d\|} = e^j_y - e_{y(dsn)} = y^j_{\delta r} \tag{3.36}$$

$$\frac{\partial z_{\delta r}}{\partial z_u} = \frac{(z_{sv_j} - z_u)}{\|\mathbf{N}_j\|} - \frac{(z_{dsn} - z_u)}{\|\mathbf{N}_d\|} = e^j_z - e_{z(dsn)} = z^j_{\delta r} \tag{3.37}$$

$$\mathbf{E}^j_{\delta r} = \begin{bmatrix} x^j_{\delta r} & y^j_{\delta r} & z^j_{\delta r} \end{bmatrix} \tag{3.38}$$

The final **H** matrix appears in Equation (3.39) for the uniquely determined case where there are three measurements available (two direct range measurements to satellites i and j and one range difference measurement through satellite j).

$$\mathbf{H} = \begin{bmatrix} \mathbf{e}^i \\ \mathbf{e}^j \\ \mathbf{E}^j_{\delta r} \end{bmatrix} \tag{3.39}$$

IV. Constellation and Scenario Descriptions

Background

This chapter describes the orbits, satellite phasing, and shape of the constellations and scenarios examined in this research. The intent of this chapter is to provide the reader with a detailed understanding of how the satellites were arrayed for each scenario, so that the results can be examined within the context and limitations of each constellation. The dilution of precision was calculated for 10 constellations, represented by 23 scenarios, listed in Table 4.3. NASA is considering areas near the lunar South pole and lunar equator for possible future missions. Therefore, each scenario was evaluated at 46 different user positions on the lunar surface, spanning the distance from the moon's South pole (90 degrees South latitude) to the equator, by two-degree increments of latitude, along the cartesian X-Z axis, on the near side of the moon, facing the Earth. The equatorial position (zero degrees latitude) is in the center of the moon's face, as seen from Earth.

Range measurement types, for all scenarios, include either direct ranging, time-difference-of-arrival ranging, or both. Direct ranging measures the range and direction from the user to the satellite. The range measurement vector is a unit vector from the user position in the direction of the satellite of interest. TDOA ranging assumes a signal is sent from a DSN station directly to the user, as well as relayed through a satellite. The difference in the time of arrival of the signal is converted to a distance to obtain the range-difference measurement. Measurements are taken every five minutes from the start of epoch, which is 0708 Hours, 07 seconds, 3 December 2003. This time and date were arbitrarily chosen by the thesis sponsor during the initial phase of the research.

Scenarios

C1 Moon polar, low-altitude constellation consisting of 30 satellites in low moon orbit (200 Km altitude) in five orbits. The longitude of the ascending node spacing is 72 degrees between orbits, with six satellites per orbit, evenly phased every 60 degrees. This constellation is intended to provide maximum coverage to users at all latitudes.

C2 Moon polar, medium-altitude constellation (2000 Km) using two polar orbits. The longitude of the ascending node spacing is 90 degrees between orbits. This constellation is intended to provide adequate coverage of the equatorial regions with the ability to increase polar coverage during critical mission phases by shifting satellites in their orbits.

C2-3 Moon polar, medium-altitude using six satellites, three satellites evenly spaced (120 degrees) in each orbit. The satellites in each orbit are phased 60 degrees apart so that when a satellite from one orbit is over the north pole, the nearest two in the other orbit are at 30 degrees north latitude.

C2-4 Moon polar, medium-altitude using eight satellites, four satellites evenly spaced (90 degrees) in each orbit. The satellites in each orbit are phased 45 degrees apart so that when a satellite from one orbit is over the north pole, the nearest two in the other orbit are at 45 degrees north latitude.

C3 The L1-Low constellation uses evenly spaced 1,000-kg satellites in a low orbit around the Earth-moon axis, in the vicinity of the L1 distance from the moon. The distance of the plane of the L1 satellite orbits, measured from the center of the moon along the Earth-moon axis, is recalculated from 58,346 Km (at L1) to 58,363 Km in order to reflect the changes in the forces acting on the satellites as they move radially outward from L1. Details of the orbital components are provided in Table 4.1. The orbits around the L1 point are a complex oval or kidney shape, however, for simplicity and mathematical tractability, they are modelled as circular. The satellite positions are given at the start of epoch. The L1-only constellations were intended to provide the benefits of the favorable geometry of a libration point orbit, while limiting coverage to the lunar "near" side, where most operations are likely to be conducted.

C3-2 L1-Low using two satellites (12, 6 o'clock positions).

C3-3 L1-Low using three satellites (12, 8, 4 o'clock positions).

C3-4 L1-Low using four satellites (12, 9, 6, 3 o'clock positions).

Table 4.1 L1-Low Constellation Details

C3	L1-Low Constellation
Orbital Radius	3,473 Km (2 moon radii)
Moon center to L1-orbit center	58,363 Km
Centripetal Force	0.1256 Newtons
Tangential Velocity	20.91 meters/sec
Angular Velocity	6.0083×10^{-6} rad/sec
Period (sec)	1.0457×10^{6} sec
Period (Hrs)	290.47 Hrs

C4 The L1-High constellation uses evenly spaced, 1,000-kg satellites in a high orbit around the Earth-moon axis, in the vicinity of the L1 distance from the moon. The distance of the plane of the L1 satellite orbits, measured from the center of the moon along the Earth-moon axis, is recalculated from 58,346 Km (at L1) to 58,777 Km in order to reflect the changes in the forces acting on the satellites as they move radially outward from L1. Details of the orbital components are provided in Table 4.2. Again, the orbits around the L1 point are a complex oval or kidney shape, however, for simplicity and mathematical tractability, they are modelled as circular. The satellite positions are given at the start of epoch.

Table 4.2 L1-High Constellation Details

C4	L1 High Constellation
Orbital Radius	17,374 Km (10 moon radii)
Moon center to L1-orbit center	58,777 Km
Centripetal Force	0.6163 Newtons
Tangential Velocity	104.0 meters/sec
Angular Velocity	5.9249×10^{-6} rad/sec
Period (sec)	1.0605×10^{6} sec
Period (Hrs)	294.58 Hrs

C4-2 L1-High using two satellites (12, 6 o'clock positions).

C4-3 L1-High using three satellites (12, 8, 4 o'clock positions).

C4-4 L1-High using four satellites (12, 9, 6, 3 o'clock positions).

C5 The L1/L2-Low constellation uses evenly spaced satellites in a low orbit around the Earth-moon axis, in the vicinity of the L1 distance and *at* the L2 distance from the moon. The distance of the plane of the L1 satellite orbits, measured from the center of the moon along the Earth-moon axis, is recalculated to 58,363 Km, while the distance of the plane of the L2 satellite orbits is 64,038 Km on the "far" side of the moon. Furthermore, the L2 satellites are assumed to use the same tangential and angular velocities in their orbits as the L1 satellites, except the L2 satellites rotate in the opposite direction as the L1 satellites (L1 and L2 are counter-rotating). As with the L1 orbits described in constellations C3 and C4, the orbits around the L1 and L2 points are complex oval or kidney shapes, however, for simplicity and mathematical tractability, they are modelled as circular. The satellite positions are given at the start of epoch. The L1/L2 constellation was intended to provide maximum coverage at all latitudes and longitudes.

C5-1 L1/L2-Low using two satellites - one L1 satellite at the 12 o'clock position and one L2 satellite at the 6 o'clock position.

C5-2 L1/L2-Low using four satellites - two L1 satellites (12, 6 o'clock positions) and two L2 satellites (9, 3 o'clock positions).

C5-3 L1/L2-Low using six satellites - three L1 satellites (12, 8, 4 o'clock positions) and three L2 satellites (6, 2, 10 o'clock positions).

C5-4 L1/L2-Low using eight satellites - four L1 and four L2 satellites (12, 9, 6, 3 o'clock positions).

C6 The L1/L2-High constellation uses evenly spaced satellites in a high orbit around the Earth-moon axis, in the vicinity of the L1 distance and *at* the L2 distance from the moon. The distance of the plane of the L1 satellite orbits, measured from the center of the moon along the Earth-moon axis, is recalculated to 58,777 Km, while the

distance of the plane of the L2 satellite orbits is 64,038 Km on the "far" side of the moon. Furthermore, the L2 satellites are assumed to use the same tangential and angular velocities in their orbits as the L1 satellites, except the L2 satellites rotate in the opposite direction as the L1 satellites (L1 and L2 are counter-rotating). As with the L1 orbits described in constellations C3 and C4, the orbits around the L1 and L2 points are complex oval or kidney shapes, however, for simplicity and mathematical tractability, they are modelled as circular. The satellite positions are given at the start of epoch.

C6-1 L1/L2-Low using two satellites - one L1 satellite at the 12 o'clock position and one L2 satellite at the 6 o'clock position.

C6-2 L1/L2-Low using four satellites - two L1 satellites (12, 6 o'clock positions) and two L2 satellites (9, 3 o'clock positions).

C6-3 L1/L2-Low using six satellites - three L1 satellites (12, 8, 4 o'clock positions) and three L2 satellites (6, 2, 10 o'clock positions).

C6-4 L1/L2-Low using eight satellites - four L1 and four L2 satellites (12, 9, 6, 3 o'clock positions).

C7 The L1-Geo constellation uses two L1 satellites (12, 6 o'clock positions) and three Earth-geosynchronous satellites in a circular, equatorial orbit over longitudes 179 degrees West, 59 degrees West, and 61 degrees East. Satellite positions are given at the start of epoch. The L1/Earth-based Augmentation constellations (C7 through C10) were intended to explore lunar navigation coverage using low-risk approaches that took advantage of existing or easily implemented assets.

C7-L L1-Geo Low using the three geosynchronous satellites plus two satellites in an L1-Low orbit (3,473 Km) as described in constellation C3.

C7-H L1-Geo High using the three geosynchronous satellites plus two satellites in an L1-high orbit (17,384 Km) as described in constellation C4.

C8 The L1-2xGeo constellation uses two L1 satellites (12, 6 o'clock positions) and three Earth satellites at twice the geosynchronous altitude in a circular, equatorial orbit

over longitudes 179 degrees West, 59 degrees West, and 61 degrees East at the start of epoch.

C8-L L1-2xGeo Low using the three twice-geosynchronous-altitude satellites plus two satellites in an L1-Low orbit (3,473 Km) as described in constellation C3.

C8-H L1-2xGeo High using the three twice-geosynchronous-altitude satellites plus two satellites in an L1-high orbit (17,384 Km) as described in constellation C4.

C9 The DSN-Geo constellation uses all DSN stations in view to the user (one or two) and three Earth-geosynchronous satellites as described in constellation C7 as direct ranging sources, as well as using the three geosynchronous satellites for TDOA measurements.

C10 DSN-2xGeo constellation uses all DSN stations in view to the user (one or two) and three evenly spaced, Earth satellites at twice the geosynchronous altitude, as described in constellation C8, for direct ranging sources, as well as using the three twice-geosynchronous-altitude satellites for TDOA measurements.

Table 4.3 summarizes the candidate constellations and related scenarios.

Table 4.3 Candidate Constellations

Constellation		Description
C1		Moon polar, low-altitude constellation
C2		Moon polar, medium-altitude constellation
	C2-3	3 satellites per orbit
	C2-4	4 satellites per orbit
C3		L1 Low altitude constellation
	C3-2	2 satellites per orbit
	C3-3	3 satellites per orbit
	C3-4	4 satellites per orbit
C4		L1 High altitude constellation
	C4-2	2 satellites per orbit
	C4-3	3 satellites per orbit
	C4-4	4 satellites per orbit
C5		L1/L2 Low altitude constellation
	C5-1	1 satellites per orbit
	C5-2	2 satellites per orbit
	C5-3	3 satellites per orbit
	C5-4	4 satellites per orbit
C6		L1/L2 High altitude constellation
	C6-1	1 satellites per orbit
	C6-2	2 satellites per orbit
	C6-3	3 satellites per orbit
	C6-4	4 satellites per orbit
C7		L1-Earth Geosynchronous
	C7-L	Low altitude
	C7-H	High altitude
C8		L1-2xEarth Geosynchronous
	C8-L	Low altitude
	C8-H	High altitude
C9		DSN-Earth Geosynchronous
C10		DSN-2xEarth Geosynchronous

V. Results and Analysis by Constellation

NASA wants to provide an onboard, real-time, accurate navigational capability for future lunar missions. This entails providing a high-accuracy navigation solution 100 percent of the time during mission operations. Since the areas under consideration for future missions are the moon's South pole and the equator near the center of the lunar "near" side, this thesis analyzes 46 user positions from the South pole to the equator in increments of two degrees of lunar latitude. Candidate navigation satellite constellation analysis focuses on the issues of acceptable DOP value availability and position solution relative accuracy, as indicated by the available DOP value magnitudes.

However, it should be kept in mind that DOP represents a statistical description of the position error and is not a direct measure of the absolute error in an individual position estimate. A lower DOP value does not guarantee a lower position error for every measurement. Since each range measurement includes a small, random error, the position estimate derived from those measurements will also include a random error. The distribution of the position estimates is assumed to be Gaussian, described by its mean (average) and covariance (the spread of the position estimates around the mean). The mean represents the best combined or overall estimate (in an unweighted, least squares sense) of the true user position, while the covariance represents how far the individual position estimates may vary, or spread out, from this best estimate. The square root of the covariance is referred to the standard deviation. The standard deviation of the position estimates, taking into account all error sources, is called the user range error standard deviation (σ_{ure}). The root-mean-squared (RMS) average of the position errors is equal to σ_{ure} times the DOP, as shown in Equation (5.1), given the assumptions that the measurement errors are zero-mean and identically distributed (as described in chapter three for the derivation of the geometry matrix).

$$RMS\ position\ error = \sigma_{ure} \cdot DOP \tag{5.1}$$

Therefore, assuming a constant σ_{ure}, DOP can be considered an indication of the average error that is likely to occur in a user position estimate. Actual position errors may be larger or smaller than this average. Dilution of precision, as a multiplier of σ_{ure}, is a linear operator. Therefore, DOP values can be directly compared to one another to determine relative accuracy between two constellations or scenarios. A DOP of five will result in a three-sigma accuracy that is two-times better (on average) than that provided by a DOP of ten, for the same user range error statistics.

The effect of geometry on the navigation position solution can be demonstrated with a simple two-dimensional case, shown in Figure 5.1, as described by Misra and Enge [17]. A user determines the distance from his location to two satellites at known positions. If the measurements were perfect, the user's position would be at one of the intersections of the two circles described by the range to the satellites. If the user knows the general location of his position, one of the two possible points can be eliminated, and the exact location determined.

However, if he uses an imperfect device that includes a random error in the range measurement with a three-sigma accuracy of δ units, an area of uncertainty exists, within which lies the user's true location. The geometry of the satellites affects the size of this area. The area is smallest in case (b) for which the measurements are coming from orthogonal directions. This represents the optimal geometry for this two-dimensional space. Case (c) includes a position ambiguity, as well as position uncertainty, because the two possible user locations are too close together to determine which is correct. The uncertainty in case (a)

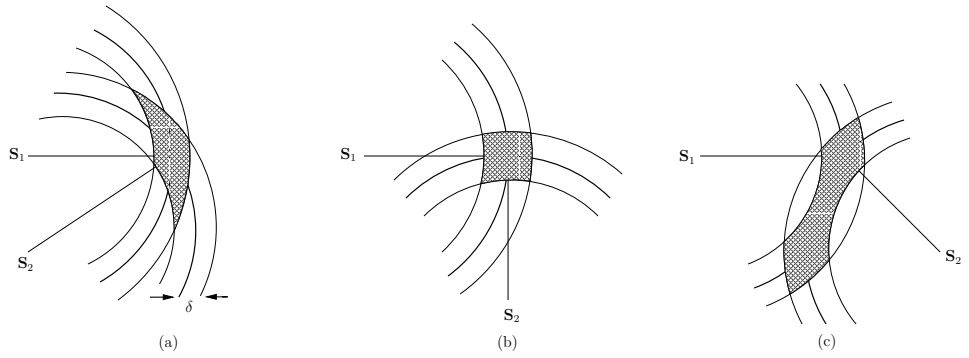

Figure 5.1 Position Estimation with Range Measurements

potentially has the greatest area, since it will increase as the angle between the satellites decreases. In the extreme situation in which the angle is zero, the second measurement is redundant and does not contribute to the position solution. This would represent an underdetermined case for which a position solution is not determinable.

In general, lower DOP values indicate better accuracy, however, DOP cannot be zero, as this would indicate that a user would always get a perfect position solution regardless of the measurement errors. A negative DOP value is undefined according to Equation (5.1), since an RMS position error must be non-negative. Under optimal geometries with large numbers of measurements (generally 13 or more), position DOP can take on a value less than one, indicating that the RMS average of the position error is smaller than the measurement standard deviation.

The following categories relate the DOP values for a three-dimensional position to the RMS position error for each scenario.

- Very Good (DOP ≤ 5)
- Good ($5 <$ DOP ≤ 10)
- Marginal ($10 <$ DOP ≤ 30)
- Unavailable ($30 <$ DOP)

This research used the Satellite Orbital Analysis Program [1] to simulate all lunar orbits, Earth station positions, and Earth satellite orbits. The positions of all simulation objects were calculated at five minute intervals for 655.7 hours (one lunar sidereal month), resulting in 7,869 measurement epochs (a lunar sidereal month is the time for the moon to make one complete revolution around the Earth). A lunar sidereal month was chosen as the simulation length to capture any long-term, low dynamic effects on the DOP levels by the moon's motion. The satellite positions were stored in a file, which was accessed by a MATLAB®[2] program that determined line-of-sight visibility between the user and the simulation objects, generated the measurement matrix, and calculated the DOP for each epoch. As stated previously, DOP values greater than 30 were assumed to exceed any future specifications to such an extent that a useful position solution would be unavailable.

Constellation C1 - Low Polar

DOP is affected by the number of measurements available, as well as the user-satellite geometries. The first scenario considered is that of a user on the lunar surface at the south pole. Figure 5.2 shows the available DOP values with both direct ranging and TDOA measurements available for the first twelve hours of the simulation. The cyclic behavior of low DOP values followed by unavailable values (DOP > 30) repeats at approximately 80 to 85 minute intervals, with the DOP remaining below five for approximately 50 to 55 minutes of that time. The cause of the large and sudden variability of the DOP can be determined from the number of measurements available during the period. As the constellation moves, the number of satellites in view varies from two to five, as shown in Figure 5.3. Note that the DOP is always above 30 when there are only two measurements available because there are insufficient measurements to determine a position solution. When there are fewer than three measurements available, the DOP is infinite. Even though the number of measurements is a key factor in determining DOP, it is not the only one. Satellite

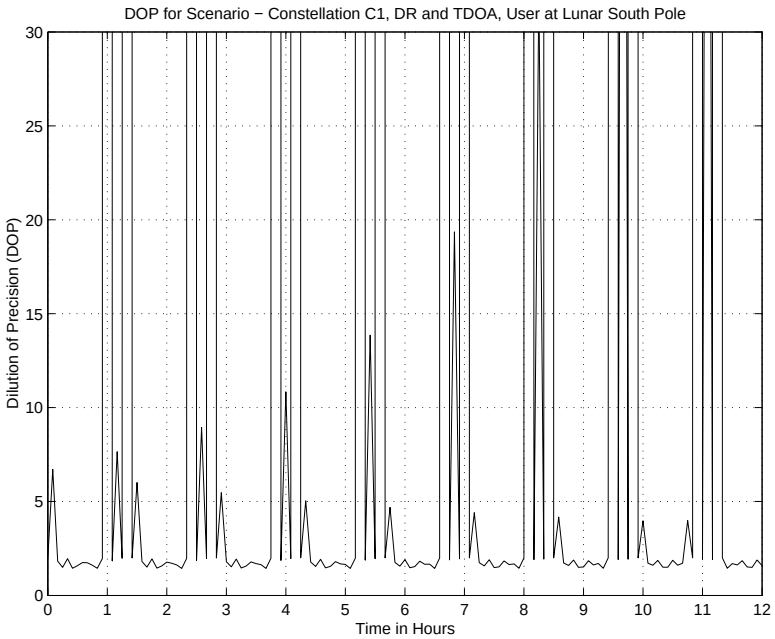

Figure 5.2 DOP Versus Time (First 12 Hours of Simulation) for Constellation C1 (Low Polar), User at the Lunar South Pole, Direct Ranging and TDOA Measurements Available

geometry also has a significant effect. Consider the DOP for two epochs with only three direct ranging measurements available, occurring at 6 hours, 50 minutes (6.83 hours) and 7 hours, 10 minutes (7.17 hours) into the simulation, as shown in Figures 5.4 and 5.5 (it will be shown in a later section that only direct ranging measurements are available for a user at the South pole during this time). The DOP levels are 19.35 and 4.41, respectively. This large difference in DOP for the same number and type of measurements is due solely to the changing geometry of the constellation.

Figure 5.6 shows the DOP levels for the same user at the South pole over the entire month, where the effect of the moon's motion on the available DOP can be seen. The period from the 73rd hour to the 422nd hour of the simulation has lower DOP values, in general, than the rest of the period due to the availability of TDOA measurements in addition to the direct ranging measurements. This is confirmed by the plot of the number of TDOA measurements available, shown in Figure 5.7, which shows that there were no TDOA measurements available during the first 73 hours and the last 234 hours of the

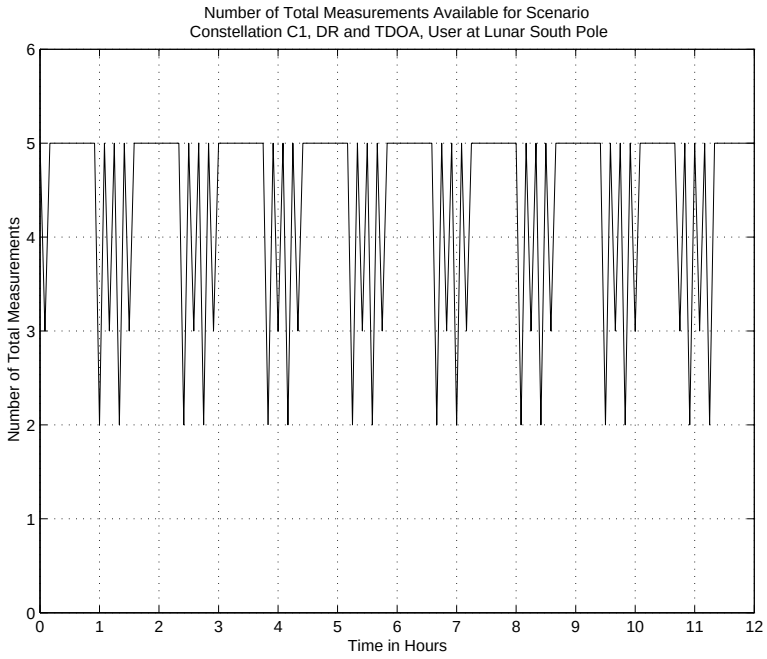

Figure 5.3 Total Number of Available Measurements Versus Time (First 12 Hours of Simulation) for Constellation C1 (Low Polar), User at the Lunar South Pole, Direct Ranging and TDOA Measurements Available

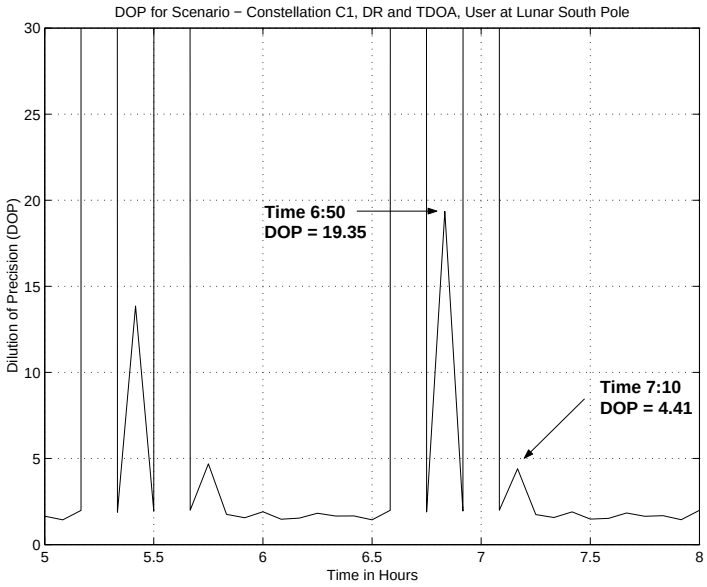

Figure 5.4 DOP Versus Time (Hours Five to Eight of Simulation) for Constellation C1 (Low Polar), User at the Lunar South Pole, Direct Ranging Measurements Only Available

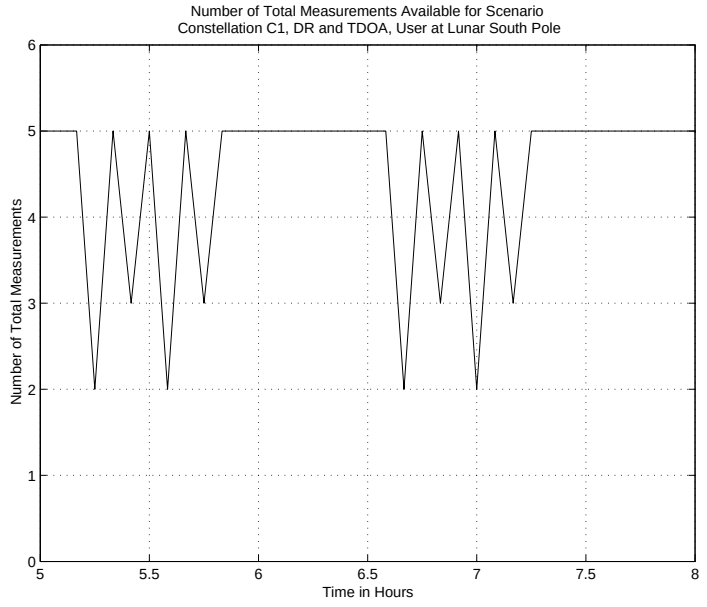

Figure 5.5 Total Number of Available Measurements Versus Time (Hours Five to Eight of Simulation) for Constellation C1 (Low Polar), User at the Lunar South Pole, Direct Ranging Measurements Only Available

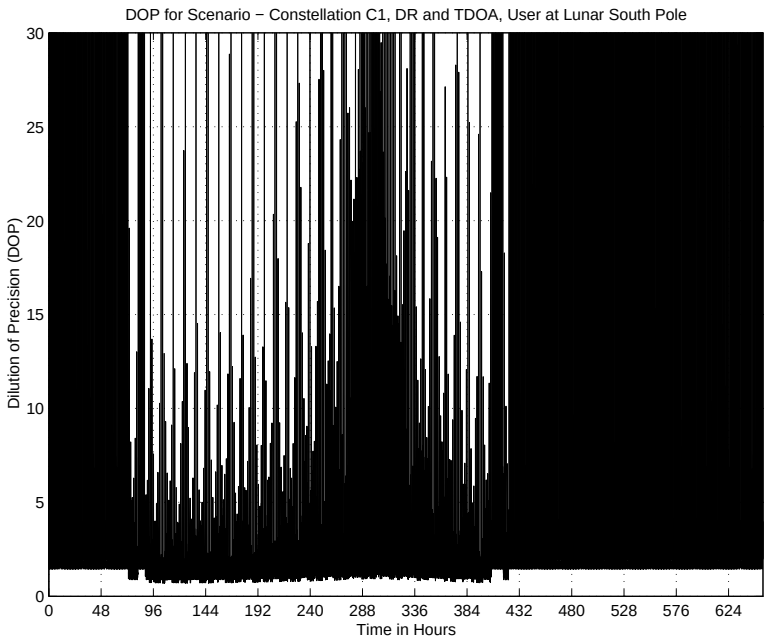

Figure 5.6 DOP Versus Time for Constellation C1 (Low Polar), User at the Lunar South Pole, Direct Ranging and TDOA Measurements Available

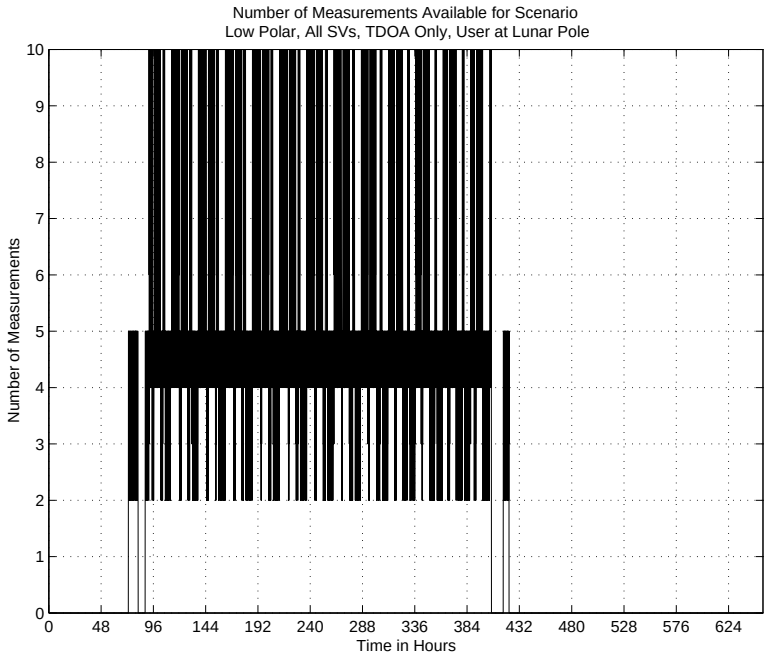

Figure 5.7 Number of Available Measurements for Constellation C1 (Low Polar), TDOA Measurements Only, User at the lunar South Pole, 27 days of data

simulation. This significant gap in TDOA measurement coverage is due to the motion of the moon in its orbit. During the lunar month, the moon exhibits an apparent rocking motion along a North-East/South-West line, as viewed from the Earth. This results in the lunar south pole being blocked from the Earth's view for approximately two weeks during the month. Since TDOA measurements require the user and the Earth-based DSN station to have a direct line of sight, they are unavailable during this period.

The cumulative probability of achieving at least a given level of DOP during the lunar month for a user at the south pole is shown in Figure 5.8. For example, the probability value for a DOP of 30 represents the percentage of measurement epochs for which the DOP was less than or equal to 30 (note that this is referred to as the total availability). The graph also indicates the quality of the available position solutions by the shape of the curve. A curve that rose to 100 percent before reaching a DOP of 5 would indicate that a "Very Good" position solution would always be available.

In order to determine where the best operating locations on the moon might occur, the availability of DOP values is plotted versus South latitude (see Figure 5.9). The top plot shows the total availability of DOP (30 or less), along with the corresponding availabilities for Very Good (DOP ≤ 5), Good ($5 <$ DOP ≤ 10), and Marginal ($10 <$ DOP ≤ 30). The bottom plot shows the RMS value of the available DOP (the RMS of available DOP should not be confused with the RMS position error, as described in Equation (5.1)). DOP values over 30 were removed from the RMS calculation for each scenario and an RMS value was not calculated for latitudes where all DOP values were larger than 30. The data used to create the availability graphs is provided in tabular form in Appendix A.

Figure 5.9 shows that availability is essentially 100 percent from 66 degrees to 84 degrees South latitude. The accuracy of the position solution for this region is high, as indicated by both the high availability of "Very Good" DOP in the upper plot and the low RMS values in the lower plot. The drop in availability from approximately 84 degrees to the pole results from the moon's rocking motion. This is similar to the Arctic and Antarctic circles on Earth, above which the tilt of the Earth blocks the sun from view during part of the Earth's solar orbit. When the user is in a position where the Earth is in view, the TDOA measurements complement the direct ranging measurements, resulting in

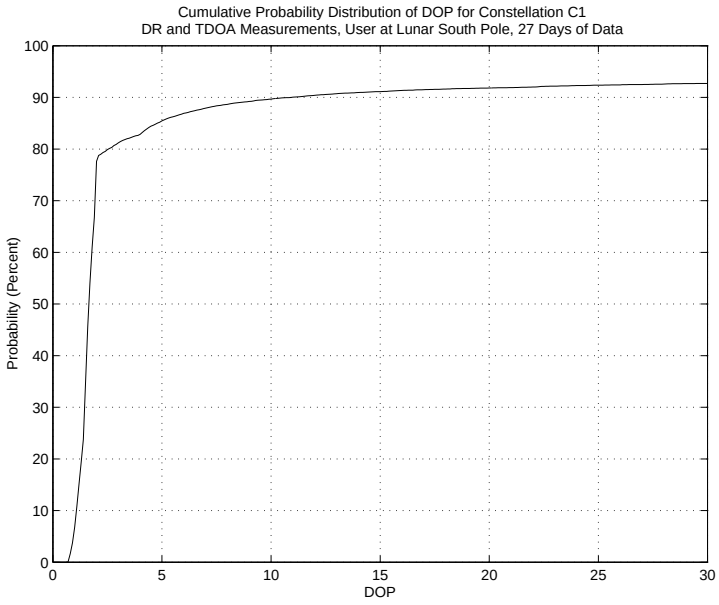

Figure 5.8 Probability Distribution of DOP for Constellation C1 (Low Polar), Direct Ranging and TDOA Measurements Available, User at the Lunar South Pole, 27 Days of Data

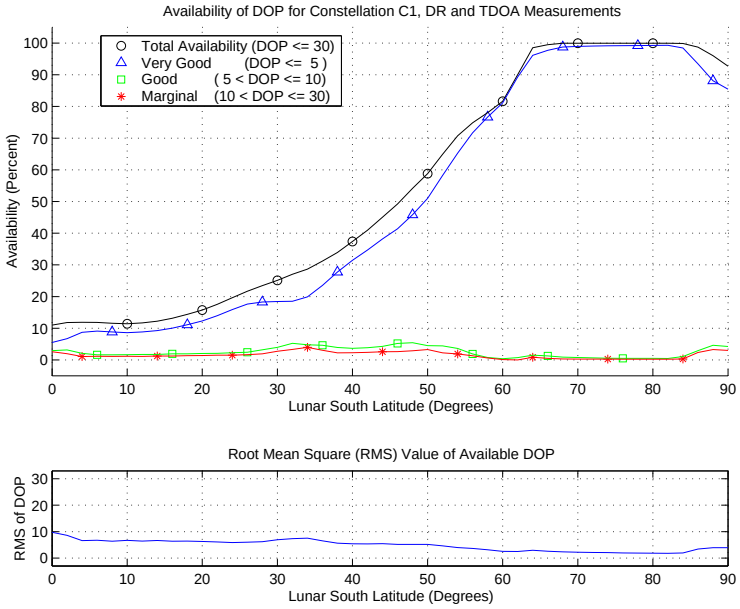

Figure 5.9 Percent Availability and RMS Value of DOP Versus South Latitude for Constellation C1 (Low Polar), Direct Ranging and TDOA Measurements Available, 27 Days of Data

lower DOP values and greater availability from the equator to 84 degrees South latitude. These results indicates that if critical operations are necessary between 84 degrees and the South pole, they should be conducted during the two week window when the pole is facing the Earth to allow minimum DOP levels with the accompanying greater navigational accuracies. Figure 5.10 shows the percent availability of DOP values for a user at the South pole during the period when the pole is facing the Earth, using both direct ranging and TDOA ranging. The overall availability increases from 92.46 percent to 97.61 percent, with the percentage availabilities of DOP increasing to 89.79 percent (Very Good), 4.43 percent (Good), and 3.39 percent (Marginal), for this 310-hour period.

It should be noted that there were 332 epochs for which the position DOP was less than one, using both ranging methods with the user at the south pole. The lowest DOP was 0.8414, which occurred at 104 hours, 50 minutes (1,259th epoch) when there were five satellites (1d, 2c, 3d, 4c, 5d) and two DSN stations (Australia and Spain) in view, resulting in 15 measurements being available (5 direct range, 10 TDOA). This favorable geometry results from satellites 1d, 3d, and 5d evenly subtending an arc of 144 degrees in azimuth (around the horizon) with satellite 3d on the horizon facing away from the Earth, while satellites 2c and 4c are almost directly overhead the user. This is close to the optimum five-satellite GPS configuration described by Spilker [20], in which three satellites on the horizon are separated by 120 degrees in azimuth with two satellites overhead. By incorporating TDOA measurements, however, the DOP of the lunar constellation exceeds both the expected DOP of the GPS system for a similar geometry (with three satellites spread 72 degrees apart in azimuth and two overhead), as well as the optimal, five-satellite GPS DOP. The estimated position DOP for GPS using the same configuration is 2.6, while the optimal GPS position DOP with five satellites is 1.5 [6]. The higher DOP values for a comparable GPS configuration result from GPS satellites only providing one measurement per satellite, while combined direct ranging and TDOA measurements can provide up to three measurements per satellite (one direct ranging and two TDOA). The rapid variability of DOP can be seen in Figure 5.11, in which the prevailing DOP values during the 104th hour are generally in the vicinity of unity, with a large spike to 69.34 at 104 hours, 30 min, followed twenty minutes later by the minimum DOP for the entire lunar month.

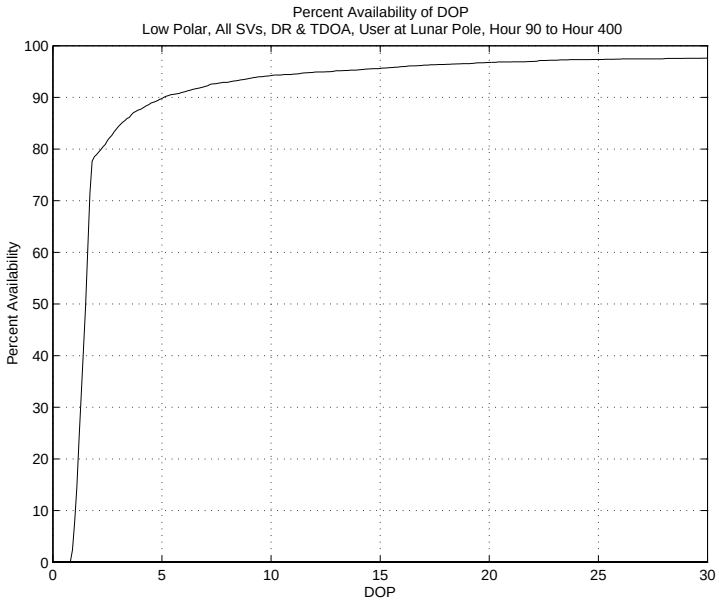

Figure 5.10 Percent Availability of DOP for Constellation C1 (Low Polar), Direct Ranging and TDOA Measurements Available, User at the lunar South Pole During Period When South Pole Faces the Earth (Hour 90 to Hour 400)

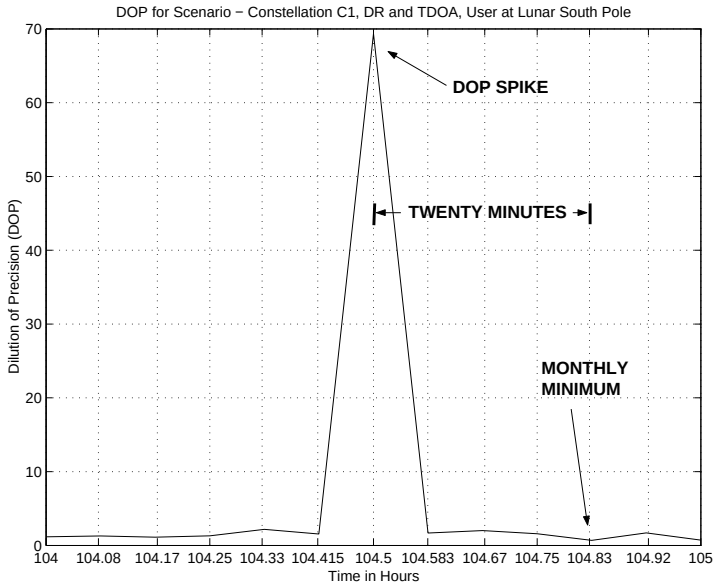

Figure 5.11 Minimum DOP for Constellation C1 (Low Polar)(0.8414 at 104 Hrs, 50 Min [104.833 Hrs]), Direct Ranging and TDOA Measurements, User at the lunar South Pole, 27 days of data

For the C1 constellation, the price to be paid for good performance at higher latitudes is poor performance in the equatorial region, due primarily to the lack of overlapping satellite coverage. Figure 5.12 shows the number of direct ranging measurements available to the user at the equator, indicating there were no more than two satellites visible at any time. This limits the maximum number of measurements available to six. The effect of satellite geometry on the position solution can be seen from Figures 5.13 and 5.14, which show the total number of measurements available and the corresponding DOP values for the 31st hour of the simulation. During this time, the DOP exceeds 30 when there are three measurements available (one satellite and two DSN stations), even though a position solution is possible (actual DOP values for these epochs are between 100 and 500). When four measurements are available (two satellites and one DSN station) the DOP values drop to 2.6; however, when six measurements are available (two satellites and two DSN stations) the DOP value actually increases to 3.9. While these are very good values, it demonstrates that adding more measurements cannot always overcome poor geometry. In this case, when the second DSN station came into view, the satellites had moved to a slightly less advantageous geometry. The addition of another TDOA measurement does not dramatically increase the accuracy of the resulting position solution because both TDOA measurements come from almost identical directions (note that the DOP value of 3.9 would be higher without the second TDOA measurement).

Figure 5.15 summarizes the total availability versus latitude for all three measurement types, direct ranging and TDOA measurements combined, direct ranging measurements only, and TDOA measurements only, along with the respective RMS values for the available DOP. The benefits of combining the measurement types can be seen in the latitudes from zero to 40 degrees, where neither measurement type by itself provides a solution for any appreciable amount of time, but the combined measurement is available 10 percent of the time or more, while providing a "Good" RMS value over the region. The TDOA-only measurements provide a "Marginal" solution only 0.06 percent of the time or less for this region, as reflected by the TDOA RMS line in the lower plot reading slightly below 30. At the equator, the availability of four TDOA measurements when two DSN stations are in view drives the DOP down below 30 for only three epochs during the entire month, which

occur at 480 hours, 45 minutes (DOP of 29.2), 481 hours, 05 minutes (DOP of 28.7), and 481 hours, 50 minutes (DOP of 29.3).

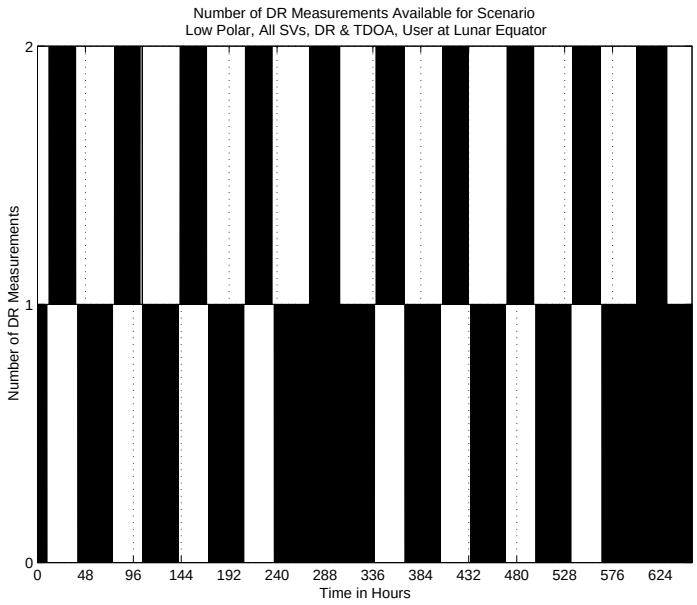

Figure 5.12 Number of Direct Ranging Measurements for Constellation C1 (Low Polar), User at the Equator, 27 days of data

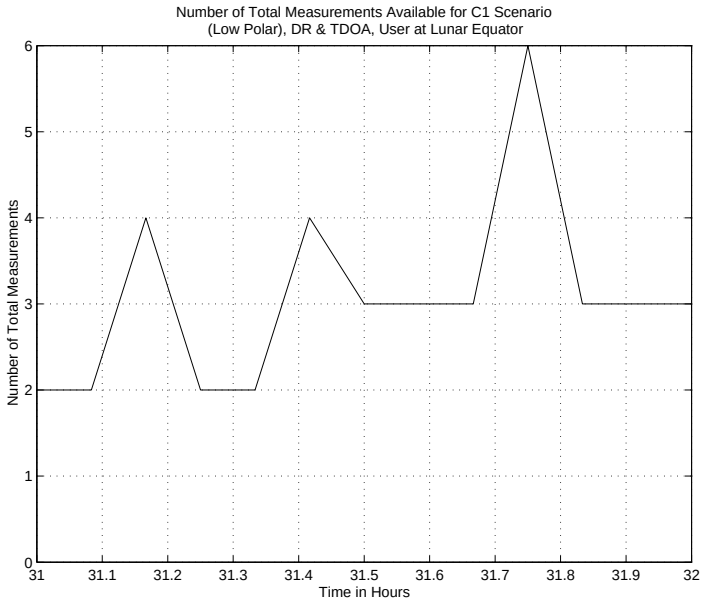

Figure 5.13 Total Number of Available Measurements for Constellation C1 (Low Polar) during the 31st Hour, User at the Equator, 27 days of data

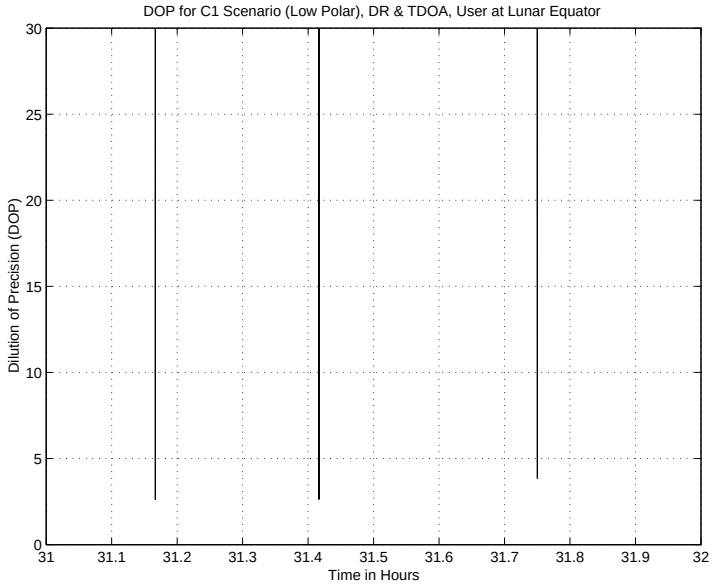

Figure 5.14 DOP for Constellation C1 (Low Polar) during the 31st Hour, User at the Equator, 27 days of data

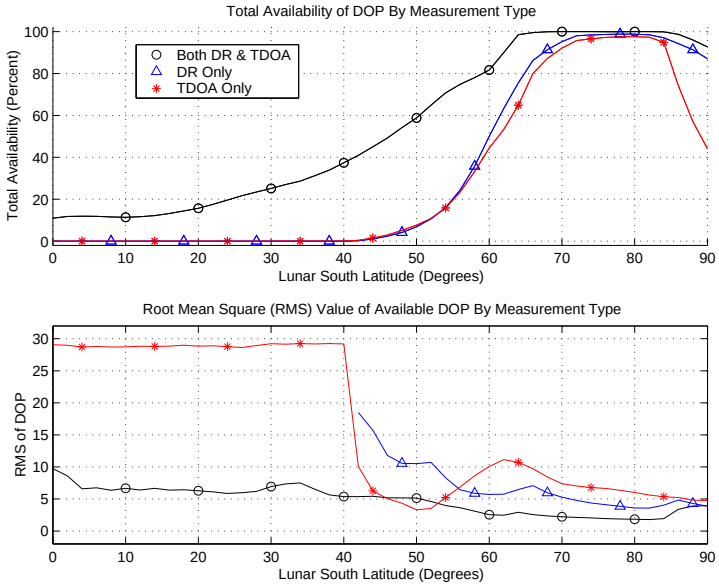

Figure 5.15 Total Availability and RMS Value By Measurement Type for Constellation C1 (Low Polar), 27 Days of Data

Constellation C2 - Medium Polar

The advantages of a medium altitude constellation over a low altitude constellation are larger areas of coverage for each satellite, along with slower orbital speeds. These two effects result in longer viewing times and greater overlap of coverage between satellites. Because of these factors, a medium altitude constellation requires fewer satellites than a low altitude constellation to obtain comparable levels of accuracy and availability.

The DOP analysis was performed for constellations C2-3 and C2-4, as shown in Figures 5.16 and 5.17, which are medium polar orbits with three and four satellites per orbit, respectively (see Chapter 4 for a complete description of the these constellations). Most noticeably, the overall availability for constellation C2-3 at the pole is 47.5 percent versus 92.5 percent for the C1 constellation, due to the reduced number of satellites in view from the pole, as well as the restriction of TDOA measurements, as discussed for constellation C1. However, both constellations C1 and C2 exhibit a similar increase in availability and accuracy as the user position moves into full view of the Earth from the equator to 84 degrees South latitude.

While the geographic coverage where the maximum availabilities occur is similar to that of the low polar constellation, the availability for the medium constellation does not decrease as quickly with decreasing latitude as does the low constellation. Constellation C2-3 provides DOP availabilities above 80 percent down to 36 degrees latitude, as compared with 60 degrees latitude for constellation C1. The higher RMS levels of C2-3 are balanced by the increased availability across a larger geographic region. DOP availability for C2-3 at the equator only drops to 59.9 percent, as opposed to C1 which drops to 10.9 percent, indicating that a medium altitude constellation with 80 percent fewer satellites (6 for C2-3 versus 30 for C1) almost matches the performance of a low constellation.

The RMS values of Figure 5.16 appear to show that the direct ranging measurement performance exceeds the combined measurement performance, however, this is not the case. Care should be taken when comparing RMS values for measurement types that do not have the same availability for a given latitude. The RMS values are calculated from the available DOP only, not all DOP values. The figure's total availability section shows

that the combined measurement availability is much greater than the direct ranging availability. During epochs when the direct ranging and TDOA measurements are unavailable individually, they may provide enough measurements for a combined position solution. This combined solution may have a relatively poor DOP value, contributing to the high RMS value, however, it is obviously higher than the zero value of the other measurement types during that epoch.

Constellation C2-4 uses eight satellites in a medium altitude constellation, which provides the low DOP levels of the low altitude constellation with the larger geographic coverage of the medium constellation. Not only are the maximum availabilities of constellation C2-4 above 98 percent from 84 to 46 degrees South latitude, but the DOP values at the majority of latitudes are less than 5. At the equator, constellation C2-4 provides a 51.3 percent availability, which is slightly lower than the 62.7 percent of C2-3. The latter provides higher availability from zero to 26 degrees South latitude. However, the increased accuracy of C2-4, which is three times better than C2-3, compensates for the slight decrease in availability. This is shown by the RMS DOP values of 15.17 for C2-3

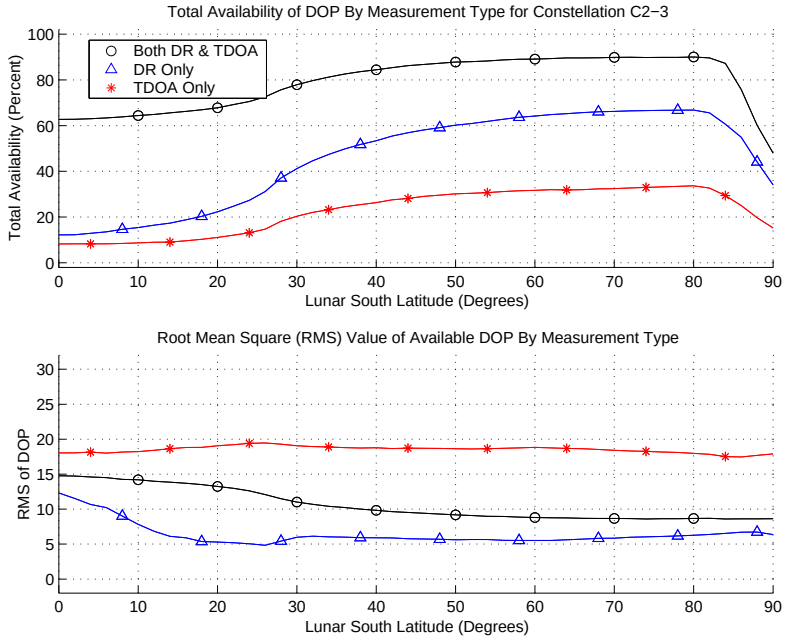

Figure 5.16 Total Availability and RMS Value By Measurement Type for Constellation C2-3 (Medium Polar), 27 Days of Data

versus 5.18 for C2-4 at the equator. The RMS accuracy of constellation C2-4 is higher than that of C2-3 at all latitudes, which indicates that the former provides a better position solution, when available.

Figure 5.18 shows the DOP for constellation C2-4, for a user at the South pole. The high DOP levels at the beginning and end of the period are due to the lack of TDOA measurements, as was the case with constellation C1. This is confirmed by the number of measurements available, as shown in Figure 5.19. In contrast, the variability of DOP values for a user at 82 degrees South latitude, shown in Figure 5.20 with the corresponding availability of measurements shown in Figure 5.21, results not from additional measurements, but almost entirely from changes in the constellation geometry.

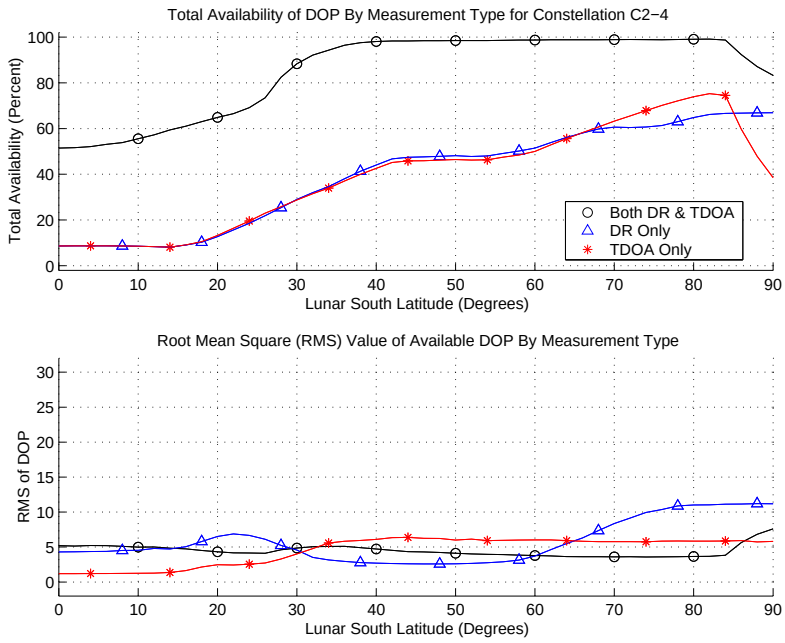

Figure 5.17 Total Availability and RMS Value By Measurement Type for Constellation C2-4 (Medium Polar), 27 Days of Data

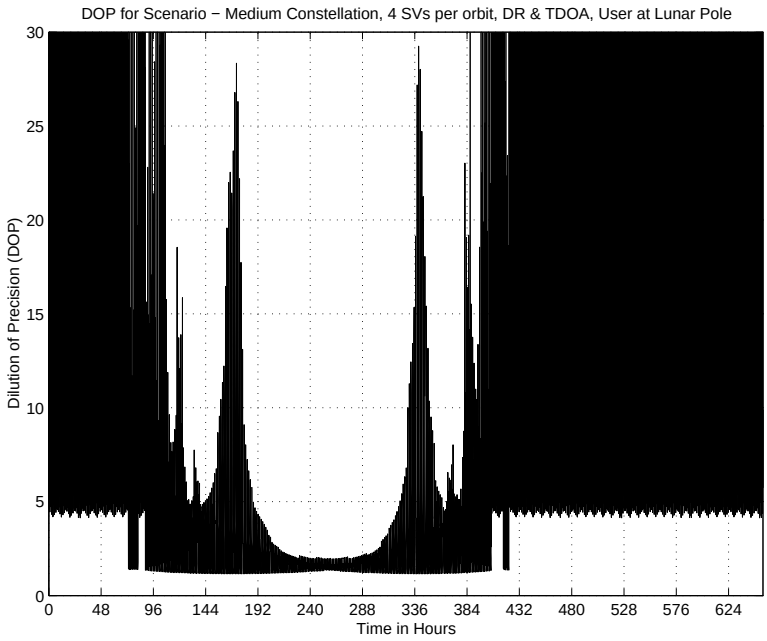

Figure 5.18 DOP for Constellation C2-4 (Medium Polar), Direct Ranging and TDOA Measurements, User at South Pole, 27 days of data

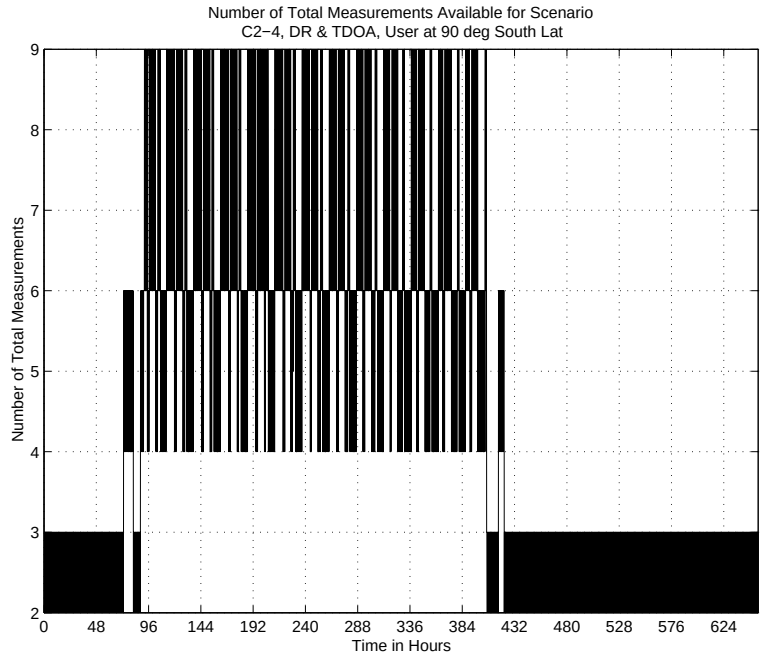

Figure 5.19 Number of Measurements Available for Constellation C2-4 (Medium Polar), Direct Ranging and TDOA Measurements, User at South Pole, 27 days of data

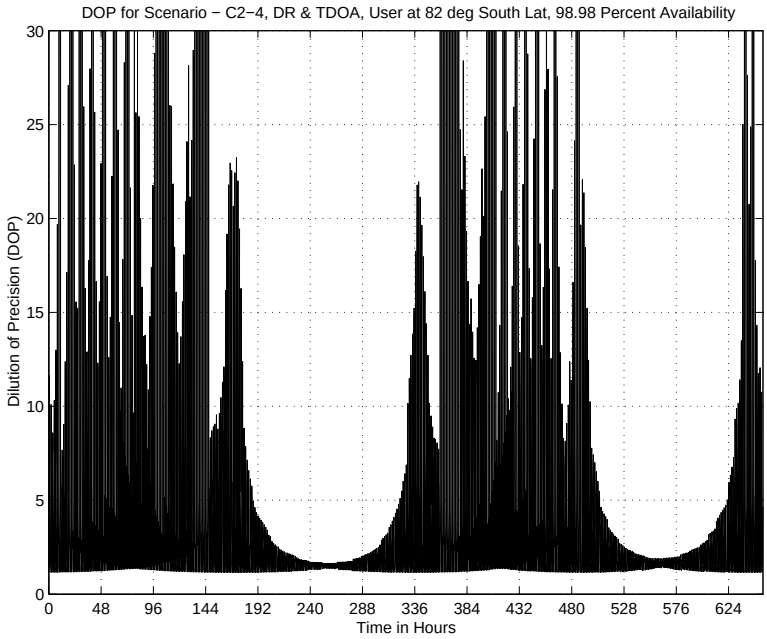

Figure 5.20 DOP for Constellation C2-4 (Medium Polar), Direct Ranging and TDOA Measurements, User at 82 Degrees South Latitude, 27 days of data

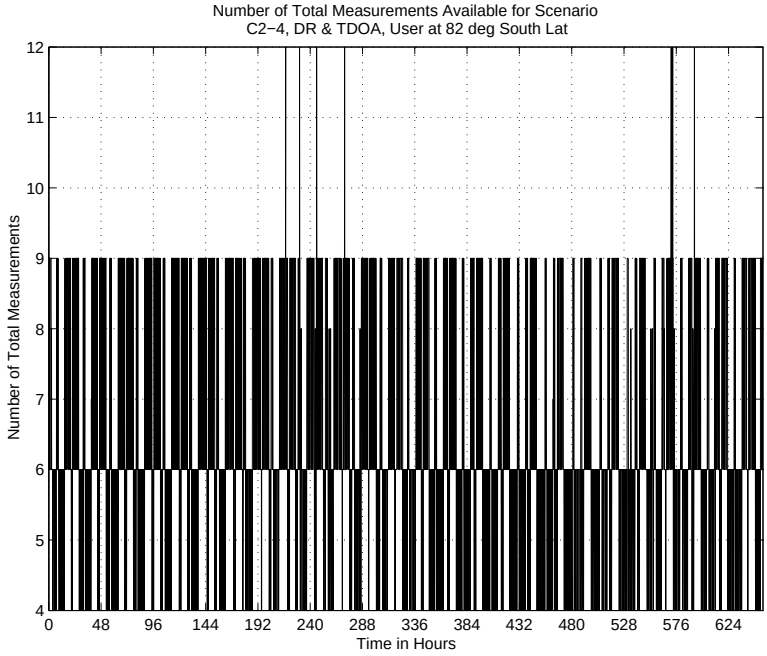

Figure 5.21 Number of Available Measurements for Constellation C2-4 (Medium Polar), Direct Ranging and TDOA Measurements, User at 82 Degrees South Latitude, 27 days of data

Constellation C3 - L1 Low

The L1 constellations hold an advantage over the moon orbiting constellations in that a user can operate over a large geographic range and keep all the L1 satellites in view. Since the L1 point is between the Earth and moon, it is also ideally suited to the use of TDOA measurements. The major drawback of an L1-only constellation is that its coverage does not reach the lunar "far" side and is limited at the poles. However, if these areas are not required for mission operations, then the lack of coverage for them is a moot issue.

Figure 5.22 shows the availability of constellation C3-2 for all measurement types. This constellation contains two satellites in a low L1 orbit, with an orbital radius of 3,473 Km (twice the moon's radius). The shape of the availability curve is more consistent over a much larger region, remaining in the range of 67 to 75 percent from the equator to 84 degrees South latitude. While this is less desirable, in general, than the results of constellation C2-4 (medium polar constellation with eight satellites), it demonstrates the characteristic availability of the L1 constellations. The combined measurement (direct ranging and TDOA) availability rises to 100 percent over the same region for constellation C3-3 by using three, evenly distributed satellites, as shown in Figure 5.23. The contribution of the TDOA measurements to the accuracy of the position solution is clearly visible in the lower plot of RMS values, in which the combined RMS is approximately half of the direct ranging RMS for latitudes between the equator and 84 degrees. An additional benefit of this constellation is that it provides almost total coverage for two different measurement types. If mission requirements can be met with RMS values near 20, then the complexity of the navigation system can be reduced by only using direct ranging measurements. Unfortunately, their availability drops off sharply near the South pole, where it is down to 28.9 percent at 86 degrees and zero at 88 degrees, as well as at the pole. The combined measurements provide slightly better availability, with 63 percent at 86 degrees latitude, 20 percent at 88 degrees latitude, and 2 percent at the pole. At these extreme southern latitudes, the user is "over the horizon" and the curvature of the moon blocks the satellites from view as they rotate in the "northern" portion of the L1 orbit.

Figure 5.24, availability of constellation C3-4 (four satellites in low L1 orbit) for all measurement types, shows an improvement in both coverage and RMS values, in which the

availability is 100 percent from the equator to 86 degrees latitude for both the combined and direct ranging measurements. The direct ranging measurement availability increases to 18 percent at 88 degrees latitude, while the combined measurement availability increases to 44 percent at 88 degrees and 11 percent at the pole. The effect on the RMS values is less noticeable: the direct ranging RMS values are lowered by approximately 2.5 and the combined measurement RMS values drop by around 1.3 from the equator to 84 degrees. If future missions must operate at the extreme southern latitudes (between 84 and 90 degrees), then the cost of using a fourth satellite for this constellation may be justified. However, this will probably not be the case for operations at the other latitudes, where the additional accuracy brought by the fourth satellite is rather small.

The DOP values for constellation C3-3 reflect the availability of measurements, as discussed for constellation C1, and seen in Figure 5.25, which shows DOP versus time for the combined measurements for a user at 82 degrees South latitude. All three satellites are in constant view of the user from this location. The changing number of measurements, from six to nine, causes the high frequency component of the DOP graph, as the DSN stations pass into and out of view. The low frequency component appears to have a period close to 345 hours, which is slightly longer than half of the moon's sidereal period of 655.7 hours. A similar undulation appears in the DOP graph at all latitudes from 82 degrees to the equator. The direct ranging measurements provide DOP values that are much more stable during the month because the constellation appears to rotate in the same portion of the sky, with all three satellites visible at all times. Figure 5.26 shows DOP versus time for direct ranging measurements for a user at 82 degrees South latitude, where it can be seen that the DOP is constant for the entire month.

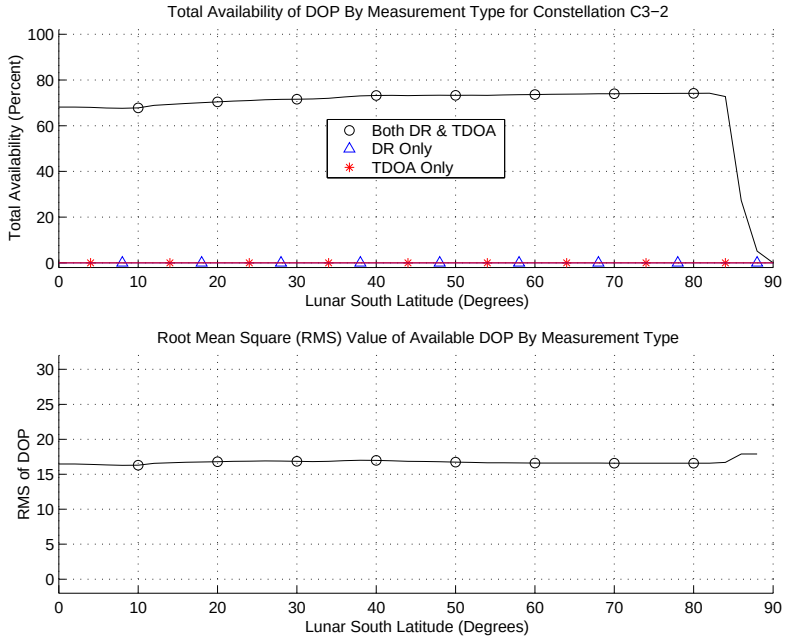

Figure 5.22 Total Availability and RMS Value By Measurement Type for Constellation C3-2 (L1 Low), 27 Days of Data

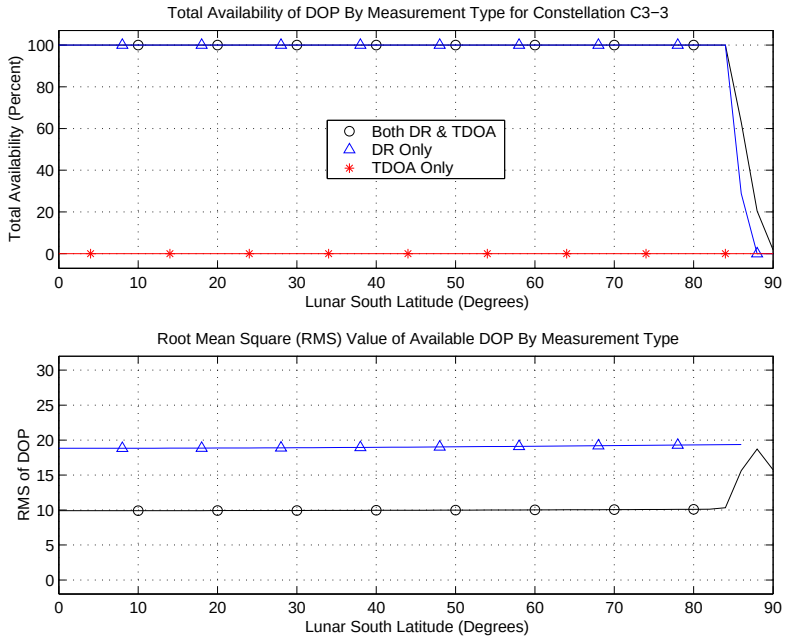

Figure 5.23 Total Availability and RMS Value By Measurement Type for Constellation C3-3 (L1 Low), 27 Days of Data

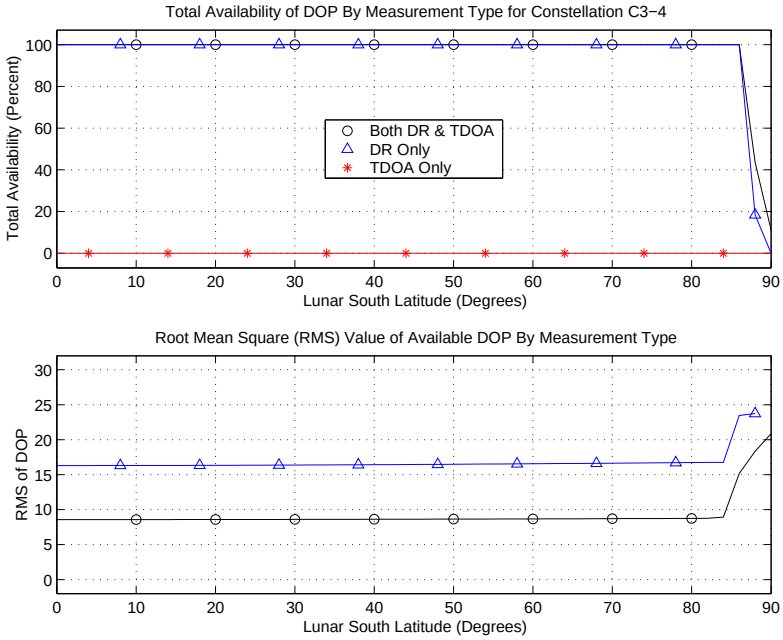

Figure 5.24 Total Availability and RMS Value By Measurement Type for Constellation C3-4 (L1 Low), 27 Days of Data

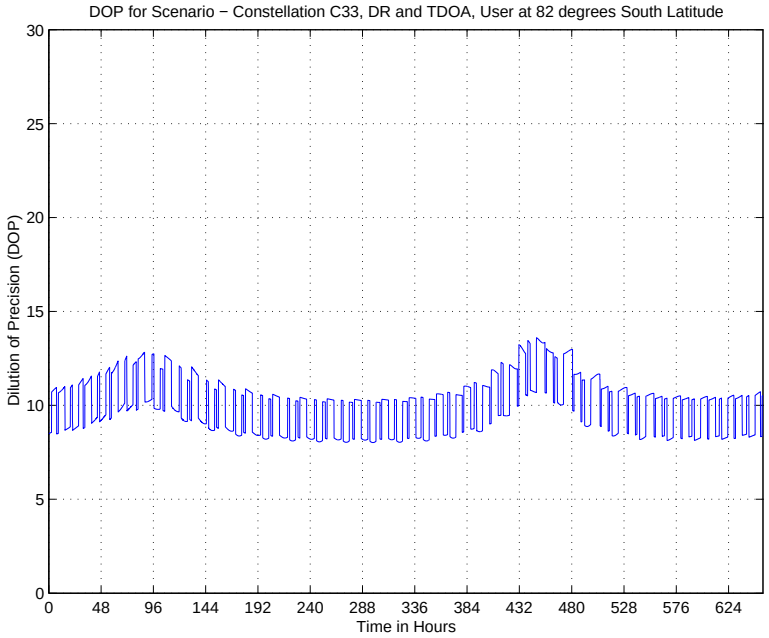

Figure 5.25 DOP Versus Time for Constellation C3-3 (L1 Low), User at 82 Degrees South Latitude, Direct Ranging and TDOA Measurements Available

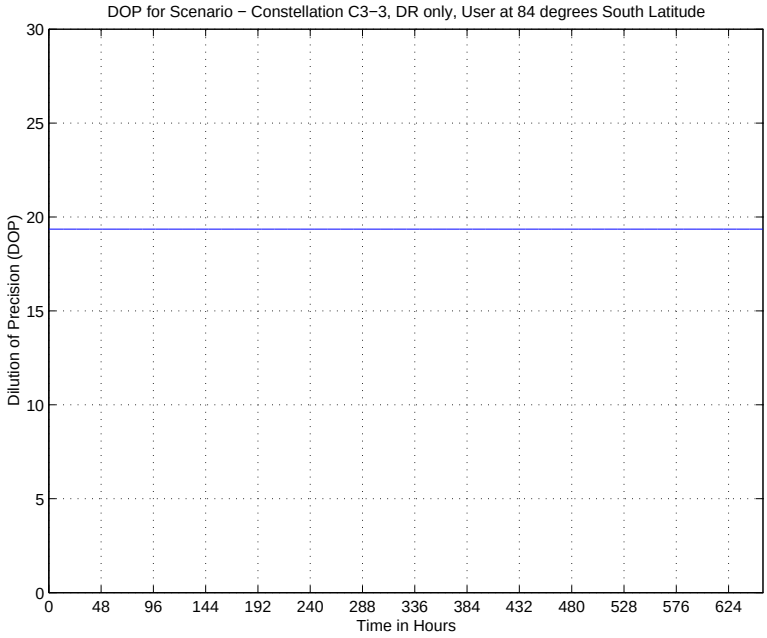

Figure 5.26 DOP Versus Time for Constellation C3-3 (L1 Low), User at 82 Degrees South Latitude, Direct Ranging Measurements Only Available, 27 Days of Data

Constellation C4 - L1 High

Constellation C4 comprises the same arrangement of satellites around the L1 point as constellation C3, except using an orbital radius of 17,374 Km (10 moon radii), which is five times as large as C3. While it can be seen in Figure 5.27, which shows availability of constellation C4-2, that the coverage for the polar region is significantly poorer; the longer baseline between satellites provides slightly better RMS values, along with slightly higher availabilities near the equator and at the mid-latitudes. Coverage begins to drop quickly from 70 degrees latitude to the pole, reaching 12 percent at 84 degrees latitude, compared with constellation C3-2 which maintained over 70 percent availability until 84 degrees latitude. The reduced coverage of the polar region by the L1 High constellation occurs because the angle between the line of sight from the "top" of the orbit to the moon (that point when a satellite is at its highest point above the lunar North pole) and the orbital radius decreases with altitude. In the extreme case, an L1 satellite at an infinite distance above the moon's North pole would essentially be in a polar orbit, and would only be able to see the southern lunar hemisphere 50 percent of the time.

Figure 5.28, availability for constellation C4-3, shows improvement in RMS values over constellation C4-2 due to the increased satellite separation and the more favorable geometry that results. This constellation provides 100 percent coverage for all three measurement types from 0 to 70 degrees South latitude. The RMS values for direct ranging and combined measurements, which were approximately 19 and 10, respectively, for constellation C3-3, improve to approximately 4 and 3, respectively, at latitudes where 100 percent coverage is available. Coverage of the pole also increases to 21 percent, due to having more satellites in the orbit.

Adding the fourth satellite to constellation C4 provides almost total coverage at all latitudes, including the pole, as seen by the availability plot in Figure 5.29. Availability is 100 percent from 0 to 82 degrees, with coverage only dropping off to 45 percent at the pole.

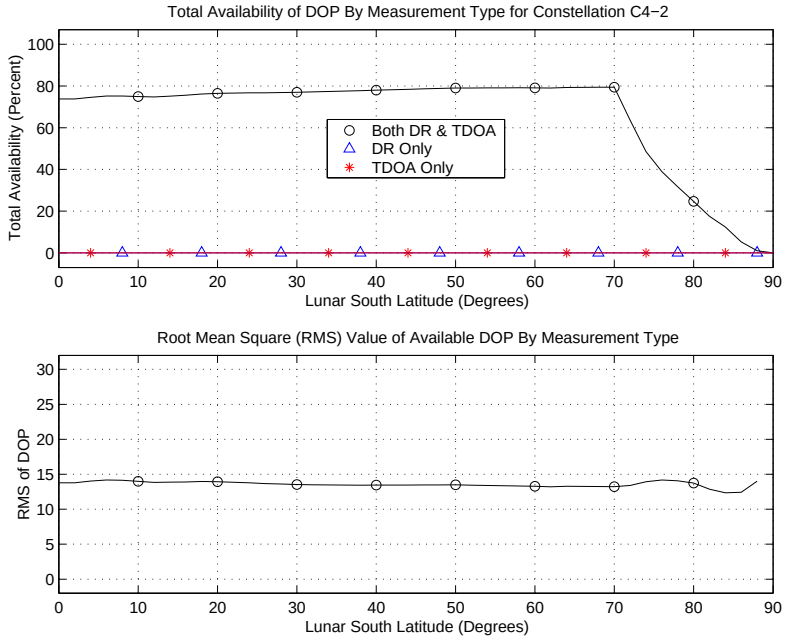

Figure 5.27 Total Availability and RMS Value By Measurement Type for Constellation C4-2 (L1 High), 27 Days of Data

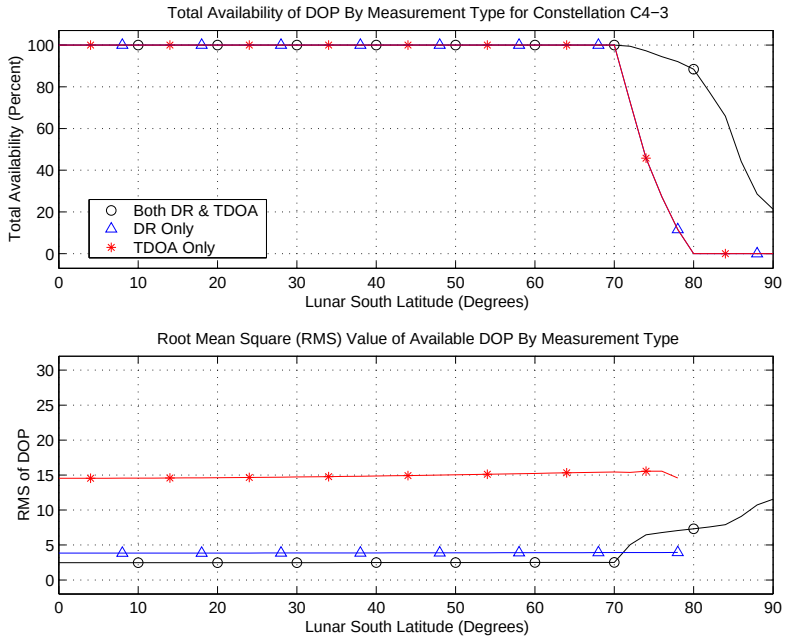

Figure 5.28 Total Availability and RMS Value By Measurement Type for Constellation C4-3 (L1 High), 27 Days of Data

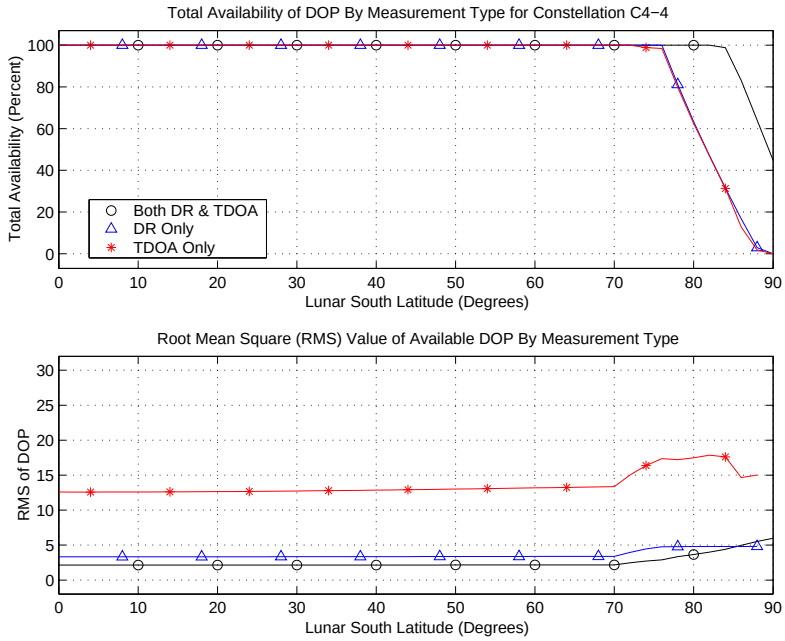

Figure 5.29 Total Availability and RMS Value By Measurement Type for Constellation C4-4 (L1 High), 27 Days of Data

Constellation C5 - L1/L2 Low

Constellation C5 is an expansion of constellation C3, with additional satellites around the L2 point on the lunar "far" side. Overall, these satellites do not significantly contribute to the position solution availability or accuracy. User locations that could take advantage of the additional measurements would be out of view from the Earth, thus precluding the use of TDOA measurements. The primary benefit of using "far" side satellites is for improved coverage and accuracy at the poles. In general, unless future missions absolutely must operate in the polar regions, the costs associated with putting satellites in low orbit around the L2 point will not be offset by improved navigation performance from the additional satellites.

Figure 5.30 shows the availability of constellation C5-2, a low, four satellite L1/L2 constellation (two satellites around each libration point). The only difference between this plot and Figure 5.22 (constellation C3-2) is the slight improvement in availability at the South pole for the combined measurement availability, where the coverage increased from zero percent for C3-2 to eight percent for C5-2. Figure 5.31 shows the availability of C5-3, a low, six satellite L1/L2 constellation, for which the only two changes are an increase in availability at the pole, from 2 percent (constellation C3-3) to 17 percent (constellation C5-3) for the combined measurements and from zero to 2 percent, respectively, for the TDOA measurements. Figure 5.32 shows the coverage of C5-4, a low, eight satellite L1/L2 constellation. Again the availability at the pole increases from 11 percent for C3-4 to 34 percent for C5-4 for combined measurements and from zero to 14 percent, respectively, for TDOA measurements.

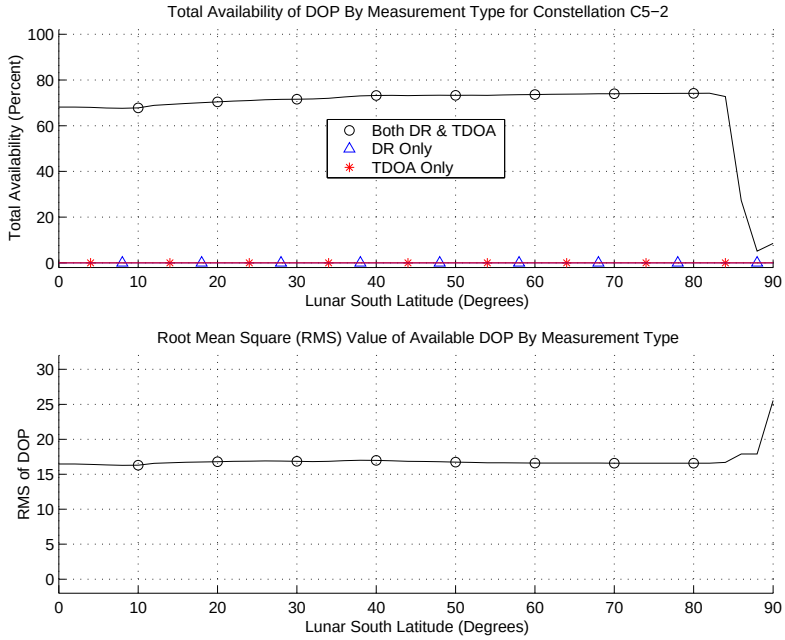

Figure 5.30 Total Availability and RMS Value By Measurement Type for Constellation C5-2 (L1/L2 Low), 27 Days of Data

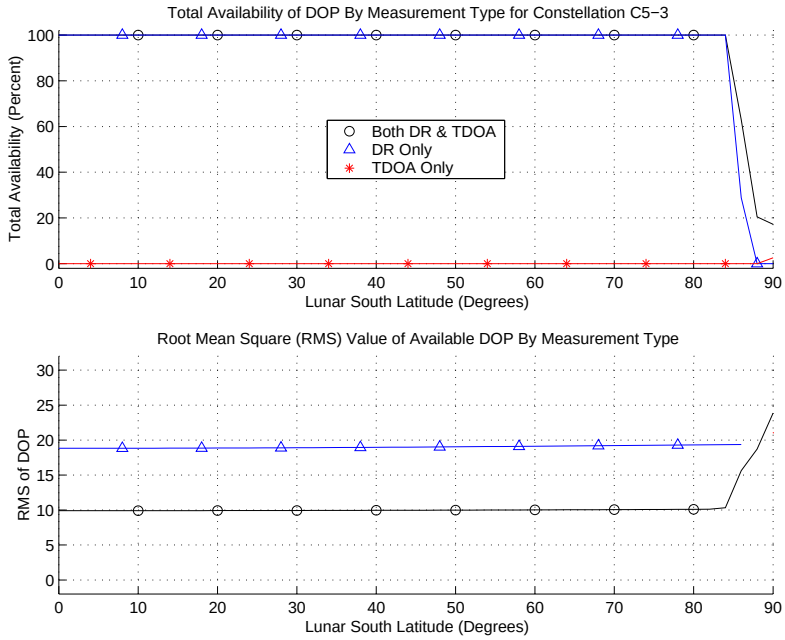

Figure 5.31 Total Availability and RMS Value By Measurement Type for Constellation C5-3 (L1/L2 Low), 27 Days of Data

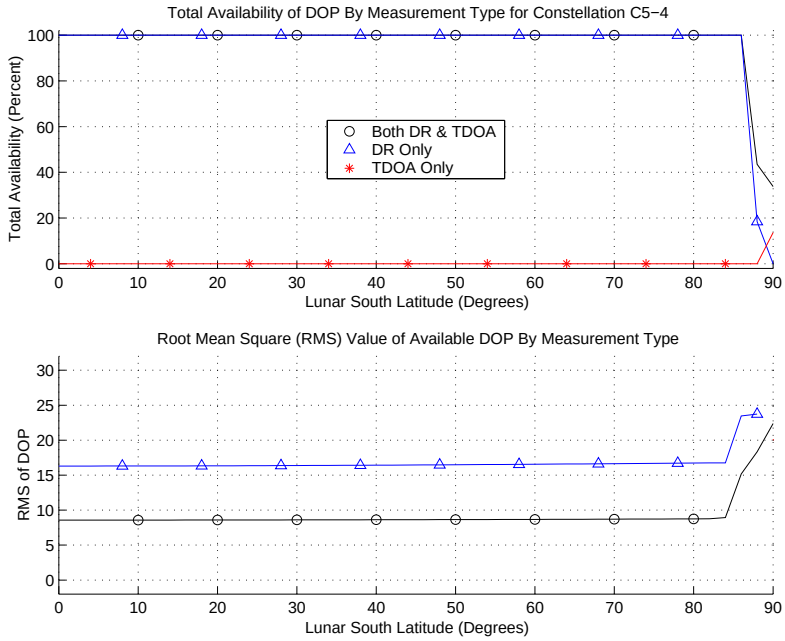

Figure 5.32 Total Availability and RMS Value By Measurement Type for Constellation C5-4 (L1/L2 Low), 27 Days of Data

Constellation C6 - L1/L2 High

In contrast to constellation C5 (L1/L2 Low), which saw limited benefit from including satellites around the L2 point, constellation C6 (L1/L2 High) demonstrates significant improvement in the polar region from the addition of L2 satellites. Figure 5.33 shows the availability for C6-2, a four-satellite constellation, for which the combined measurement availability curve stops decreasing at 76 degrees latitude, then increases slightly, staying above 38 percent at all latitudes, in contrast to Figure 5.27, where the curve for constellation C4-2 continues to decline at 76 degrees latitude. Figure 5.34 shows the availability for C6-3, a six-satellite constellation. Note that the combined availability never drops below 86 percent. The drop in both direct range and TDOA availability at 76 degrees latitude occurs because the user is losing sight of the "near" side satellites at the "top" of the orbit but not seeing the "far" side satellites yet. If only direct range measurements are used, missions to this area of the moon could be negatively impacted. Availability for this region improves with the addition of a fourth satellite to both the L1 and L2 orbits. Constellation C6-4, an eight satellite configuration, has excellent availability and accuracy, as shown in Figure 5.35. The combined measurements provide 100 percent availability from 0 to 88 degrees latitude and 95 percent coverage at the pole.

Using direct ranging only, there is incomplete coverage at only three latitudes, 78 degrees (81 percent coverage), 80 degrees (94 percent coverage), and 90 degrees (90 percent coverage). This represents a small decrease in overall availability from using combined measurements, and a significant improvement over most other constellations. Figure 5.36 shows the DOP versus time for direct ranging measurements only for a user at the South pole. There are, at most, three satellites in view from this location, with the gaps occurring when only two satellites are visible. The low DOP results from the favorable geometry of having one of the three satellites on the opposite side of the moon from the other two. Constellation C6-3 provided 83.66 percent availability using only direct ranging measurements at the South pole, which increased to 90 percent for constellation C6-4. Adding a fifth satellite to each orbital plane would likely bring the availability up to 100 percent, not only for all latitudes, but for all longitudes as well (both the "near" and "far" sides), providing complete availability of low DOP values for the entire moon.

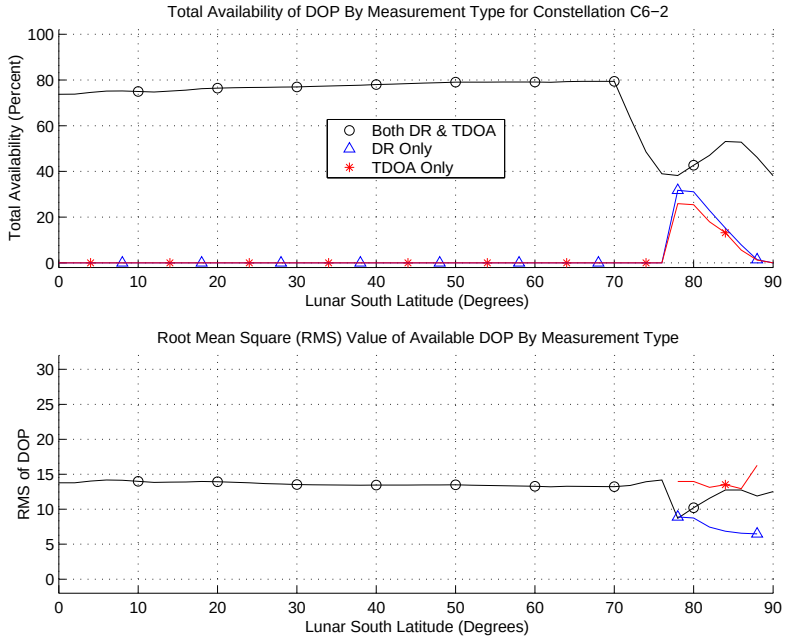

Figure 5.33 Total Availability and RMS Value By Measurement Type for Constellation C6-2 (L1/L2 High), 27 Days of Data

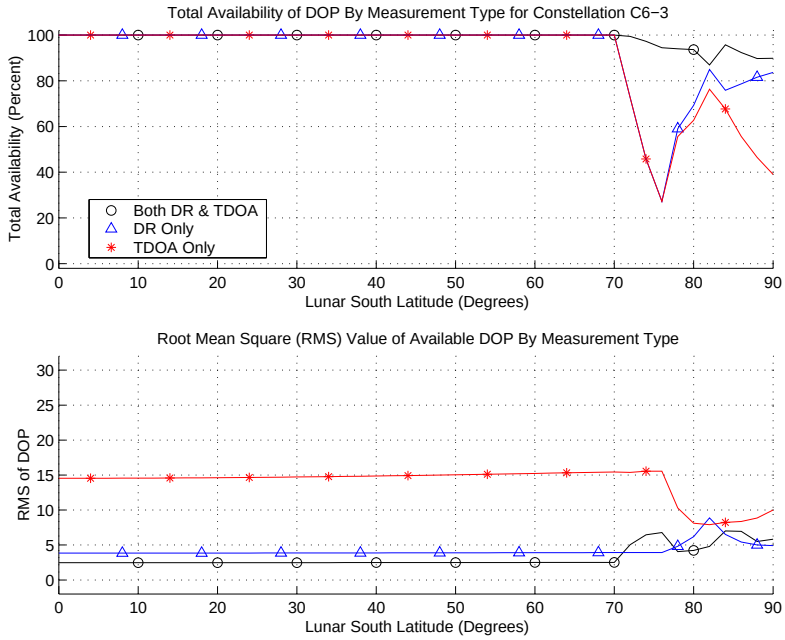

Figure 5.34 Total Availability and RMS Value By Measurement Type for Constellation C6-3 (L1/L2 High), 27 Days of Data

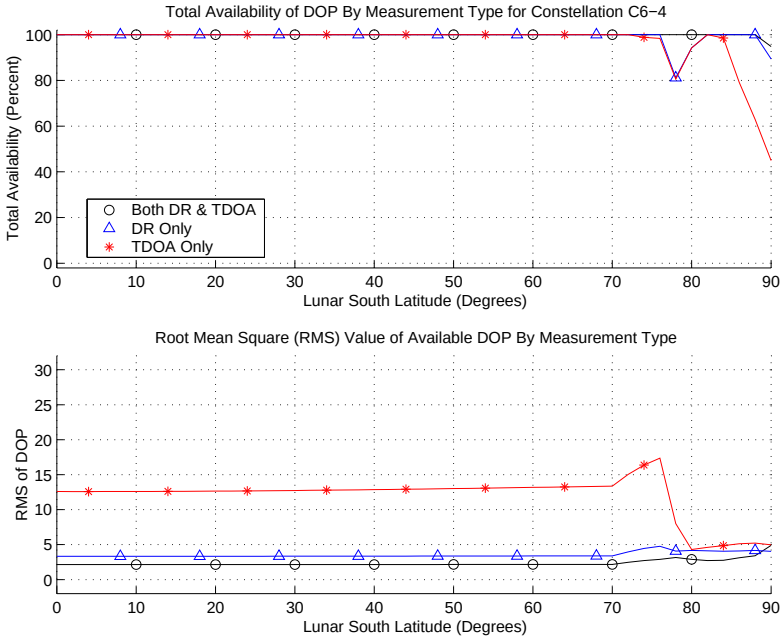

Figure 5.35 Total Availability and RMS Value By Measurement Type for Constellation C6-4 (L1/L2 High), 27 Days of Data

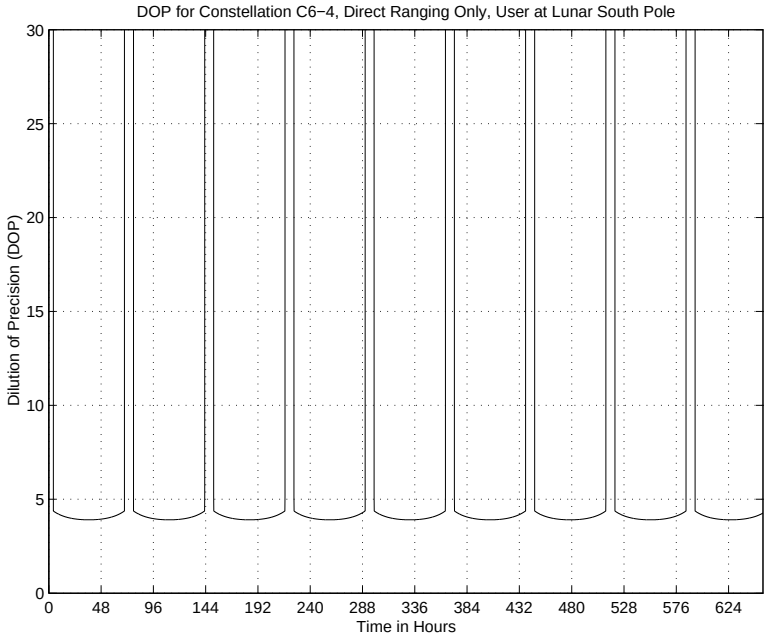

Figure 5.36 DOP Versus Time for Constellation C6-4 (L1/L2 High), User at the Lunar South Pole, Direct Ranging Measurements Only, 27 Days of Data

Constellation C7 - L1/Geosynchronous

Figure 5.37, availability for C7L, the L1 Low constellation (two L1 satellites), aided by three Earth-orbiting, geosynchronous satellites, shows that coverage is quite good from 0 to 84 degrees South latitude for combined measurements, remaining at approximately 95 percent, and dropping to only 36 percent at the pole. Figure 5.38 shows the DOP levels over the month at 48 degrees South latitude, which was chosen as a representative example of this constellation. The DOP values are continuously available throughout the month, until the end of the simulation. Unlike constellation C6-4, for which the total unavailability of coverage was spread over the month in relatively equal, repeating periods, all the unavailability for constellation C7L occurs at one time. This gap in coverage develops despite having between 7 and 13 measurements available during this time.

Figure 5.39 shows the C7 High constellation availability, with geosynchronous aiding. This constellation provides 97 percent coverage from 0 to 78 degrees latitude, before falling off to 47 percent at the pole. The earlier availability drop-off reflects the same effect as shown by constellation C4, due to the more restrictive line of sight for a satellite at a larger orbital radius. The lack of 100 percent coverage may not affect future missions, if they are of relatively short duration (less than 25 days) and planned around the gap in coverage. While the polar coverage is much lower than for constellation C6-4, it is accomplished with only five satellites, three of which are in Earth orbit, not in an L1 or lunar orbit. This shows that aiding by Earth satellites can greatly improve an otherwise unacceptable constellation.

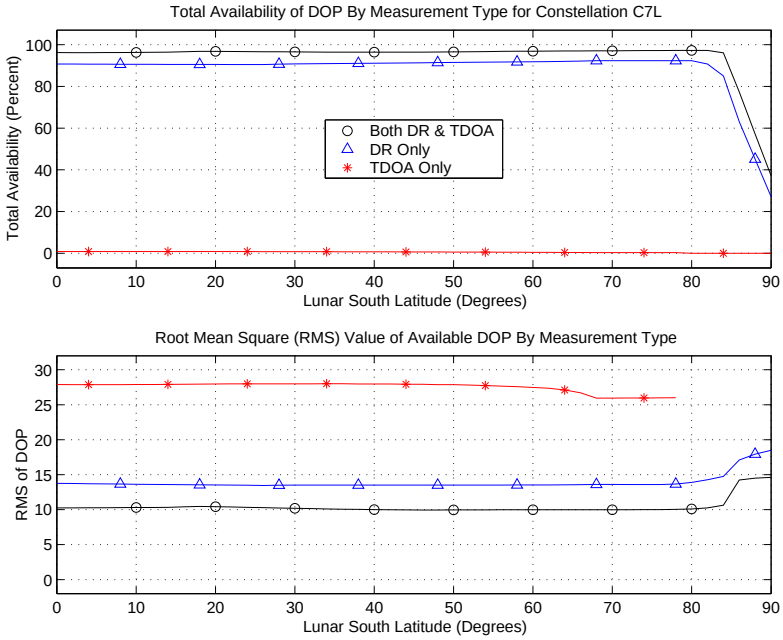

Figure 5.37 Total Availability and RMS Value By Measurement Type for Constellation C7L (L1 Low/Geosynchronous), 27 Days of Data

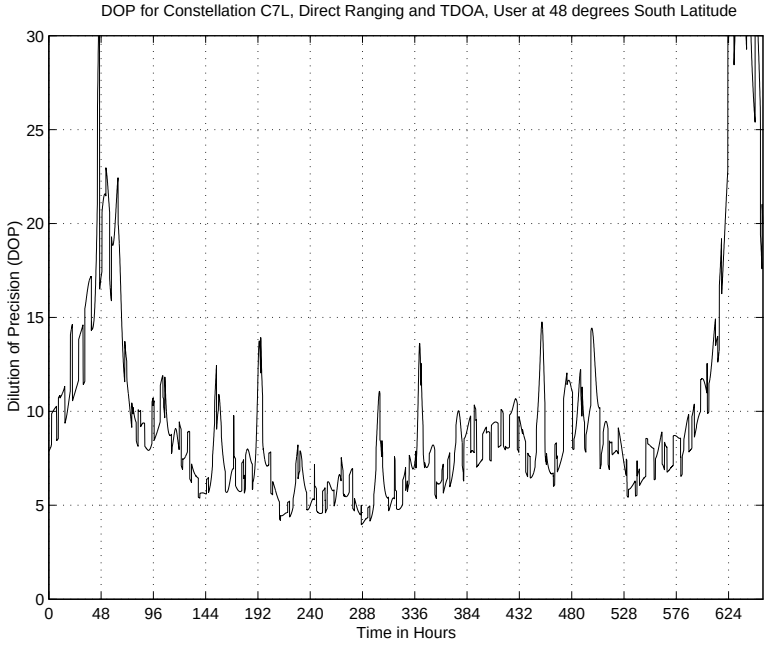

Figure 5.38 DOP Versus Time for Constellation C7L (L1 Low/Geosynchronous), 27 Days of Data

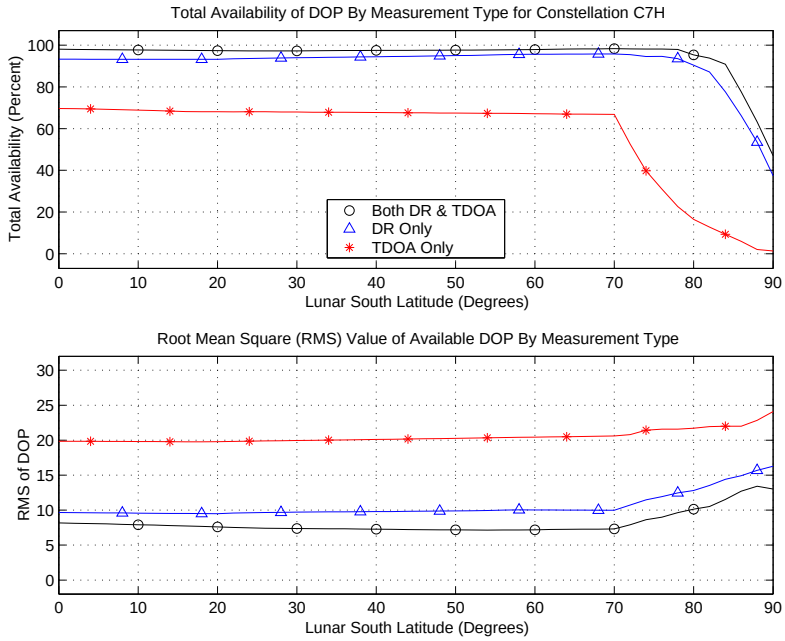

Figure 5.39 Total Availability and RMS Value By Measurement Type for Constellation C7H (L1 High/Geosynchronous), 27 Days of Data

Constellation C8 - L1/2× Geosynchronous

Constellation C8 makes use of Earth aiding satellites with a larger orbital radius, to try to improve the limited angular separation of the measurements. This is exacerbated by the use of L1 satellites which are in the same quadrant as the Earth-orbiting satellites. Figure 5.40 shows that the extra baseline helps improve the geometry of the navigation solution, as the availability is effectively 100 percent from the equator through 74 degrees. Figure 5.41 shows that the effect of increasing the baseline of the L1 satellites actually reduces the availability slightly, for latitudes between 80 and 90 degrees, as discussed for constellation C6. In this case, the better coverage angle of the L1 Low satellites has more effect on availability than the wider L1 High constellation.

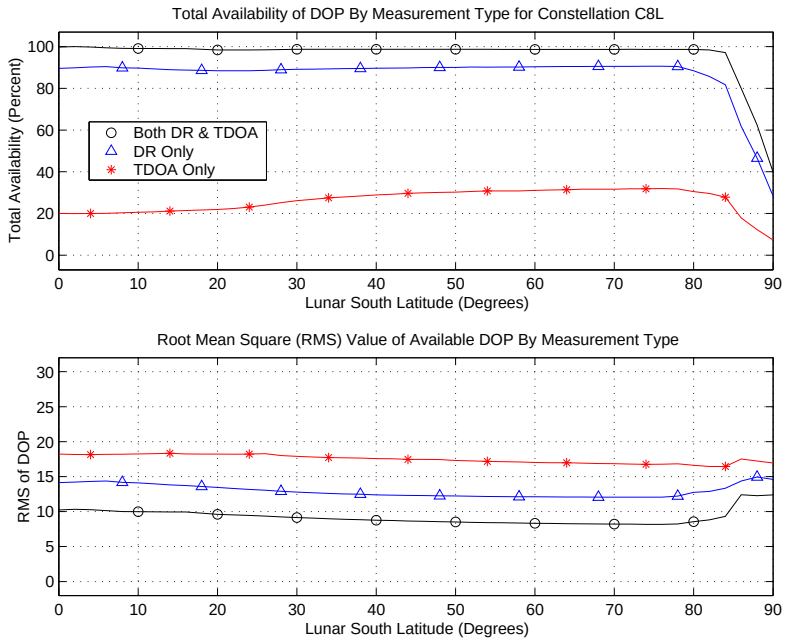

Figure 5.40 Total Availability and RMS Value By Measurement Type for Constellation C8L (L1 Low/2×Geosynchronous), 27 Days of Data

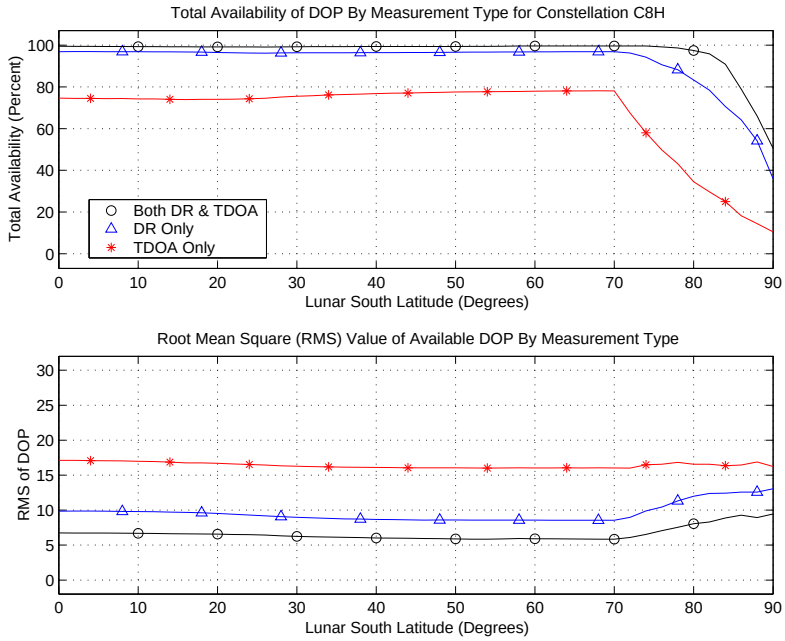

Figure 5.41 Total Availability and RMS Value By Measurement Type for Constellation C8H (L1 High/2×Geosynchronous), 27 Days of Data

Constellation C9 - DSN/Geosynchronous

Figure 5.42 shows the availability for constellation C9, which uses Earth-based ground stations for aiding. In general, this does not provide as much coverage as constellations C7 and C8. This is due, in part, to the DSN stations inability to act as a TDOA signal source and as a TDOA relay satellite, simultaneously, thus reducing the total number of available measurements at all latitudes.

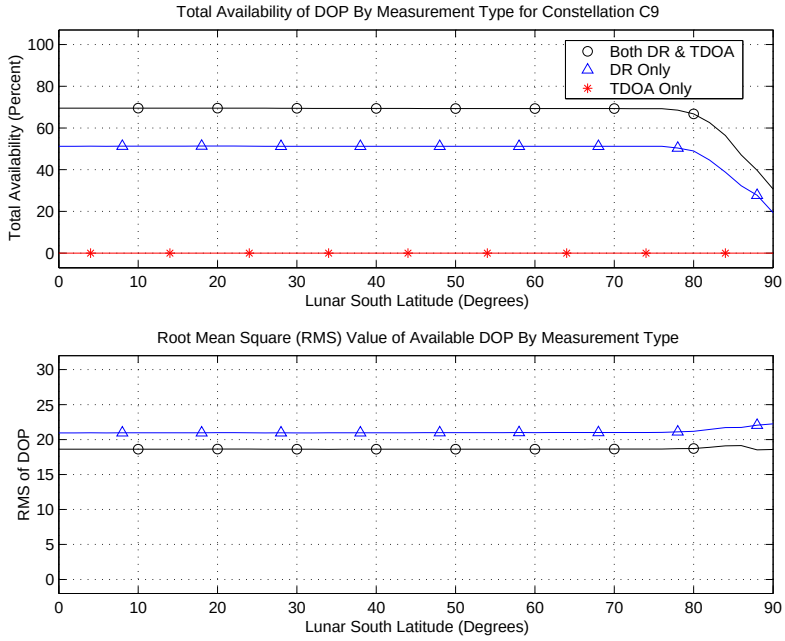

Figure 5.42 Total Availability and RMS Value By Measurement Type for Constellation C9 (DSN/Geosynchronous), 27 Days of Data

Constellation C10 - DSN/2× Geosynchronous

The availability for constellation C10, Figure 5.43, shows that, again, the greater orbital radius for the Earth orbiting satellites increases availability marginally (approximately five percentage points); however, it still has approximately 30 percent coverage at the South pole, as does constellation C9. While constellations C9 and C10 could be implemented with relatively low risk, the critical mission segments would need to be carefully scheduled around navigational outages caused by the limited availability.

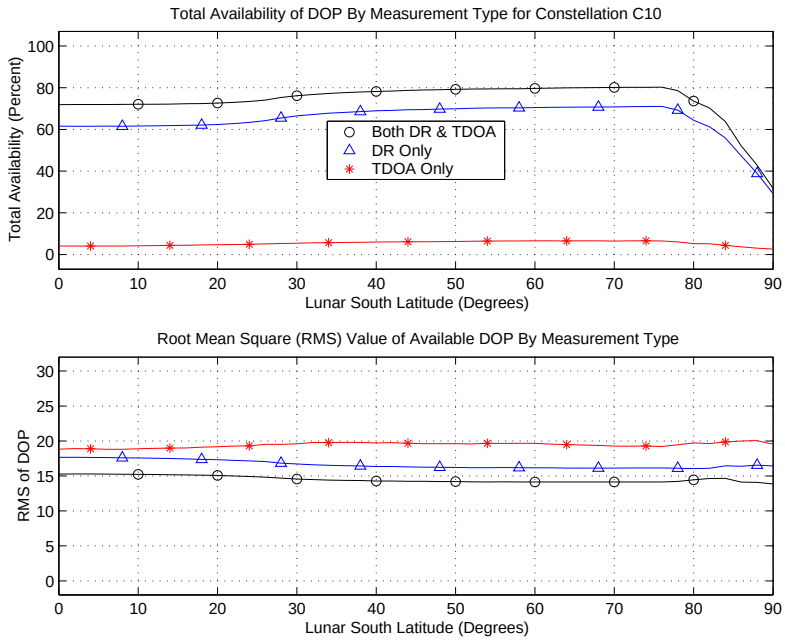

Figure 5.43 Total Availability and RMS Value By Measurement Type for Constellation C10 (DSN/2×Geosynchronous), 27 Days of Data

VI. Conclusions and Recommendations

Conclusions

Table 6.1 summarizes the 23 constellations and scenarios evaluated in this thesis. It provides the maximum total availability achieved by each scenario, the latitude range over which the maximum availability occurred, the size of the latitude range, the measurement types used to achieve the maximum availability, the availabilities at the lunar South pole and equator, and the number of satellites in the scenario.

Due to the moon's spherical shape, availability results can be extrapolated to symmetric lunar regions, based on the geometry of the constellations. For example, the L1-only constellations should provide similar results in the northern hemisphere as the southern hemisphere, on the moon's "near" side. For scenarios which depend solely on combined measurements, reduced availabilities will occur on the moon's "far" side. This results from losing the TDOA measurements when the user does not have the Earth-based DSN stations in view. Furthermore, constellations that use only Earth-based or Earth-orbiting assets will have no navigational position availability when the user is over the lunar horizon from these assets.

Constellation C1, using low altitude, polar orbits around the moon, provided very good coverage in the high southern latitudes (60 to 90 degrees South latitude) using combined measurements that include both direct ranging and TDOA measurements. The equatorial region had poor availability due to the limited satellite footprint overlap, which prevented the user from seeing more than two satellites at a time. This constellation's major drawback is the low satellite altitudes and high orbital speeds, which minimize footprint and reduce satellite view time.

Constellation C2, using medium altitude, polar orbits around the moon, showed improvement over constellation C1, providing almost 100 percent coverage of the middle and high southern latitudes (30 to 90 degrees South latitude), with the exception of the area within six degrees of the South pole, where coverage is slightly reduced. The equatorial region, again, has poor availability, with coverage available approximately half the time. This

constellation also relies on combined measurements, as does constellation C1, to provide these results. Using direct ranging measurements only provides much poorer results.

Constellation C3, using satellites with a "low" orbital radius around the L1 point, has excellent coverage over almost all latitudes examined in this research, when employing three or more satellites. This constellation should provides 100 percent coverage to all locations on the "near" side of the lunar surface that have an uninterrupted view of all satellites, using either combined measurements or direct ranging only. This coverage should extend not only from 86 degrees North to 86 degrees South latitude, but also from 86 degrees West to 86 East longitude. The results showed that from 86 to 90 degrees South latitude, the availability fell quickly from 100 percent to near zero. A slight improvement in availability at the South pole resulted from increasing the number of satellites in the constellation, however, the low L1 orbit's poor geometry at the pole would likely prevent this constellation from ever providing good polar coverage.

Constellation C4, using satellites with a "high" orbital radius around the L1 point, also has 100 percent coverage over most latitudes, as did C3. The most notable difference is the polar availability drop-off occurs approximately ten degrees further from the pole than constellation C3, for direct ranging only measurements. This results from the lower view angle from the pole of satellites at the orbit's opposite side, as explained in Chapter 5. Using combined measurements, however, this constellation provided 100 percent coverage to with six degrees of the South pole, as well as 50 percent coverage at the pole. As seen in constellation C3, increasing the number of satellites generally increases availability. Using more than four satellites would likely provide better direct ranging coverage, as well as higher polar availability.

L1-only orbits with a very large orbital radius (beyond 86,850 Km/50 moon radii) and using enough satellites to "fill" the orbit (provide three or more satellites in view to the user at all times) will approximate a high altitude polar orbit in an orbital plane that does not rotate about the North-South axis of the moon, as do the low and medium polar constellation's orbital planes. This lack of rotation for an extreme L1-only orbit would allow 100 percent coverage over most regions for both the "near" and "far" sides of the moon. The minor drawback of this type of constellation would be no coverage at the

center of the "far" side and reduced coverage at the center of the "near" side, however, the number of satellites necessary to provide this coverage and the extreme distance from the L1 point would likely make this type of constellation unfeasible.

Constellation C5, using satellites with a "low" orbital radius around both the L1 and L2 points, has excellent coverage very similar to constellation C3, with a slight improvement at the South pole from near zero to about 35 percent availability. The improvement at the pole results from the contribution of the L2 satellites. The addition of L2 satellites increases the availability on the "far" side, but does not change the "near" side coverage except at the poles.

Constellation C6, using satellites with a "high" orbital radius around the L1 and L2 points, has 100 percent coverage over more latitudes than C4. Unlike constellation C5, however, the addition of the high L2 satellites increased the polar availability to 95 percent. This demonstrates the largest benefit of an L1/L2 constellation, its almost total coverage, including both the "near" and "far" sides. This is the only type of constellation that provides coverage over such a large lunar area. The need for total coverage will be driven by the final choice of mission locations. If few missions are planned for the lunar "far" side, then the added cost and complexity of inserting satellites into an L2 orbit will not be required.

Constellations C7 and C8 use two satellites in an L1 orbit and three Earth-orbiting satellites in geosynchronous and twice geosynchronous altitude orbits, respectively. They provide essentially 100 percent availabilities from the equator to 84 degrees latitude for the low L1 scenarios, C7L and C8L, and the equator to 78 degrees latitude for the high L1 scenarios, C7H and C8H. The low and high scenarios also provide 40 percent and 50 percent coverage of the South pole, respectively. These constellations provide similar coverage to the L1-only constellations (C3 and C4), but with slightly higher RMS values for the regions that have 100 percent coverage. The benefit of using Earth-orbiting satellites is the reduced number of satellites in the L1 orbit. The L1 orbits are unstable, requiring active control and higher fuel usage for satellites to stay in position. Use of either of these constellations would provide excellent coverage for non-polar missions, while reducing the programmatic risks (cost, schedule, and performance) of future lunar efforts. A drawback

to these constellations is that the user on the moon is assumed to be able to obtain a direct ranging measurement from an Earth orbiting satellite. This may be difficult to implement because of the power required to reach the satellites, especially for the twice geosynchronous satellites when they are on the far side of the earth from the moon.

Constellations C9 and C10 use DSN stations to augment geosynchronous and twice geosynchronous Earth-orbiting satellites, respectively. They have the same drawback as constellations C7 and C8 for obtaining a direct ranging measurement. However, a significant benefit of these constellations is that they could be implemented with the least programmatic risk to a deployment schedule. Constellation C9 provides approximately 70 percent availability for combined and 50 percent availability for direct ranging measurements. This limited availability could be used to augment existing navigation methods to provide a higher level of autonomy for a lunar spacecraft in transit to the moon or in orbit around it, even if a real-time position solution cannot always be determined. Constellation C10 provides slightly higher availabilities, from 60 to 70 percent for direct ranging and 70 to 80 percent for combined measurements.

Table 6.1 Constellation Summary

Const. Number	Max. Avail.	Lat. Range	Size of Range	Measurement Type	Avail. at South Pole	Avail. at Equator	No. Sats.
C1	100	64 - 84	20	Combination	92	0	30
C2-3	89	56 - 84	28	Combination	48	63	6
C2-4	100	40 - 84	44	Combination	83	51	8
C3-2	74	40 - 84	44	Combination	0	68	2
C3-3	100	0 - 84	84	Comb/DR	2	100	3
C3-4	100	0 - 84	84	Comb/DR	11	100	4
C4-2	80	20 - 70	50	Combination	0	74	2
C4-3	100	0 - 70	70	Comb/DR/TDOA	21	100	3
C4-4	100	0 - 84	84	Comb/DR	45	100	4
C5-2	75	40 - 84	44	Combination	9	68	4
C5-3	100	0 - 84	84	Comb/DR	17	100	6
C5-4	100	0 - 86	86	Comb/DR	34	100	8
C6-2	80	40 - 70	30	Combination	38	74	4
C6-3	100	0 - 70	70	Comb/DR/TDOA	90	100	6
C6-4	100	0 - 88	88	Comb/DR/TDOA	95	100	8
C7L	98	0 - 84	84	Combination	37	96	5
C7H	98	0 - 78	78	Combination	47	97	5
C8L	99	0 - 84	84	Combination	39	99	5
C8H	100	0 - 80	80	Combination	50	99	5
C9	70	0 - 80	80	Combination	30	69	3
C10	80	30 - 78	78	Combination	32	72	3

Recommendations

Further research into this satellite navigation project falls into two categories, expanded evaluation of the current constellations and investigations into additional scenarios and augmentation methods. The first category includes the following:

- Evaluating user positions above the lunar surface to determine availabilities and RMS values for spacecraft in lunar orbit and in the descent/landing phase.
- Evaluating different satellite orbital phasing for constellations C1 and C2 to determine if availability can be increased for any regions of interest.
- Investigating the frequency and duration of outages for regions that do not have full coverage to facilitate planning missions to occur during times of adequate availability.
- Exploring lower inclination orbits for constellations C1 and C2 to determine if equatorial coverage can be improved, and if so, at what cost to availability in the polar region.
- Analyzing a high polar orbit to determine if the number of satellites can be further reduced while maintaining acceptable coverage over regions of interest.
- Evaluating a sampling interval shorter than five minutes to determine if any short-term, high dynamic behavior was masked by the current sampling interval
- Improving the L1 and L2 orbit modelling to increase the fidelity of the results.

The second category includes:

- Using pseudolites on the lunar surface to augment a satellite constellation and determine if position solution availabilities can be improved for regions with poor coverage.
- Incorporating a Kalman filter to propagate a vehicle state estimate (position and velocity).
- Using other onboard sensors, such as a radar altimeter or Doppler radar, to provide additional measurements for updating a state estimate.
- Using an inertial navigation system to improve vehicle state estimation and to provide attitude information for aligning sensors.

Appendix A. Availability Tables

The tables in this Appendix provide the DOP availabilities, by category and South latitude, for all constellations and scenarios. All tables are based on 27.3 days of data (one lunar sidereal month). There are three tables for each scenario, combined measurements (DR and TDOA), direct ranging measurements (DR Only), and time-difference-of-arrival measurements (TDOA Only), with the exception of C5-1 and C6-1, which have data for combined measurements only because the other two measurement types generate DOP values greater than 30 for all latitudes. The following list associates each table with its corresponding constellation or scenario.

C1 Tables A.1 through A.3
C2-3 Tables A.4 through A.6
C2-4 Tables A.7 through A.9
C3-2 Tables A.10 through A.12
C3-3 Tables A.13 through A.15
C3-4 Tables A.16 through A.18
C4-2 Tables A.19 through A.21
C4-3 Tables A.22 through A.24
C4-4 Tables A.25 through A.27
C5-1 Table A.28
C5-2 Tables A.29 through A.31
C5-3 Tables A.32 through A.34
C5-4 Tables A.35 through A.37
C6-1 Table A.38
C6-2 Tables A.39 through A.41
C6-3 Tables A.42 through A.44
C6-4 Tables A.45 through A.47
C7L Tables A.48 through A.50
C7H Tables A.51 through A.53
C8L Tables A.54 through A.56
C8H Tables A.57 through A.59
C9 Tables A.60 through A.62
C10 Tables A.63 through A.65

Table A.1 DOP Availability Vs. South Latitude for Constellation C1, DR and TDOA

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	85.45	4.23	3.02	92.70	7.30	3.94
88	88.13	4.61	3.28	96.02	3.98	3.90
86	93.44	2.94	2.34	98.72	1.28	3.39
84	98.46	1.09	0.32	99.87	0.13	1.93
82	99.30	0.44	0.22	99.96	0.04	1.78
80	99.26	0.48	0.22	99.96	0.04	1.85
78	99.22	0.51	0.22	99.95	0.05	1.88
76	99.20	0.51	0.24	99.95	0.05	1.94
74	99.17	0.53	0.27	99.97	0.03	2.06
72	99.06	0.66	0.25	99.97	0.03	2.13
70	98.95	0.75	0.28	99.97	0.03	2.23
68	98.77	0.89	0.29	99.95	0.05	2.36
66	97.74	1.28	0.50	99.52	0.48	2.57
64	96.16	1.51	0.85	98.53	1.47	2.93
62	89.31	0.72	0.00	90.04	9.96	2.46
60	81.14	0.38	0.13	81.65	18.35	2.54
58	76.66	0.75	0.62	78.04	21.96	3.11
56	71.68	1.87	1.30	74.85	25.15	3.64
54	65.29	3.61	1.87	70.77	29.23	3.98
52	58.25	4.45	2.22	64.92	35.08	4.60
50	50.99	4.50	3.29	58.78	41.22	5.15
48	45.84	5.44	2.90	54.18	45.82	5.18
46	41.41	5.21	2.62	49.24	50.76	5.17
44	38.19	4.28	2.57	45.04	54.96	5.42
42	34.70	3.85	2.40	40.95	59.05	5.37
40	31.43	3.66	2.29	37.38	62.62	5.38
38	27.73	3.94	2.25	33.92	66.08	5.63
36	23.53	4.64	3.05	31.22	68.78	6.53
34	19.90	4.77	3.98	28.65	71.35	7.51
32	18.51	5.24	3.30	27.05	72.95	7.36
30	18.43	3.98	2.72	25.13	74.87	6.93
28	18.29	3.22	1.94	23.45	76.55	6.18
26	17.63	2.43	1.64	21.70	78.30	5.98
24	15.87	2.26	1.49	19.62	80.38	5.87
22	13.98	2.10	1.49	17.56	82.44	6.11
20	12.32	2.03	1.37	15.72	84.28	6.29
18	11.12	1.93	1.35	14.40	85.60	6.44
16	10.04	1.91	1.22	13.17	86.83	6.39
14	9.27	1.72	1.23	12.21	87.79	6.66
12	8.82	1.73	1.13	11.68	88.32	6.40
10	8.59	1.64	1.17	11.40	88.60	6.67
8	8.83	1.63	1.12	11.58	88.42	6.36
6	9.09	1.60	1.17	11.86	88.14	6.73
4	8.73	2.08	1.08	11.90	88.10	6.60
2	6.71	3.15	1.96	11.82	88.18	8.60
0	5.50	2.91	2.58	10.99	89.01	9.73

Table A.2 DOP Availability Vs. South Latitude for Constellation C1, DR Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	79.86	4.56	2.63	87.05	12.95	3.88
88	81.56	5.78	4.00	91.34	8.66	4.29
86	83.31	6.15	4.82	94.28	5.72	4.84
84	87.23	6.95	2.91	97.09	2.91	4.03
82	91.74	4.86	1.91	98.50	1.50	3.58
80	93.07	3.57	2.11	98.75	1.25	3.60
78	92.16	4.28	2.38	98.82	1.18	3.87
76	90.47	5.47	2.73	98.67	1.33	4.12
74	88.51	6.46	3.43	98.40	1.60	4.37
72	86.64	7.17	4.22	98.03	1.97	4.78
70	78.81	11.48	4.93	95.22	4.78	5.29
68	71.75	12.48	7.16	91.38	8.62	5.96
66	65.37	11.13	9.72	86.22	13.78	7.08
64	55.74	13.92	5.88	75.55	24.45	6.48
62	43.14	16.38	3.85	63.37	36.63	5.75
60	34.35	14.11	1.58	50.04	49.96	5.71
58	26.87	6.89	2.03	35.79	64.21	5.88
56	17.50	4.52	2.43	24.45	75.55	6.44
54	8.90	4.30	2.82	16.01	83.99	8.32
52	3.93	4.47	2.29	10.69	89.31	10.72
50	1.87	3.88	1.11	6.85	93.15	10.51
48	0.67	2.35	1.16	4.18	95.82	10.55
46	0.09	1.17	1.13	2.39	97.61	11.80
44	0.00	0.32	0.72	1.04	98.96	15.73
42	0.00	0.01	0.18	0.19	99.81	18.49
40	0.00	0.00	0.00	0.00	100.00	Inf
38	0.00	0.00	0.00	0.00	100.00	Inf
36	0.00	0.00	0.00	0.00	100.00	Inf
34	0.00	0.00	0.00	0.00	100.00	Inf
32	0.00	0.00	0.00	0.00	100.00	Inf
30	0.00	0.00	0.00	0.00	100.00	Inf
28	0.00	0.00	0.00	0.00	100.00	Inf
26	0.00	0.00	0.00	0.00	100.00	Inf
24	0.00	0.00	0.00	0.00	100.00	Inf
22	0.00	0.00	0.00	0.00	100.00	Inf
20	0.00	0.00	0.00	0.00	100.00	Inf
18	0.00	0.00	0.00	0.00	100.00	Inf
16	0.00	0.00	0.00	0.00	100.00	Inf
14	0.00	0.00	0.00	0.00	100.00	Inf
12	0.00	0.00	0.00	0.00	100.00	Inf
10	0.00	0.00	0.00	0.00	100.00	Inf
8	0.00	0.00	0.00	0.00	100.00	Inf
6	0.00	0.00	0.00	0.00	100.00	Inf
4	0.00	0.00	0.00	0.00	100.00	Inf
2	0.00	0.00	0.00	0.00	100.00	Inf
0	0.00	0.00	0.00	0.00	100.00	Inf

Table A.3 DOP Availability Vs. South Latitude for Constellation C1, TDOA Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	36.03	6.61	1.40	44.04	55.96	4.74
88	47.09	8.03	1.96	57.08	42.92	4.83
86	59.74	11.26	3.28	74.28	25.72	5.24
84	73.96	16.04	4.94	94.94	5.06	5.35
82	74.49	16.15	6.63	97.28	2.72	5.62
80	74.25	14.92	8.43	97.60	2.40	6.02
78	73.13	14.60	9.79	97.52	2.48	6.36
76	71.71	14.86	10.68	97.24	2.76	6.65
74	70.37	15.47	10.71	96.56	3.44	6.78
72	68.35	16.37	11.03	95.75	4.25	7.02
70	61.41	18.86	11.86	92.13	7.87	7.40
68	51.44	20.68	15.09	87.20	12.80	8.42
66	42.13	18.85	19.01	79.99	20.01	9.73
64	33.24	14.50	17.15	64.88	35.12	10.71
62	24.80	12.94	15.61	53.34	46.66	11.16
60	22.37	11.48	10.61	44.46	55.54	10.05
58	19.78	7.40	6.09	33.26	66.74	8.64
56	16.84	3.81	2.80	23.45	76.55	6.88
54	13.50	1.65	0.71	15.86	84.14	5.24
52	10.45	0.33	0.09	10.87	89.13	3.52
50	7.55	0.05	0.05	7.65	92.35	3.31
48	5.07	0.00	0.09	5.16	94.84	4.34
46	2.87	0.00	0.08	2.95	97.05	5.04
44	1.41	0.00	0.06	1.47	98.53	6.27
42	0.38	0.00	0.05	0.43	99.57	10.08
40	0.00	0.00	0.06	0.06	99.94	29.18
38	0.00	0.00	0.05	0.05	99.95	29.25
36	0.00	0.00	0.05	0.05	99.95	29.19
34	0.00	0.00	0.04	0.04	99.96	29.24
32	0.00	0.00	0.05	0.05	99.95	29.15
30	0.00	0.00	0.04	0.04	99.96	29.22
28	0.00	0.00	0.04	0.04	99.96	28.93
26	0.00	0.00	0.03	0.03	99.97	28.63
24	0.00	0.00	0.04	0.04	99.96	28.76
22	0.00	0.00	0.04	0.04	99.96	28.91
20	0.00	0.00	0.04	0.04	99.96	28.84
18	0.00	0.00	0.04	0.04	99.96	28.99
16	0.00	0.00	0.04	0.04	99.96	28.85
14	0.00	0.00	0.04	0.04	99.96	28.80
12	0.00	0.00	0.04	0.04	99.96	28.82
10	0.00	0.00	0.04	0.04	99.96	28.73
8	0.00	0.00	0.04	0.04	99.96	28.71
6	0.00	0.00	0.04	0.04	99.96	28.79
4	0.00	0.00	0.03	0.03	99.97	28.71
2	0.00	0.00	0.04	0.04	99.96	28.97
0	0.00	0.00	0.04	0.04	99.96	29.06

Table A.4 DOP Availability Vs. South Latitude for Constellation C23, DR and TDOA

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	32.07	5.80	10.08	47.94	52.06	8.62
88	39.77	7.68	12.68	60.13	39.87	8.61
86	50.28	9.53	15.98	75.79	24.21	8.62
84	58.43	10.49	18.33	87.24	12.76	8.59
82	59.04	11.11	19.47	89.62	10.38	8.70
80	59.18	11.36	19.45	89.98	10.02	8.68
78	59.34	11.49	19.03	89.86	10.14	8.64
76	59.48	11.57	18.77	89.82	10.18	8.63
74	59.63	11.67	18.47	89.77	10.23	8.59
72	59.63	11.85	18.40	89.88	10.12	8.65
70	59.86	11.63	18.34	89.83	10.17	8.67
68	59.91	11.49	18.28	89.68	10.32	8.68
66	59.80	11.45	18.37	89.62	10.38	8.69
64	59.62	11.50	18.47	89.59	10.41	8.75
62	59.35	11.58	18.38	89.31	10.69	8.77
60	58.93	11.53	18.65	89.11	10.89	8.80
58	58.57	11.71	18.76	89.03	10.97	8.86
56	57.79	11.79	19.17	88.75	11.25	8.95
54	56.90	11.92	19.42	88.24	11.76	8.98
52	56.08	12.09	19.80	87.96	12.04	9.08
50	55.47	12.33	20.03	87.82	12.18	9.18
48	54.31	12.48	20.50	87.29	12.71	9.30
46	53.19	12.86	20.70	86.76	13.24	9.41
44	51.92	13.10	21.20	86.22	13.78	9.53
42	50.48	13.41	21.45	85.35	14.65	9.63
40	48.54	13.66	22.22	84.42	15.58	9.82
38	47.05	13.84	22.71	83.60	16.40	10.01
36	45.09	14.06	23.39	82.54	17.46	10.22
34	42.87	14.40	23.95	81.22	18.78	10.41
32	40.15	14.73	24.78	79.66	20.34	10.69
30	37.14	14.76	25.97	77.86	22.14	11.01
28	33.86	14.13	27.68	75.67	24.33	11.49
26	29.11	13.49	30.01	72.60	27.40	12.08
24	25.36	13.57	31.62	70.55	29.45	12.62
22	22.76	13.68	32.78	69.22	30.78	12.98
20	20.54	13.61	33.66	67.81	32.19	13.25
18	18.45	14.07	34.41	66.93	33.07	13.50
16	16.89	14.16	35.14	66.19	33.81	13.71
14	15.02	14.74	35.80	65.57	34.43	13.87
12	13.52	15.35	35.97	64.84	35.16	13.99
10	11.45	16.27	36.68	64.40	35.60	14.19
8	9.71	17.01	37.09	63.80	36.20	14.27
6	8.03	17.40	37.94	63.37	36.63	14.50
4	7.00	17.54	38.45	62.99	37.01	14.60
2	6.23	17.50	39.06	62.79	37.21	14.73
0	5.99	17.13	39.62	62.74	37.26	14.77

Table A.5 DOP Availability Vs. South Latitude for Constellation C23, DR Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	26.86	3.94	3.27	34.06	65.94	6.37
88	33.71	5.77	4.64	44.12	55.88	6.72
86	42.39	6.69	5.82	54.89	45.11	6.71
84	47.25	7.18	6.19	60.63	39.37	6.54
82	51.61	7.59	6.37	65.57	34.43	6.38
80	52.95	7.56	6.27	66.78	33.22	6.27
78	52.99	7.54	6.19	66.71	33.29	6.17
76	53.05	7.60	6.01	66.66	33.34	6.10
74	53.11	7.70	5.73	66.55	33.45	6.03
72	53.14	7.88	5.43	66.45	33.55	5.97
70	53.29	7.87	5.05	66.20	33.80	5.85
68	53.48	7.75	4.82	66.05	33.95	5.82
66	53.38	7.80	4.52	65.71	34.29	5.71
64	53.25	7.60	4.38	65.24	34.76	5.61
62	52.99	7.45	4.36	64.79	35.21	5.51
60	52.47	7.45	4.28	64.20	35.80	5.53
58	52.19	7.23	4.26	63.68	36.32	5.52
56	51.42	7.13	4.22	62.77	37.23	5.54
54	50.58	6.96	4.31	61.86	38.14	5.65
52	49.86	6.77	4.27	60.90	39.10	5.66
50	49.24	6.75	4.21	60.19	39.81	5.61
48	48.11	6.80	4.18	59.09	40.91	5.69
46	47.18	6.85	4.11	58.13	41.87	5.74
44	46.03	6.76	4.09	56.89	43.11	5.78
42	44.80	6.46	4.17	55.43	44.57	5.89
40	42.90	6.37	4.09	53.36	46.64	5.91
38	41.32	6.43	4.02	51.77	48.23	5.93
36	39.57	6.11	4.07	49.75	50.25	5.99
34	37.49	5.95	3.93	47.37	52.63	6.03
32	35.42	5.41	3.77	44.61	55.39	6.13
30	33.16	4.83	3.19	41.18	58.82	5.99
28	30.67	4.04	2.38	37.09	62.91	5.44
26	27.31	2.43	1.41	31.15	68.85	4.83
24	23.84	2.14	1.36	27.34	72.66	5.05
22	21.29	2.10	1.35	24.73	75.27	5.21
20	18.57	2.48	1.25	22.29	77.71	5.30
18	16.27	2.90	1.13	20.30	79.70	5.37
16	14.12	3.57	1.12	18.81	81.19	5.90
14	12.01	4.19	1.12	17.32	82.68	6.11
12	9.99	4.82	1.66	16.47	83.53	6.84
10	8.02	4.94	2.47	15.43	84.57	7.84
8	6.62	4.86	3.18	14.65	85.35	9.02
6	5.55	4.49	3.50	13.54	86.46	10.21
4	5.08	3.85	3.94	12.87	87.13	10.67
2	4.65	3.14	4.46	12.25	87.75	11.52
0	4.63	2.95	4.61	12.19	87.81	12.30

Table A.6 DOP Availability Vs. South Latitude for Constellation C23, TDOA Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	1.89	0.32	13.00	15.21	84.79	17.90
88	2.38	0.46	16.89	19.73	80.27	17.70
86	2.89	1.00	21.15	25.04	74.96	17.45
84	3.53	1.09	24.76	29.38	70.62	17.52
82	3.47	1.17	28.02	32.66	67.34	17.84
80	3.37	1.23	29.08	33.68	66.32	17.98
78	3.18	1.17	29.09	33.44	66.56	18.10
76	2.94	1.08	29.18	33.20	66.80	18.17
74	2.69	1.00	29.26	32.96	67.04	18.26
72	2.52	0.95	29.25	32.71	67.29	18.31
70	2.15	1.00	29.28	32.44	67.56	18.42
68	1.82	0.97	29.52	32.31	67.69	18.54
66	1.50	0.92	29.56	31.98	68.02	18.65
64	1.33	0.90	29.61	31.85	68.15	18.68
62	1.26	0.84	29.88	31.98	68.02	18.75
60	1.16	0.83	29.70	31.69	68.31	18.83
58	1.18	0.86	29.49	31.53	68.47	18.76
56	1.12	0.83	29.23	31.18	68.82	18.69
54	1.18	0.84	28.70	30.72	69.28	18.65
52	1.12	0.81	28.50	30.43	69.57	18.61
50	0.99	0.78	28.41	30.17	69.83	18.65
48	0.78	0.79	28.01	29.58	70.42	18.68
46	0.57	0.78	27.72	29.07	70.93	18.70
44	0.56	0.71	26.87	28.14	71.86	18.72
42	0.51	0.70	26.36	27.57	72.43	18.67
40	0.41	0.64	25.25	26.30	73.70	18.78
38	0.36	0.65	24.47	25.47	74.53	18.74
36	0.33	0.58	23.59	24.50	75.50	18.80
34	0.20	0.58	22.46	23.25	76.75	18.89
32	0.19	0.52	21.33	22.04	77.96	18.94
30	0.18	0.47	19.70	20.35	79.65	19.06
28	0.11	0.39	17.62	18.12	81.88	19.29
26	0.15	0.15	14.43	14.73	85.27	19.46
24	0.05	0.11	12.99	13.15	86.85	19.40
22	0.05	0.14	11.90	12.09	87.91	19.22
20	0.04	0.15	10.88	11.07	88.93	19.06
18	0.03	0.17	10.09	10.28	89.72	18.84
16	0.00	0.18	9.44	9.62	90.38	18.80
14	0.00	0.18	8.90	9.07	90.93	18.63
12	0.00	0.22	8.76	8.97	91.03	18.41
10	0.00	0.23	8.49	8.72	91.28	18.22
8	0.00	0.23	8.24	8.46	91.54	18.17
6	0.00	0.25	8.03	8.29	91.71	18.01
4	0.00	0.22	8.06	8.27	91.73	18.15
2	0.00	0.25	8.02	8.27	91.73	18.06
0	0.00	0.24	7.97	8.21	91.79	18.03

Table A.7 DOP Availability Vs. South Latitude for Constellation C24, DR and TDOA

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	52.91	18.39	11.97	83.27	16.73	7.59
88	61.69	15.37	10.03	87.09	12.91	6.82
86	73.44	11.95	6.95	92.34	7.66	5.64
84	89.57	6.22	2.95	98.73	1.27	3.83
82	90.79	5.76	2.57	99.11	0.89	3.67
80	90.99	5.45	2.61	99.05	0.95	3.65
78	91.10	5.26	2.57	98.93	1.07	3.61
76	91.31	5.17	2.34	98.82	1.18	3.59
74	91.48	5.06	2.33	98.87	1.13	3.58
72	91.64	4.97	2.31	98.92	1.08	3.61
70	91.81	4.83	2.26	98.91	1.09	3.60
68	91.85	4.78	2.20	98.83	1.17	3.61
66	91.90	4.72	2.22	98.84	1.16	3.62
64	91.99	4.54	2.29	98.82	1.18	3.64
62	92.04	4.31	2.44	98.79	1.21	3.73
60	91.73	4.49	2.50	98.72	1.28	3.79
58	91.28	4.80	2.59	98.68	1.32	3.85
56	90.93	4.88	2.81	98.61	1.39	3.93
54	90.44	5.19	2.87	98.50	1.50	3.95
52	90.14	5.26	3.08	98.47	1.53	4.02
50	89.68	5.55	3.23	98.46	1.54	4.11
48	89.39	5.67	3.37	98.42	1.58	4.22
46	88.97	5.90	3.56	98.42	1.58	4.31
44	88.41	6.06	3.85	98.32	1.68	4.34
42	87.33	6.74	4.21	98.27	1.73	4.54
40	85.57	7.79	4.72	98.08	1.92	4.71
38	83.81	8.76	4.94	97.51	2.49	4.91
36	82.13	8.87	5.41	96.42	3.58	5.10
34	80.52	8.49	5.27	94.28	5.72	5.09
32	78.89	8.07	5.13	92.09	7.91	5.04
30	76.97	6.91	4.46	88.35	11.65	4.86
28	73.18	5.68	3.58	82.45	17.55	4.62
26	66.87	4.16	2.43	73.45	26.55	4.11
24	62.77	4.07	2.28	69.12	30.88	4.15
22	59.91	4.31	2.26	66.48	33.52	4.18
20	58.17	4.32	2.35	64.84	35.16	4.32
18	56.10	4.31	2.62	63.03	36.97	4.51
16	54.03	4.16	2.85	61.03	38.97	4.74
14	52.10	4.35	2.94	59.38	40.62	4.85
12	49.40	4.79	3.02	57.22	42.78	5.01
10	47.69	4.87	3.00	55.55	44.45	4.99
8	46.15	4.60	3.08	53.83	46.17	5.11
6	45.16	4.79	3.11	53.06	46.94	5.20
4	44.42	4.56	3.10	52.08	47.92	5.21
2	43.94	4.66	3.02	51.63	48.37	5.15
0	43.72	4.74	3.00	51.46	48.54	5.20

Table A.8 DOP Availability Vs. South Latitude for Constellation C24, DR Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	13.36	31.89	21.64	66.89	33.11	11.19
88	13.29	31.83	21.76	66.88	33.12	11.20
86	14.07	31.01	21.64	66.73	33.27	11.14
84	16.41	28.63	21.57	66.61	33.39	11.13
82	18.82	25.99	21.31	66.13	33.87	11.04
80	20.73	23.20	20.91	64.83	35.17	11.02
78	23.23	20.51	19.26	63.00	37.00	10.87
76	25.98	18.25	17.09	61.32	38.68	10.36
74	28.66	17.08	14.96	60.70	39.30	9.94
72	31.61	16.09	12.76	60.46	39.54	9.14
70	34.32	15.56	10.71	60.59	39.41	8.37
68	37.02	14.98	7.80	59.81	40.19	7.35
66	39.76	13.52	4.79	58.07	41.93	6.30
64	42.31	10.96	2.83	56.10	43.90	5.51
62	44.87	7.36	1.64	53.86	46.14	4.63
60	47.17	3.76	0.55	51.47	48.53	3.70
58	48.30	1.74	0.11	50.15	49.85	3.14
56	48.26	0.89	0.00	49.15	50.85	2.90
54	47.64	0.38	0.00	48.02	51.98	2.76
52	47.69	0.08	0.00	47.76	52.24	2.66
50	48.12	0.00	0.00	48.12	51.88	2.61
48	47.85	0.00	0.00	47.85	52.15	2.59
46	47.64	0.00	0.00	47.64	52.36	2.58
44	47.46	0.00	0.00	47.46	52.54	2.60
42	46.71	0.00	0.00	46.71	53.29	2.64
40	44.05	0.00	0.00	44.05	55.95	2.70
38	41.29	0.00	0.00	41.29	58.71	2.79
36	37.58	0.48	0.00	38.07	61.93	2.94
34	33.13	1.47	0.00	34.61	65.39	3.16
32	29.37	2.52	0.10	31.99	68.01	3.52
30	24.86	3.38	0.78	29.02	70.98	4.58
28	20.83	3.42	1.16	25.41	74.59	5.23
26	17.59	2.75	1.53	21.86	78.14	6.12
24	14.37	2.54	1.65	18.57	81.43	6.66
22	11.87	2.36	1.44	15.67	84.33	6.88
20	9.48	2.16	1.11	12.75	87.25	6.52
18	7.50	2.20	0.57	10.27	89.73	5.80
16	6.77	2.11	0.18	9.06	90.94	5.06
14	6.24	1.88	0.03	8.15	91.85	4.73
12	6.24	2.12	0.00	8.36	91.64	4.80
10	6.83	1.69	0.00	8.52	91.48	4.54
8	7.16	1.49	0.00	8.64	91.36	4.50
6	7.84	0.84	0.00	8.68	91.32	4.38
4	8.27	0.44	0.00	8.72	91.28	4.35
2	8.67	0.01	0.00	8.68	91.32	4.32
0	8.66	0.00	0.00	8.66	91.34	4.31

Table A.9 DOP Availability Vs. South Latitude for Constellation C24, TDOA Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	31.91	3.80	2.77	38.49	61.51	5.82
88	39.76	4.91	3.27	47.93	52.07	5.74
86	48.21	7.18	4.35	59.74	40.26	5.92
84	59.25	10.18	5.08	74.52	25.48	5.86
82	59.76	10.28	5.21	75.25	24.75	5.85
80	59.24	9.39	5.27	73.91	26.09	5.86
78	58.27	8.64	5.17	72.09	27.91	5.86
76	57.03	8.07	5.05	70.14	29.86	5.84
74	55.15	7.79	4.92	67.86	32.14	5.74
72	53.04	7.84	4.65	65.53	34.47	5.78
70	50.81	7.96	4.45	63.22	36.78	5.78
68	48.44	7.97	4.26	60.66	39.34	5.78
66	46.06	7.93	4.21	58.20	41.80	5.84
64	43.62	7.98	3.98	55.58	44.42	5.93
62	41.12	7.83	3.94	52.89	47.11	6.02
60	38.51	7.75	3.72	49.99	50.01	6.01
58	37.09	7.83	3.51	48.42	51.58	6.00
56	36.22	7.78	3.47	47.47	52.53	5.96
54	35.18	7.77	3.39	46.34	53.66	5.92
52	34.77	7.68	3.77	46.23	53.77	6.14
50	35.08	7.68	3.67	46.43	53.57	5.99
48	34.76	7.50	3.94	46.20	53.80	6.23
46	34.77	7.40	3.75	45.92	54.08	6.25
44	34.77	6.84	4.23	45.84	54.16	6.37
42	34.44	6.63	4.07	45.14	54.86	6.34
40	32.93	6.09	3.56	42.58	57.42	6.10
38	31.48	5.41	3.05	39.95	60.05	5.93
36	30.20	4.28	2.59	37.07	62.93	5.84
34	28.29	3.56	2.08	33.93	66.07	5.59
32	27.44	2.77	1.27	31.48	68.52	4.78
30	26.03	2.11	0.65	28.79	71.21	4.02
28	24.24	1.36	0.22	25.81	74.19	3.29
26	22.29	0.61	0.09	22.99	77.01	2.72
24	19.20	0.32	0.03	19.55	80.45	2.54
22	16.23	0.17	0.01	16.41	83.59	2.43
20	13.22	0.03	0.03	13.27	86.73	2.47
18	10.52	0.00	0.01	10.54	89.46	2.15
16	9.09	0.00	0.00	9.09	90.91	1.63
14	8.15	0.00	0.00	8.15	91.85	1.37
12	8.36	0.00	0.00	8.36	91.64	1.27
10	8.52	0.00	0.00	8.52	91.48	1.25
8	8.64	0.00	0.00	8.64	91.36	1.23
6	8.68	0.00	0.00	8.68	91.32	1.22
4	8.72	0.00	0.00	8.72	91.28	1.21
2	8.68	0.00	0.00	8.68	91.32	1.20
0	8.66	0.00	0.00	8.66	91.34	1.20

Table A.10 DOP Availability Vs. South Latitude for Constellation C32, DR and TDOA

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	0.00	0.00	100.00	Inf
88	0.00	0.51	4.65	5.16	94.84	17.90
86	0.00	4.82	22.48	27.30	72.70	17.90
84	0.00	12.43	60.35	72.78	27.22	16.70
82	0.00	13.93	60.28	74.21	25.79	16.59
80	0.00	13.97	60.21	74.17	25.83	16.58
78	0.00	14.01	60.16	74.16	25.84	16.58
76	0.00	14.06	60.05	74.11	25.89	16.57
74	0.00	14.10	60.02	74.11	25.89	16.58
72	0.00	14.13	59.93	74.06	25.94	16.58
70	0.00	14.16	59.84	74.00	26.00	16.58
68	0.00	14.20	59.76	73.96	26.04	16.59
66	0.00	14.23	59.65	73.88	26.12	16.59
64	0.00	14.23	59.58	73.82	26.18	16.60
62	0.00	14.25	59.47	73.72	26.28	16.61
60	0.00	14.27	59.34	73.61	26.39	16.61
58	0.00	14.35	59.19	73.54	26.46	16.62
56	0.00	14.40	59.02	73.42	26.58	16.63
54	0.00	14.57	58.72	73.28	26.72	16.64
52	0.00	14.69	58.64	73.34	26.66	16.69
50	0.00	14.97	58.31	73.28	26.72	16.73
48	0.00	15.18	58.17	73.35	26.65	16.79
46	0.00	15.28	58.02	73.30	26.70	16.83
44	0.00	15.40	57.77	73.17	26.83	16.85
42	0.00	15.48	57.78	73.26	26.74	16.93
40	0.00	15.56	57.68	73.23	26.77	16.98
38	0.00	15.65	57.42	73.07	26.93	17.00
36	0.00	15.71	56.86	72.57	27.43	16.94
34	0.00	15.79	56.19	71.98	28.02	16.84
32	0.00	15.62	56.05	71.67	28.33	16.82
30	0.00	15.75	55.82	71.57	28.43	16.84
28	0.00	15.34	56.20	71.54	28.46	16.89
26	0.00	15.32	56.05	71.37	28.63	16.90
24	0.00	15.39	55.63	71.02	28.98	16.86
22	0.00	15.40	55.38	70.78	29.22	16.85
20	0.00	15.81	54.59	70.40	29.60	16.80
18	0.00	16.00	54.07	70.07	29.93	16.76
16	0.00	16.08	53.63	69.71	30.29	16.71
14	0.00	16.09	53.20	69.29	30.71	16.64
12	0.00	16.01	52.86	68.87	31.13	16.57
10	0.00	16.24	51.55	67.79	32.21	16.30
8	0.00	16.38	51.22	67.60	32.40	16.27
6	0.00	16.36	51.40	67.76	32.24	16.33
4	0.00	16.32	51.69	68.01	31.99	16.42
2	0.00	16.60	51.56	68.16	31.84	16.47
0	0.00	16.61	51.51	68.12	31.88	16.47

Table A.11 DOP Availability Vs. South Latitude for Constellation C32, DR Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	0.00	0.00	100.00	Inf
88	0.00	0.00	0.00	0.00	100.00	Inf
86	0.00	0.00	0.00	0.00	100.00	Inf
84	0.00	0.00	0.00	0.00	100.00	Inf
82	0.00	0.00	0.00	0.00	100.00	Inf
80	0.00	0.00	0.00	0.00	100.00	Inf
78	0.00	0.00	0.00	0.00	100.00	Inf
76	0.00	0.00	0.00	0.00	100.00	Inf
74	0.00	0.00	0.00	0.00	100.00	Inf
72	0.00	0.00	0.00	0.00	100.00	Inf
70	0.00	0.00	0.00	0.00	100.00	Inf
68	0.00	0.00	0.00	0.00	100.00	Inf
66	0.00	0.00	0.00	0.00	100.00	Inf
64	0.00	0.00	0.00	0.00	100.00	Inf
62	0.00	0.00	0.00	0.00	100.00	Inf
60	0.00	0.00	0.00	0.00	100.00	Inf
58	0.00	0.00	0.00	0.00	100.00	Inf
56	0.00	0.00	0.00	0.00	100.00	Inf
54	0.00	0.00	0.00	0.00	100.00	Inf
52	0.00	0.00	0.00	0.00	100.00	Inf
50	0.00	0.00	0.00	0.00	100.00	Inf
48	0.00	0.00	0.00	0.00	100.00	Inf
46	0.00	0.00	0.00	0.00	100.00	Inf
44	0.00	0.00	0.00	0.00	100.00	Inf
42	0.00	0.00	0.00	0.00	100.00	Inf
40	0.00	0.00	0.00	0.00	100.00	Inf
38	0.00	0.00	0.00	0.00	100.00	Inf
36	0.00	0.00	0.00	0.00	100.00	Inf
34	0.00	0.00	0.00	0.00	100.00	Inf
32	0.00	0.00	0.00	0.00	100.00	Inf
30	0.00	0.00	0.00	0.00	100.00	Inf
28	0.00	0.00	0.00	0.00	100.00	Inf
26	0.00	0.00	0.00	0.00	100.00	Inf
24	0.00	0.00	0.00	0.00	100.00	Inf
22	0.00	0.00	0.00	0.00	100.00	Inf
20	0.00	0.00	0.00	0.00	100.00	Inf
18	0.00	0.00	0.00	0.00	100.00	Inf
16	0.00	0.00	0.00	0.00	100.00	Inf
14	0.00	0.00	0.00	0.00	100.00	Inf
12	0.00	0.00	0.00	0.00	100.00	Inf
10	0.00	0.00	0.00	0.00	100.00	Inf
8	0.00	0.00	0.00	0.00	100.00	Inf
6	0.00	0.00	0.00	0.00	100.00	Inf
4	0.00	0.00	0.00	0.00	100.00	Inf
2	0.00	0.00	0.00	0.00	100.00	Inf
0	0.00	0.00	0.00	0.00	100.00	Inf

Table A.12 DOP Availability Vs. South Latitude for Constellation C32, TDOA Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	0.00	0.00	100.00	Inf
88	0.00	0.00	0.00	0.00	100.00	Inf
86	0.00	0.00	0.00	0.00	100.00	Inf
84	0.00	0.00	0.00	0.00	100.00	Inf
82	0.00	0.00	0.00	0.00	100.00	Inf
80	0.00	0.00	0.00	0.00	100.00	Inf
78	0.00	0.00	0.00	0.00	100.00	Inf
76	0.00	0.00	0.00	0.00	100.00	Inf
74	0.00	0.00	0.00	0.00	100.00	Inf
72	0.00	0.00	0.00	0.00	100.00	Inf
70	0.00	0.00	0.00	0.00	100.00	Inf
68	0.00	0.00	0.00	0.00	100.00	Inf
66	0.00	0.00	0.00	0.00	100.00	Inf
64	0.00	0.00	0.00	0.00	100.00	Inf
62	0.00	0.00	0.00	0.00	100.00	Inf
60	0.00	0.00	0.00	0.00	100.00	Inf
58	0.00	0.00	0.00	0.00	100.00	Inf
56	0.00	0.00	0.00	0.00	100.00	Inf
54	0.00	0.00	0.00	0.00	100.00	Inf
52	0.00	0.00	0.00	0.00	100.00	Inf
50	0.00	0.00	0.00	0.00	100.00	Inf
48	0.00	0.00	0.00	0.00	100.00	Inf
46	0.00	0.00	0.00	0.00	100.00	Inf
44	0.00	0.00	0.00	0.00	100.00	Inf
42	0.00	0.00	0.00	0.00	100.00	Inf
40	0.00	0.00	0.00	0.00	100.00	Inf
38	0.00	0.00	0.00	0.00	100.00	Inf
36	0.00	0.00	0.00	0.00	100.00	Inf
34	0.00	0.00	0.00	0.00	100.00	Inf
32	0.00	0.00	0.00	0.00	100.00	Inf
30	0.00	0.00	0.00	0.00	100.00	Inf
28	0.00	0.00	0.00	0.00	100.00	Inf
26	0.00	0.00	0.00	0.00	100.00	Inf
24	0.00	0.00	0.00	0.00	100.00	Inf
22	0.00	0.00	0.00	0.00	100.00	Inf
20	0.00	0.00	0.00	0.00	100.00	Inf
18	0.00	0.00	0.00	0.00	100.00	Inf
16	0.00	0.00	0.00	0.00	100.00	Inf
14	0.00	0.00	0.00	0.00	100.00	Inf
12	0.00	0.00	0.00	0.00	100.00	Inf
10	0.00	0.00	0.00	0.00	100.00	Inf
8	0.00	0.00	0.00	0.00	100.00	Inf
6	0.00	0.00	0.00	0.00	100.00	Inf
4	0.00	0.00	0.00	0.00	100.00	Inf
2	0.00	0.00	0.00	0.00	100.00	Inf
0	0.00	0.00	0.00	0.00	100.00	Inf

Table A.13 DOP Availability Vs. South Latitude for Constellation C33, DR and TDOA

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	1.82	1.82	98.18	15.73
88	0.00	2.73	17.74	20.48	79.52	18.71
86	0.00	12.40	50.56	62.96	37.04	15.63
84	0.00	42.69	57.31	100.00	0.00	10.32
82	0.00	43.53	56.47	100.00	0.00	10.11
80	0.00	43.57	56.43	100.00	0.00	10.10
78	0.00	43.84	56.16	100.00	0.00	10.09
76	0.00	44.05	55.95	100.00	0.00	10.08
74	0.00	44.23	55.77	100.00	0.00	10.08
72	0.00	44.32	55.68	100.00	0.00	10.07
70	0.00	44.37	55.63	100.00	0.00	10.06
68	0.00	44.45	55.55	100.00	0.00	10.05
66	0.00	44.59	55.41	100.00	0.00	10.04
64	0.00	44.73	55.27	100.00	0.00	10.04
62	0.00	44.80	55.20	100.00	0.00	10.03
60	0.00	44.84	55.16	100.00	0.00	10.02
58	0.00	44.85	55.15	100.00	0.00	10.01
56	0.00	44.87	55.13	100.00	0.00	10.01
54	0.00	44.88	55.12	100.00	0.00	10.00
52	0.00	44.87	55.13	100.00	0.00	9.99
50	0.00	44.83	55.17	100.00	0.00	9.99
48	0.00	44.83	55.17	100.00	0.00	9.98
46	0.00	44.80	55.20	100.00	0.00	9.97
44	0.00	44.79	55.21	100.00	0.00	9.97
42	0.00	44.76	55.24	100.00	0.00	9.96
40	0.00	44.71	55.29	100.00	0.00	9.96
38	0.00	44.80	55.20	100.00	0.00	9.95
36	0.00	45.06	54.94	100.00	0.00	9.95
34	0.00	45.18	54.82	100.00	0.00	9.94
32	0.00	45.11	54.89	100.00	0.00	9.94
30	0.00	44.43	55.57	100.00	0.00	9.94
28	0.00	44.47	55.53	100.00	0.00	9.93
26	0.00	44.42	55.58	100.00	0.00	9.93
24	0.00	44.56	55.44	100.00	0.00	9.92
22	0.00	44.33	55.67	100.00	0.00	9.92
20	0.00	44.23	55.77	100.00	0.00	9.92
18	0.00	44.14	55.86	100.00	0.00	9.92
16	0.00	44.26	55.74	100.00	0.00	9.91
14	0.00	44.41	55.59	100.00	0.00	9.91
12	0.00	44.62	55.38	100.00	0.00	9.91
10	0.00	44.87	55.13	100.00	0.00	9.91
8	0.00	45.06	54.94	100.00	0.00	9.91
6	0.00	45.23	54.77	100.00	0.00	9.91
4	0.00	45.40	54.60	100.00	0.00	9.91
2	0.00	45.50	54.50	100.00	0.00	9.91
0	0.00	45.59	54.41	100.00	0.00	9.91

Table A.14 DOP Availability Vs. South Latitude for Constellation C33, DR Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	0.00	0.00	100.00	Inf
88	0.00	0.00	0.00	0.00	100.00	Inf
86	0.00	0.00	28.85	28.85	71.15	19.38
84	0.00	0.00	100.00	100.00	0.00	19.36
82	0.00	0.00	100.00	100.00	0.00	19.34
80	0.00	0.00	100.00	100.00	0.00	19.32
78	0.00	0.00	100.00	100.00	0.00	19.30
76	0.00	0.00	100.00	100.00	0.00	19.28
74	0.00	0.00	100.00	100.00	0.00	19.26
72	0.00	0.00	100.00	100.00	0.00	19.24
70	0.00	0.00	100.00	100.00	0.00	19.22
68	0.00	0.00	100.00	100.00	0.00	19.20
66	0.00	0.00	100.00	100.00	0.00	19.18
64	0.00	0.00	100.00	100.00	0.00	19.16
62	0.00	0.00	100.00	100.00	0.00	19.14
60	0.00	0.00	100.00	100.00	0.00	19.12
58	0.00	0.00	100.00	100.00	0.00	19.11
56	0.00	0.00	100.00	100.00	0.00	19.09
54	0.00	0.00	100.00	100.00	0.00	19.07
52	0.00	0.00	100.00	100.00	0.00	19.06
50	0.00	0.00	100.00	100.00	0.00	19.04
48	0.00	0.00	100.00	100.00	0.00	19.02
46	0.00	0.00	100.00	100.00	0.00	19.01
44	0.00	0.00	100.00	100.00	0.00	18.99
42	0.00	0.00	100.00	100.00	0.00	18.98
40	0.00	0.00	100.00	100.00	0.00	18.97
38	0.00	0.00	100.00	100.00	0.00	18.95
36	0.00	0.00	100.00	100.00	0.00	18.94
34	0.00	0.00	100.00	100.00	0.00	18.93
32	0.00	0.00	100.00	100.00	0.00	18.92
30	0.00	0.00	100.00	100.00	0.00	18.91
28	0.00	0.00	100.00	100.00	0.00	18.90
26	0.00	0.00	100.00	100.00	0.00	18.89
24	0.00	0.00	100.00	100.00	0.00	18.88
22	0.00	0.00	100.00	100.00	0.00	18.87
20	0.00	0.00	100.00	100.00	0.00	18.86
18	0.00	0.00	100.00	100.00	0.00	18.86
16	0.00	0.00	100.00	100.00	0.00	18.85
14	0.00	0.00	100.00	100.00	0.00	18.84
12	0.00	0.00	100.00	100.00	0.00	18.84
10	0.00	0.00	100.00	100.00	0.00	18.84
8	0.00	0.00	100.00	100.00	0.00	18.83
6	0.00	0.00	100.00	100.00	0.00	18.83
4	0.00	0.00	100.00	100.00	0.00	18.83
2	0.00	0.00	100.00	100.00	0.00	18.83
0	0.00	0.00	100.00	100.00	0.00	18.83

Table A.15 DOP Availability Vs. South Latitude for Constellation C33, TDOA Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	0.00	0.00	100.00	Inf
88	0.00	0.00	0.00	0.00	100.00	Inf
86	0.00	0.00	0.00	0.00	100.00	Inf
84	0.00	0.00	0.00	0.00	100.00	Inf
82	0.00	0.00	0.00	0.00	100.00	Inf
80	0.00	0.00	0.00	0.00	100.00	Inf
78	0.00	0.00	0.00	0.00	100.00	Inf
76	0.00	0.00	0.00	0.00	100.00	Inf
74	0.00	0.00	0.00	0.00	100.00	Inf
72	0.00	0.00	0.00	0.00	100.00	Inf
70	0.00	0.00	0.00	0.00	100.00	Inf
68	0.00	0.00	0.00	0.00	100.00	Inf
66	0.00	0.00	0.00	0.00	100.00	Inf
64	0.00	0.00	0.00	0.00	100.00	Inf
62	0.00	0.00	0.00	0.00	100.00	Inf
60	0.00	0.00	0.00	0.00	100.00	Inf
58	0.00	0.00	0.00	0.00	100.00	Inf
56	0.00	0.00	0.00	0.00	100.00	Inf
54	0.00	0.00	0.00	0.00	100.00	Inf
52	0.00	0.00	0.00	0.00	100.00	Inf
50	0.00	0.00	0.00	0.00	100.00	Inf
48	0.00	0.00	0.00	0.00	100.00	Inf
46	0.00	0.00	0.00	0.00	100.00	Inf
44	0.00	0.00	0.00	0.00	100.00	Inf
42	0.00	0.00	0.00	0.00	100.00	Inf
40	0.00	0.00	0.00	0.00	100.00	Inf
38	0.00	0.00	0.00	0.00	100.00	Inf
36	0.00	0.00	0.00	0.00	100.00	Inf
34	0.00	0.00	0.00	0.00	100.00	Inf
32	0.00	0.00	0.00	0.00	100.00	Inf
30	0.00	0.00	0.00	0.00	100.00	Inf
28	0.00	0.00	0.00	0.00	100.00	Inf
26	0.00	0.00	0.00	0.00	100.00	Inf
24	0.00	0.00	0.00	0.00	100.00	Inf
22	0.00	0.00	0.00	0.00	100.00	Inf
20	0.00	0.00	0.00	0.00	100.00	Inf
18	0.00	0.00	0.00	0.00	100.00	Inf
16	0.00	0.00	0.00	0.00	100.00	Inf
14	0.00	0.00	0.00	0.00	100.00	Inf
12	0.00	0.00	0.00	0.00	100.00	Inf
10	0.00	0.00	0.00	0.00	100.00	Inf
8	0.00	0.00	0.00	0.00	100.00	Inf
6	0.00	0.00	0.00	0.00	100.00	Inf
4	0.00	0.00	0.00	0.00	100.00	Inf
2	0.00	0.00	0.00	0.00	100.00	Inf
0	0.00	0.00	0.00	0.00	100.00	Inf

Table A.16 DOP Availability Vs. South Latitude for Constellation C34, DR and TDOA

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	11.15	11.15	88.85	20.86
88	0.00	3.95	39.57	43.52	56.48	18.34
86	0.00	20.55	79.45	100.00	0.00	15.17
84	0.00	83.10	16.90	100.00	0.00	8.94
82	0.00	84.60	15.40	100.00	0.00	8.76
80	0.00	84.66	15.34	100.00	0.00	8.75
78	0.00	84.74	15.26	100.00	0.00	8.74
76	0.00	84.79	15.21	100.00	0.00	8.73
74	0.00	84.86	15.14	100.00	0.00	8.73
72	0.00	84.93	15.07	100.00	0.00	8.72
70	0.00	85.00	15.00	100.00	0.00	8.71
68	0.00	85.27	14.73	100.00	0.00	8.70
66	0.00	85.64	14.36	100.00	0.00	8.70
64	0.00	86.08	13.92	100.00	0.00	8.69
62	0.00	86.20	13.80	100.00	0.00	8.68
60	0.00	86.31	13.69	100.00	0.00	8.68
58	0.00	86.43	13.57	100.00	0.00	8.67
56	0.00	86.50	13.50	100.00	0.00	8.66
54	0.00	86.51	13.49	100.00	0.00	8.66
52	0.00	86.53	13.47	100.00	0.00	8.65
50	0.00	86.58	13.42	100.00	0.00	8.65
48	0.00	86.64	13.36	100.00	0.00	8.64
46	0.00	86.69	13.31	100.00	0.00	8.64
44	0.00	86.76	13.24	100.00	0.00	8.63
42	0.00	86.83	13.17	100.00	0.00	8.63
40	0.00	86.88	13.12	100.00	0.00	8.62
38	0.00	86.93	13.07	100.00	0.00	8.62
36	0.00	86.99	13.01	100.00	0.00	8.61
34	0.00	87.02	12.98	100.00	0.00	8.61
32	0.00	87.06	12.94	100.00	0.00	8.61
30	0.00	87.09	12.91	100.00	0.00	8.60
28	0.00	87.14	12.86	100.00	0.00	8.60
26	0.00	87.16	12.84	100.00	0.00	8.60
24	0.00	87.20	12.80	100.00	0.00	8.59
22	0.00	87.18	12.82	100.00	0.00	8.59
20	0.00	87.13	12.87	100.00	0.00	8.59
18	0.00	87.11	12.89	100.00	0.00	8.59
16	0.00	87.00	13.00	100.00	0.00	8.58
14	0.00	86.90	13.10	100.00	0.00	8.58
12	0.00	86.85	13.15	100.00	0.00	8.58
10	0.00	86.78	13.22	100.00	0.00	8.58
8	0.00	86.81	13.19	100.00	0.00	8.58
6	0.00	86.86	13.14	100.00	0.00	8.58
4	0.00	86.91	13.09	100.00	0.00	8.58
2	0.00	86.95	13.05	100.00	0.00	8.58
0	0.00	86.93	13.07	100.00	0.00	8.58

Table A.17 DOP Availability Vs. South Latitude for Constellation C34, DR Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	0.00	0.00	100.00	Inf
88	0.00	0.00	18.42	18.42	81.58	23.73
86	0.00	0.00	100.00	100.00	0.00	23.47
84	0.00	0.00	100.00	100.00	0.00	16.76
82	0.00	0.00	100.00	100.00	0.00	16.74
80	0.00	0.00	100.00	100.00	0.00	16.73
78	0.00	0.00	100.00	100.00	0.00	16.71
76	0.00	0.00	100.00	100.00	0.00	16.69
74	0.00	0.00	100.00	100.00	0.00	16.68
72	0.00	0.00	100.00	100.00	0.00	16.66
70	0.00	0.00	100.00	100.00	0.00	16.64
68	0.00	0.00	100.00	100.00	0.00	16.63
66	0.00	0.00	100.00	100.00	0.00	16.61
64	0.00	0.00	100.00	100.00	0.00	16.59
62	0.00	0.00	100.00	100.00	0.00	16.58
60	0.00	0.00	100.00	100.00	0.00	16.56
58	0.00	0.00	100.00	100.00	0.00	16.55
56	0.00	0.00	100.00	100.00	0.00	16.53
54	0.00	0.00	100.00	100.00	0.00	16.52
52	0.00	0.00	100.00	100.00	0.00	16.50
50	0.00	0.00	100.00	100.00	0.00	16.49
48	0.00	0.00	100.00	100.00	0.00	16.48
46	0.00	0.00	100.00	100.00	0.00	16.46
44	0.00	0.00	100.00	100.00	0.00	16.45
42	0.00	0.00	100.00	100.00	0.00	16.44
40	0.00	0.00	100.00	100.00	0.00	16.43
38	0.00	0.00	100.00	100.00	0.00	16.41
36	0.00	0.00	100.00	100.00	0.00	16.40
34	0.00	0.00	100.00	100.00	0.00	16.39
32	0.00	0.00	100.00	100.00	0.00	16.38
30	0.00	0.00	100.00	100.00	0.00	16.37
28	0.00	0.00	100.00	100.00	0.00	16.37
26	0.00	0.00	100.00	100.00	0.00	16.36
24	0.00	0.00	100.00	100.00	0.00	16.35
22	0.00	0.00	100.00	100.00	0.00	16.34
20	0.00	0.00	100.00	100.00	0.00	16.34
18	0.00	0.00	100.00	100.00	0.00	16.33
16	0.00	0.00	100.00	100.00	0.00	16.32
14	0.00	0.00	100.00	100.00	0.00	16.32
12	0.00	0.00	100.00	100.00	0.00	16.32
10	0.00	0.00	100.00	100.00	0.00	16.31
8	0.00	0.00	100.00	100.00	0.00	16.31
6	0.00	0.00	100.00	100.00	0.00	16.31
4	0.00	0.00	100.00	100.00	0.00	16.31
2	0.00	0.00	100.00	100.00	0.00	16.30
0	0.00	0.00	100.00	100.00	0.00	16.30

Table A.18 DOP Availability Vs. South Latitude for Constellation C34, TDOA Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	0.00	0.00	100.00	Inf
88	0.00	0.00	0.00	0.00	100.00	Inf
86	0.00	0.00	0.00	0.00	100.00	Inf
84	0.00	0.00	0.00	0.00	100.00	Inf
82	0.00	0.00	0.00	0.00	100.00	Inf
80	0.00	0.00	0.00	0.00	100.00	Inf
78	0.00	0.00	0.00	0.00	100.00	Inf
76	0.00	0.00	0.00	0.00	100.00	Inf
74	0.00	0.00	0.00	0.00	100.00	Inf
72	0.00	0.00	0.00	0.00	100.00	Inf
70	0.00	0.00	0.00	0.00	100.00	Inf
68	0.00	0.00	0.00	0.00	100.00	Inf
66	0.00	0.00	0.00	0.00	100.00	Inf
64	0.00	0.00	0.00	0.00	100.00	Inf
62	0.00	0.00	0.00	0.00	100.00	Inf
60	0.00	0.00	0.00	0.00	100.00	Inf
58	0.00	0.00	0.00	0.00	100.00	Inf
56	0.00	0.00	0.00	0.00	100.00	Inf
54	0.00	0.00	0.00	0.00	100.00	Inf
52	0.00	0.00	0.00	0.00	100.00	Inf
50	0.00	0.00	0.00	0.00	100.00	Inf
48	0.00	0.00	0.00	0.00	100.00	Inf
46	0.00	0.00	0.00	0.00	100.00	Inf
44	0.00	0.00	0.00	0.00	100.00	Inf
42	0.00	0.00	0.00	0.00	100.00	Inf
40	0.00	0.00	0.00	0.00	100.00	Inf
38	0.00	0.00	0.00	0.00	100.00	Inf
36	0.00	0.00	0.00	0.00	100.00	Inf
34	0.00	0.00	0.00	0.00	100.00	Inf
32	0.00	0.00	0.00	0.00	100.00	Inf
30	0.00	0.00	0.00	0.00	100.00	Inf
28	0.00	0.00	0.00	0.00	100.00	Inf
26	0.00	0.00	0.00	0.00	100.00	Inf
24	0.00	0.00	0.00	0.00	100.00	Inf
22	0.00	0.00	0.00	0.00	100.00	Inf
20	0.00	0.00	0.00	0.00	100.00	Inf
18	0.00	0.00	0.00	0.00	100.00	Inf
16	0.00	0.00	0.00	0.00	100.00	Inf
14	0.00	0.00	0.00	0.00	100.00	Inf
12	0.00	0.00	0.00	0.00	100.00	Inf
10	0.00	0.00	0.00	0.00	100.00	Inf
8	0.00	0.00	0.00	0.00	100.00	Inf
6	0.00	0.00	0.00	0.00	100.00	Inf
4	0.00	0.00	0.00	0.00	100.00	Inf
2	0.00	0.00	0.00	0.00	100.00	Inf
0	0.00	0.00	0.00	0.00	100.00	Inf

Table A.19 DOP Availability Vs. South Latitude for Constellation C42, DR and TDOA

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	0.00	0.00	100.00	Inf
88	0.13	0.41	0.51	1.04	98.96	14.01
86	0.84	2.71	1.69	5.24	94.76	12.43
84	1.09	5.97	5.36	12.43	87.57	12.34
82	1.35	7.88	8.27	17.50	82.50	12.87
80	2.26	10.19	12.20	24.66	75.34	13.74
78	3.61	11.85	16.18	31.63	68.37	14.07
76	4.69	14.13	20.13	38.96	61.04	14.17
74	6.14	16.90	25.47	48.51	51.49	13.94
72	9.42	23.64	30.47	63.52	36.48	13.40
70	12.67	30.83	35.89	79.40	20.60	13.22
68	12.66	30.72	36.03	79.41	20.59	13.25
66	12.65	30.59	36.13	79.37	20.63	13.27
64	12.62	30.50	36.17	79.30	20.70	13.28
62	12.60	30.81	35.61	79.02	20.98	13.21
60	12.56	30.82	35.70	79.08	20.92	13.27
58	12.53	30.69	35.90	79.13	20.87	13.33
56	12.51	30.66	35.92	79.08	20.92	13.35
54	12.48	30.62	35.97	79.07	20.93	13.39
52	12.44	30.62	35.99	79.05	20.95	13.44
50	12.38	30.66	36.01	79.04	20.96	13.49
48	12.29	30.63	35.90	78.83	21.17	13.47
46	12.20	30.63	35.79	78.62	21.38	13.46
44	12.19	30.31	35.90	78.41	21.59	13.46
42	12.13	30.08	35.98	78.19	21.81	13.45
40	12.05	29.99	35.97	78.01	21.99	13.46
38	11.96	29.91	35.87	77.73	22.27	13.44
36	11.88	29.84	35.80	77.53	22.47	13.45
34	11.83	29.88	35.63	77.34	22.66	13.47
32	11.81	29.96	35.40	77.16	22.84	13.50
30	11.82	29.96	35.18	76.96	23.04	13.52
28	11.82	29.68	35.38	76.88	23.12	13.60
26	11.81	29.63	35.32	76.75	23.25	13.67
24	11.78	29.66	35.28	76.73	23.27	13.78
22	11.78	29.60	35.22	76.60	23.40	13.86
20	11.77	29.61	35.07	76.45	23.55	13.93
18	11.86	29.35	34.98	76.18	23.82	13.97
16	11.99	29.04	34.53	75.56	24.44	13.89
14	12.07	28.83	34.25	75.15	24.85	13.87
12	12.11	28.62	34.01	74.75	25.25	13.83
10	12.16	28.33	34.44	74.94	25.06	13.98
8	12.19	28.02	35.00	75.22	24.78	14.14
6	12.16	27.00	36.01	75.17	24.83	14.19
4	12.11	26.54	35.92	74.57	25.43	14.04
2	12.07	26.42	35.28	73.78	26.22	13.78
0	11.99	26.45	35.32	73.75	26.25	13.78

Table A.20 DOP Availability Vs. South Latitude for Constellation C42, DR Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	0.00	0.00	100.00	Inf
88	0.00	0.00	0.00	0.00	100.00	Inf
86	0.00	0.00	0.00	0.00	100.00	Inf
84	0.00	0.00	0.00	0.00	100.00	Inf
82	0.00	0.00	0.00	0.00	100.00	Inf
80	0.00	0.00	0.00	0.00	100.00	Inf
78	0.00	0.00	0.00	0.00	100.00	Inf
76	0.00	0.00	0.00	0.00	100.00	Inf
74	0.00	0.00	0.00	0.00	100.00	Inf
72	0.00	0.00	0.00	0.00	100.00	Inf
70	0.00	0.00	0.00	0.00	100.00	Inf
68	0.00	0.00	0.00	0.00	100.00	Inf
66	0.00	0.00	0.00	0.00	100.00	Inf
64	0.00	0.00	0.00	0.00	100.00	Inf
62	0.00	0.00	0.00	0.00	100.00	Inf
60	0.00	0.00	0.00	0.00	100.00	Inf
58	0.00	0.00	0.00	0.00	100.00	Inf
56	0.00	0.00	0.00	0.00	100.00	Inf
54	0.00	0.00	0.00	0.00	100.00	Inf
52	0.00	0.00	0.00	0.00	100.00	Inf
50	0.00	0.00	0.00	0.00	100.00	Inf
48	0.00	0.00	0.00	0.00	100.00	Inf
46	0.00	0.00	0.00	0.00	100.00	Inf
44	0.00	0.00	0.00	0.00	100.00	Inf
42	0.00	0.00	0.00	0.00	100.00	Inf
40	0.00	0.00	0.00	0.00	100.00	Inf
38	0.00	0.00	0.00	0.00	100.00	Inf
36	0.00	0.00	0.00	0.00	100.00	Inf
34	0.00	0.00	0.00	0.00	100.00	Inf
32	0.00	0.00	0.00	0.00	100.00	Inf
30	0.00	0.00	0.00	0.00	100.00	Inf
28	0.00	0.00	0.00	0.00	100.00	Inf
26	0.00	0.00	0.00	0.00	100.00	Inf
24	0.00	0.00	0.00	0.00	100.00	Inf
22	0.00	0.00	0.00	0.00	100.00	Inf
20	0.00	0.00	0.00	0.00	100.00	Inf
18	0.00	0.00	0.00	0.00	100.00	Inf
16	0.00	0.00	0.00	0.00	100.00	Inf
14	0.00	0.00	0.00	0.00	100.00	Inf
12	0.00	0.00	0.00	0.00	100.00	Inf
10	0.00	0.00	0.00	0.00	100.00	Inf
8	0.00	0.00	0.00	0.00	100.00	Inf
6	0.00	0.00	0.00	0.00	100.00	Inf
4	0.00	0.00	0.00	0.00	100.00	Inf
2	0.00	0.00	0.00	0.00	100.00	Inf
0	0.00	0.00	0.00	0.00	100.00	Inf

Table A.21 DOP Availability Vs. South Latitude for Constellation C42, TDOA Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	0.00	0.00	100.00	Inf
88	0.00	0.00	0.00	0.00	100.00	Inf
86	0.00	0.00	0.00	0.00	100.00	Inf
84	0.00	0.00	0.00	0.00	100.00	Inf
82	0.00	0.00	0.00	0.00	100.00	Inf
80	0.00	0.00	0.00	0.00	100.00	Inf
78	0.00	0.00	0.00	0.00	100.00	Inf
76	0.00	0.00	0.00	0.00	100.00	Inf
74	0.00	0.00	0.00	0.00	100.00	Inf
72	0.00	0.00	0.00	0.00	100.00	Inf
70	0.00	0.00	0.00	0.00	100.00	Inf
68	0.00	0.00	0.00	0.00	100.00	Inf
66	0.00	0.00	0.00	0.00	100.00	Inf
64	0.00	0.00	0.00	0.00	100.00	Inf
62	0.00	0.00	0.00	0.00	100.00	Inf
60	0.00	0.00	0.00	0.00	100.00	Inf
58	0.00	0.00	0.00	0.00	100.00	Inf
56	0.00	0.00	0.00	0.00	100.00	Inf
54	0.00	0.00	0.00	0.00	100.00	Inf
52	0.00	0.00	0.00	0.00	100.00	Inf
50	0.00	0.00	0.00	0.00	100.00	Inf
48	0.00	0.00	0.00	0.00	100.00	Inf
46	0.00	0.00	0.00	0.00	100.00	Inf
44	0.00	0.00	0.00	0.00	100.00	Inf
42	0.00	0.00	0.00	0.00	100.00	Inf
40	0.00	0.00	0.00	0.00	100.00	Inf
38	0.00	0.00	0.00	0.00	100.00	Inf
36	0.00	0.00	0.00	0.00	100.00	Inf
34	0.00	0.00	0.00	0.00	100.00	Inf
32	0.00	0.00	0.00	0.00	100.00	Inf
30	0.00	0.00	0.00	0.00	100.00	Inf
28	0.00	0.00	0.00	0.00	100.00	Inf
26	0.00	0.00	0.00	0.00	100.00	Inf
24	0.00	0.00	0.00	0.00	100.00	Inf
22	0.00	0.00	0.00	0.00	100.00	Inf
20	0.00	0.00	0.00	0.00	100.00	Inf
18	0.00	0.00	0.00	0.00	100.00	Inf
16	0.00	0.00	0.00	0.00	100.00	Inf
14	0.00	0.00	0.00	0.00	100.00	Inf
12	0.00	0.00	0.00	0.00	100.00	Inf
10	0.00	0.00	0.00	0.00	100.00	Inf
8	0.00	0.00	0.00	0.00	100.00	Inf
6	0.00	0.00	0.00	0.00	100.00	Inf
4	0.00	0.00	0.00	0.00	100.00	Inf
2	0.00	0.00	0.00	0.00	100.00	Inf
0	0.00	0.00	0.00	0.00	100.00	Inf

Table A.22 DOP Availability Vs. South Latitude for Constellation C43, DR and TDOA

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	2.85	12.20	6.27	21.31	78.69	11.56
88	5.44	16.55	6.58	28.57	71.43	10.73
86	19.22	18.35	6.63	44.20	55.80	9.08
84	35.82	23.36	6.72	65.90	34.10	7.90
82	41.65	29.02	6.75	77.41	22.59	7.58
80	47.83	33.78	6.80	88.41	11.59	7.32
78	54.61	30.63	6.85	92.09	7.91	7.07
76	63.98	23.54	6.91	94.43	5.57	6.78
74	72.50	17.77	6.99	97.25	2.75	6.46
72	85.74	8.68	4.99	99.42	0.58	5.04
70	100.00	0.00	0.00	100.00	0.00	2.51
68	100.00	0.00	0.00	100.00	0.00	2.51
66	100.00	0.00	0.00	100.00	0.00	2.51
64	100.00	0.00	0.00	100.00	0.00	2.50
62	100.00	0.00	0.00	100.00	0.00	2.50
60	100.00	0.00	0.00	100.00	0.00	2.50
58	100.00	0.00	0.00	100.00	0.00	2.50
56	100.00	0.00	0.00	100.00	0.00	2.50
54	100.00	0.00	0.00	100.00	0.00	2.50
52	100.00	0.00	0.00	100.00	0.00	2.49
50	100.00	0.00	0.00	100.00	0.00	2.49
48	100.00	0.00	0.00	100.00	0.00	2.49
46	100.00	0.00	0.00	100.00	0.00	2.49
44	100.00	0.00	0.00	100.00	0.00	2.49
42	100.00	0.00	0.00	100.00	0.00	2.49
40	100.00	0.00	0.00	100.00	0.00	2.48
38	100.00	0.00	0.00	100.00	0.00	2.48
36	100.00	0.00	0.00	100.00	0.00	2.48
34	100.00	0.00	0.00	100.00	0.00	2.48
32	100.00	0.00	0.00	100.00	0.00	2.48
30	100.00	0.00	0.00	100.00	0.00	2.48
28	100.00	0.00	0.00	100.00	0.00	2.48
26	100.00	0.00	0.00	100.00	0.00	2.48
24	100.00	0.00	0.00	100.00	0.00	2.48
22	100.00	0.00	0.00	100.00	0.00	2.47
20	100.00	0.00	0.00	100.00	0.00	2.47
18	100.00	0.00	0.00	100.00	0.00	2.47
16	100.00	0.00	0.00	100.00	0.00	2.47
14	100.00	0.00	0.00	100.00	0.00	2.47
12	100.00	0.00	0.00	100.00	0.00	2.47
10	100.00	0.00	0.00	100.00	0.00	2.47
8	100.00	0.00	0.00	100.00	0.00	2.47
6	100.00	0.00	0.00	100.00	0.00	2.47
4	100.00	0.00	0.00	100.00	0.00	2.47
2	100.00	0.00	0.00	100.00	0.00	2.47
0	100.00	0.00	0.00	100.00	0.00	2.47

Table A.23 DOP Availability Vs. South Latitude for Constellation C43, DR Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	0.00	0.00	100.00	Inf
88	0.00	0.00	0.00	0.00	100.00	Inf
86	0.00	0.00	0.00	0.00	100.00	Inf
84	0.00	0.00	0.00	0.00	100.00	Inf
82	0.00	0.00	0.00	0.00	100.00	Inf
80	0.00	0.00	0.00	0.00	100.00	Inf
78	11.57	0.00	0.00	11.57	88.43	3.93
76	27.26	0.00	0.00	27.26	72.74	3.93
74	45.78	0.00	0.00	45.78	54.22	3.93
72	72.64	0.00	0.00	72.64	27.36	3.92
70	100.00	0.00	0.00	100.00	0.00	3.92
68	100.00	0.00	0.00	100.00	0.00	3.91
66	100.00	0.00	0.00	100.00	0.00	3.91
64	100.00	0.00	0.00	100.00	0.00	3.91
62	100.00	0.00	0.00	100.00	0.00	3.90
60	100.00	0.00	0.00	100.00	0.00	3.90
58	100.00	0.00	0.00	100.00	0.00	3.90
56	100.00	0.00	0.00	100.00	0.00	3.89
54	100.00	0.00	0.00	100.00	0.00	3.89
52	100.00	0.00	0.00	100.00	0.00	3.89
50	100.00	0.00	0.00	100.00	0.00	3.88
48	100.00	0.00	0.00	100.00	0.00	3.88
46	100.00	0.00	0.00	100.00	0.00	3.88
44	100.00	0.00	0.00	100.00	0.00	3.88
42	100.00	0.00	0.00	100.00	0.00	3.87
40	100.00	0.00	0.00	100.00	0.00	3.87
38	100.00	0.00	0.00	100.00	0.00	3.87
36	100.00	0.00	0.00	100.00	0.00	3.87
34	100.00	0.00	0.00	100.00	0.00	3.86
32	100.00	0.00	0.00	100.00	0.00	3.86
30	100.00	0.00	0.00	100.00	0.00	3.86
28	100.00	0.00	0.00	100.00	0.00	3.86
26	100.00	0.00	0.00	100.00	0.00	3.86
24	100.00	0.00	0.00	100.00	0.00	3.85
22	100.00	0.00	0.00	100.00	0.00	3.85
20	100.00	0.00	0.00	100.00	0.00	3.85
18	100.00	0.00	0.00	100.00	0.00	3.85
16	100.00	0.00	0.00	100.00	0.00	3.85
14	100.00	0.00	0.00	100.00	0.00	3.85
12	100.00	0.00	0.00	100.00	0.00	3.85
10	100.00	0.00	0.00	100.00	0.00	3.85
8	100.00	0.00	0.00	100.00	0.00	3.85
6	100.00	0.00	0.00	100.00	0.00	3.84
4	100.00	0.00	0.00	100.00	0.00	3.84
2	100.00	0.00	0.00	100.00	0.00	3.84
0	100.00	0.00	0.00	100.00	0.00	3.84

Table A.24 DOP Availability Vs. South Latitude for Constellation C43, TDOA Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	0.00	0.00	100.00	Inf
88	0.00	0.00	0.00	0.00	100.00	Inf
86	0.00	0.00	0.00	0.00	100.00	Inf
84	0.00	0.00	0.00	0.00	100.00	Inf
82	0.00	0.00	0.00	0.00	100.00	Inf
80	0.00	0.00	0.00	0.00	100.00	Inf
78	0.00	0.99	10.57	11.57	88.43	14.59
76	0.00	1.13	26.13	27.26	72.74	15.55
74	0.00	2.52	43.26	45.78	54.22	15.55
72	0.00	5.86	66.78	72.64	27.36	15.39
70	0.00	8.03	91.97	100.00	0.00	15.44
68	0.00	8.32	91.68	100.00	0.00	15.40
66	0.00	8.50	91.50	100.00	0.00	15.36
64	0.00	8.72	91.28	100.00	0.00	15.32
62	0.00	8.87	91.13	100.00	0.00	15.28
60	0.00	9.06	90.94	100.00	0.00	15.24
58	0.00	9.32	90.68	100.00	0.00	15.20
56	0.00	9.72	90.28	100.00	0.00	15.16
54	0.00	10.09	89.91	100.00	0.00	15.12
52	0.00	10.21	89.79	100.00	0.00	15.08
50	0.00	10.36	89.64	100.00	0.00	15.04
48	0.00	10.50	89.50	100.00	0.00	15.00
46	0.00	10.65	89.35	100.00	0.00	14.97
44	0.00	10.80	89.20	100.00	0.00	14.93
42	0.00	10.96	89.04	100.00	0.00	14.90
40	0.00	11.10	88.90	100.00	0.00	14.87
38	0.00	11.27	88.73	100.00	0.00	14.84
36	0.00	11.31	88.69	100.00	0.00	14.81
34	0.00	11.34	88.66	100.00	0.00	14.78
32	0.00	11.36	88.64	100.00	0.00	14.75
30	0.00	11.40	88.60	100.00	0.00	14.72
28	0.00	11.40	88.60	100.00	0.00	14.70
26	0.00	11.43	88.57	100.00	0.00	14.68
24	0.00	11.45	88.55	100.00	0.00	14.66
22	0.00	11.53	88.47	100.00	0.00	14.64
20	0.00	11.60	88.40	100.00	0.00	14.62
18	0.00	11.76	88.24	100.00	0.00	14.60
16	0.00	11.87	88.13	100.00	0.00	14.59
14	0.00	11.97	88.03	100.00	0.00	14.58
12	0.00	12.14	87.86	100.00	0.00	14.57
10	0.00	12.35	87.65	100.00	0.00	14.56
8	0.00	12.52	87.48	100.00	0.00	14.56
6	0.00	12.62	87.38	100.00	0.00	14.55
4	0.00	12.74	87.26	100.00	0.00	14.55
2	0.00	12.81	87.19	100.00	0.00	14.55
0	0.00	12.82	87.18	100.00	0.00	14.55

Table A.25 DOP Availability Vs. South Latitude for Constellation C44, DR and TDOA

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	21.02	22.14	1.68	44.84	55.16	5.99
88	38.75	23.56	1.77	64.08	35.92	5.52
86	60.90	20.56	1.59	83.06	16.94	4.97
84	80.34	17.55	0.90	98.79	1.21	4.39
82	86.78	13.03	0.19	100.00	0.00	3.99
80	90.40	9.60	0.00	100.00	0.00	3.66
78	94.75	5.25	0.00	100.00	0.00	3.36
76	100.00	0.00	0.00	100.00	0.00	2.89
74	100.00	0.00	0.00	100.00	0.00	2.73
72	100.00	0.00	0.00	100.00	0.00	2.48
70	100.00	0.00	0.00	100.00	0.00	2.17
68	100.00	0.00	0.00	100.00	0.00	2.17
66	100.00	0.00	0.00	100.00	0.00	2.17
64	100.00	0.00	0.00	100.00	0.00	2.17
62	100.00	0.00	0.00	100.00	0.00	2.17
60	100.00	0.00	0.00	100.00	0.00	2.16
58	100.00	0.00	0.00	100.00	0.00	2.16
56	100.00	0.00	0.00	100.00	0.00	2.16
54	100.00	0.00	0.00	100.00	0.00	2.16
52	100.00	0.00	0.00	100.00	0.00	2.16
50	100.00	0.00	0.00	100.00	0.00	2.16
48	100.00	0.00	0.00	100.00	0.00	2.16
46	100.00	0.00	0.00	100.00	0.00	2.15
44	100.00	0.00	0.00	100.00	0.00	2.15
42	100.00	0.00	0.00	100.00	0.00	2.15
40	100.00	0.00	0.00	100.00	0.00	2.15
38	100.00	0.00	0.00	100.00	0.00	2.15
36	100.00	0.00	0.00	100.00	0.00	2.15
34	100.00	0.00	0.00	100.00	0.00	2.15
32	100.00	0.00	0.00	100.00	0.00	2.15
30	100.00	0.00	0.00	100.00	0.00	2.15
28	100.00	0.00	0.00	100.00	0.00	2.14
26	100.00	0.00	0.00	100.00	0.00	2.14
24	100.00	0.00	0.00	100.00	0.00	2.14
22	100.00	0.00	0.00	100.00	0.00	2.14
20	100.00	0.00	0.00	100.00	0.00	2.14
18	100.00	0.00	0.00	100.00	0.00	2.14
16	100.00	0.00	0.00	100.00	0.00	2.14
14	100.00	0.00	0.00	100.00	0.00	2.14
12	100.00	0.00	0.00	100.00	0.00	2.14
10	100.00	0.00	0.00	100.00	0.00	2.14
8	100.00	0.00	0.00	100.00	0.00	2.14
6	100.00	0.00	0.00	100.00	0.00	2.14
4	100.00	0.00	0.00	100.00	0.00	2.14
2	100.00	0.00	0.00	100.00	0.00	2.14
0	100.00	0.00	0.00	100.00	0.00	2.14

Table A.26 DOP Availability Vs. South Latitude for Constellation C44, DR Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	0.00	0.00	100.00	Inf
88	2.96	0.00	0.00	2.96	97.04	4.81
86	16.75	0.00	0.00	16.75	83.25	4.80
84	31.52	0.00	0.00	31.52	68.48	4.80
82	46.98	0.00	0.00	46.98	53.02	4.80
80	63.35	0.00	0.00	63.35	36.65	4.79
78	81.16	0.00	0.00	81.16	18.84	4.79
76	100.00	0.00	0.00	100.00	0.00	4.77
74	100.00	0.00	0.00	100.00	0.00	4.46
72	100.00	0.00	0.00	100.00	0.00	3.96
70	100.00	0.00	0.00	100.00	0.00	3.39
68	100.00	0.00	0.00	100.00	0.00	3.39
66	100.00	0.00	0.00	100.00	0.00	3.39
64	100.00	0.00	0.00	100.00	0.00	3.38
62	100.00	0.00	0.00	100.00	0.00	3.38
60	100.00	0.00	0.00	100.00	0.00	3.38
58	100.00	0.00	0.00	100.00	0.00	3.37
56	100.00	0.00	0.00	100.00	0.00	3.37
54	100.00	0.00	0.00	100.00	0.00	3.37
52	100.00	0.00	0.00	100.00	0.00	3.37
50	100.00	0.00	0.00	100.00	0.00	3.36
48	100.00	0.00	0.00	100.00	0.00	3.36
46	100.00	0.00	0.00	100.00	0.00	3.36
44	100.00	0.00	0.00	100.00	0.00	3.36
42	100.00	0.00	0.00	100.00	0.00	3.35
40	100.00	0.00	0.00	100.00	0.00	3.35
38	100.00	0.00	0.00	100.00	0.00	3.35
36	100.00	0.00	0.00	100.00	0.00	3.35
34	100.00	0.00	0.00	100.00	0.00	3.35
32	100.00	0.00	0.00	100.00	0.00	3.34
30	100.00	0.00	0.00	100.00	0.00	3.34
28	100.00	0.00	0.00	100.00	0.00	3.34
26	100.00	0.00	0.00	100.00	0.00	3.34
24	100.00	0.00	0.00	100.00	0.00	3.34
22	100.00	0.00	0.00	100.00	0.00	3.34
20	100.00	0.00	0.00	100.00	0.00	3.34
18	100.00	0.00	0.00	100.00	0.00	3.33
16	100.00	0.00	0.00	100.00	0.00	3.33
14	100.00	0.00	0.00	100.00	0.00	3.33
12	100.00	0.00	0.00	100.00	0.00	3.33
10	100.00	0.00	0.00	100.00	0.00	3.33
8	100.00	0.00	0.00	100.00	0.00	3.33
6	100.00	0.00	0.00	100.00	0.00	3.33
4	100.00	0.00	0.00	100.00	0.00	3.33
2	100.00	0.00	0.00	100.00	0.00	3.33
0	100.00	0.00	0.00	100.00	0.00	3.33

Table A.27 DOP Availability Vs. South Latitude for Constellation C44, TDOA Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	0.00	0.00	100.00	Inf
88	0.00	0.00	1.88	1.88	98.12	15.02
86	0.00	0.00	12.81	12.81	87.19	14.66
84	0.00	0.00	31.30	31.30	68.70	17.61
82	0.00	0.00	46.87	46.87	53.13	17.86
80	0.00	0.00	62.48	62.48	37.52	17.48
78	0.00	0.00	79.74	79.74	20.26	17.21
76	0.00	0.08	98.30	98.37	1.63	17.36
74	0.00	4.04	94.79	98.83	1.17	16.37
72	0.00	13.98	86.02	100.00	0.00	15.04
70	0.00	19.57	80.43	100.00	0.00	13.36
68	0.00	19.73	80.27	100.00	0.00	13.32
66	0.00	19.76	80.24	100.00	0.00	13.29
64	0.00	19.85	80.15	100.00	0.00	13.25
62	0.00	19.90	80.10	100.00	0.00	13.22
60	0.00	19.92	80.08	100.00	0.00	13.18
58	0.00	19.93	80.07	100.00	0.00	13.15
56	0.00	19.99	80.01	100.00	0.00	13.11
54	0.00	20.09	79.91	100.00	0.00	13.08
52	0.00	20.25	79.75	100.00	0.00	13.04
50	0.00	20.49	79.51	100.00	0.00	13.01
48	0.00	20.89	79.11	100.00	0.00	12.98
46	0.00	21.23	78.77	100.00	0.00	12.95
44	0.00	21.43	78.57	100.00	0.00	12.92
42	0.00	21.66	78.34	100.00	0.00	12.89
40	0.00	21.91	78.09	100.00	0.00	12.86
38	0.00	22.09	77.91	100.00	0.00	12.84
36	0.00	22.17	77.83	100.00	0.00	12.81
34	0.00	22.23	77.77	100.00	0.00	12.78
32	0.00	22.31	77.69	100.00	0.00	12.76
30	0.00	22.39	77.61	100.00	0.00	12.74
28	0.00	22.47	77.53	100.00	0.00	12.72
26	0.00	22.57	77.43	100.00	0.00	12.70
24	0.00	22.75	77.25	100.00	0.00	12.68
22	0.00	22.99	77.01	100.00	0.00	12.66
20	0.00	23.39	76.61	100.00	0.00	12.65
18	0.00	23.54	76.46	100.00	0.00	12.64
16	0.00	23.63	76.37	100.00	0.00	12.62
14	0.00	23.69	76.31	100.00	0.00	12.61
12	0.00	23.70	76.30	100.00	0.00	12.61
10	0.00	23.68	76.32	100.00	0.00	12.60
8	0.00	23.67	76.33	100.00	0.00	12.59
6	0.00	23.70	76.30	100.00	0.00	12.59
4	0.00	23.78	76.22	100.00	0.00	12.59
2	0.00	23.91	76.09	100.00	0.00	12.59
0	0.00	24.01	75.99	100.00	0.00	12.59

Table A.28 DOP Availability Vs. South Latitude for Constellation C51, DR and TDOA

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	0.00	0.00	100.00	Inf
88	0.00	0.00	0.00	0.00	100.00	Inf
86	0.00	0.00	0.00	0.00	100.00	Inf
84	0.00	0.00	0.00	0.00	100.00	Inf
82	0.00	0.00	0.00	0.00	100.00	Inf
80	0.00	0.00	0.00	0.00	100.00	Inf
78	0.00	0.00	0.00	0.00	100.00	Inf
76	0.00	0.00	0.00	0.00	100.00	Inf
74	0.00	0.00	0.00	0.00	100.00	Inf
72	0.00	0.00	0.00	0.00	100.00	Inf
70	0.00	0.00	0.00	0.00	100.00	Inf
68	0.00	0.00	0.00	0.00	100.00	Inf
66	0.00	0.00	0.00	0.00	100.00	Inf
64	0.00	0.00	0.00	0.00	100.00	Inf
62	0.00	0.00	0.00	0.00	100.00	Inf
60	0.00	0.00	0.00	0.00	100.00	Inf
58	0.00	0.00	0.00	0.00	100.00	Inf
56	0.00	0.00	0.00	0.00	100.00	Inf
54	0.00	0.00	0.00	0.00	100.00	Inf
52	0.00	0.00	0.00	0.00	100.00	Inf
50	0.00	0.00	0.00	0.00	100.00	Inf
48	0.00	0.00	0.00	0.00	100.00	Inf
46	0.00	0.00	0.00	0.00	100.00	Inf
44	0.00	0.00	0.00	0.00	100.00	Inf
42	0.00	0.00	0.00	0.00	100.00	Inf
40	0.00	0.00	0.00	0.00	100.00	Inf
38	0.00	0.00	0.00	0.00	100.00	Inf
36	0.00	0.00	0.00	0.00	100.00	Inf
34	0.00	0.00	0.00	0.00	100.00	Inf
32	0.00	0.00	0.00	0.00	100.00	Inf
30	0.00	0.00	0.00	0.00	100.00	Inf
28	0.00	0.00	0.00	0.00	100.00	Inf
26	0.00	0.00	0.00	0.00	100.00	Inf
24	0.00	0.00	0.00	0.00	100.00	Inf
22	0.00	0.00	0.00	0.00	100.00	Inf
20	0.00	0.00	0.00	0.00	100.00	Inf
18	0.00	0.00	0.00	0.00	100.00	Inf
16	0.00	0.00	0.00	0.00	100.00	Inf
14	0.00	0.00	0.00	0.00	100.00	Inf
12	0.00	0.00	0.00	0.00	100.00	Inf
10	0.00	0.00	0.00	0.00	100.00	Inf
8	0.00	0.00	0.00	0.00	100.00	Inf
6	0.00	0.00	0.00	0.00	100.00	Inf
4	0.00	0.00	0.00	0.00	100.00	Inf
2	0.00	0.00	0.00	0.00	100.00	Inf
0	0.00	0.00	0.00	0.00	100.00	Inf

Table A.29 DOP Availability Vs. South Latitude for Constellation C52, DR and TDOA

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	8.52	8.52	91.48	25.54
88	0.00	0.51	4.65	5.16	94.84	17.90
86	0.00	4.82	22.48	27.30	72.70	17.90
84	0.00	12.43	60.35	72.78	27.22	16.70
82	0.00	13.93	60.28	74.21	25.79	16.59
80	0.00	13.97	60.21	74.17	25.83	16.58
78	0.00	14.01	60.16	74.16	25.84	16.58
76	0.00	14.06	60.05	74.11	25.89	16.57
74	0.00	14.10	60.02	74.11	25.89	16.58
72	0.00	14.13	59.93	74.06	25.94	16.58
70	0.00	14.16	59.84	74.00	26.00	16.58
68	0.00	14.20	59.76	73.96	26.04	16.59
66	0.00	14.23	59.65	73.88	26.12	16.59
64	0.00	14.23	59.58	73.82	26.18	16.60
62	0.00	14.25	59.47	73.72	26.28	16.61
60	0.00	14.27	59.34	73.61	26.39	16.61
58	0.00	14.35	59.19	73.54	26.46	16.62
56	0.00	14.40	59.02	73.42	26.58	16.63
54	0.00	14.57	58.72	73.28	26.72	16.64
52	0.00	14.69	58.64	73.34	26.66	16.69
50	0.00	14.97	58.31	73.28	26.72	16.73
48	0.00	15.18	58.17	73.35	26.65	16.79
46	0.00	15.28	58.02	73.30	26.70	16.83
44	0.00	15.40	57.77	73.17	26.83	16.85
42	0.00	15.48	57.78	73.26	26.74	16.93
40	0.00	15.56	57.68	73.23	26.77	16.98
38	0.00	15.65	57.42	73.07	26.93	17.00
36	0.00	15.71	56.86	72.57	27.43	16.94
34	0.00	15.79	56.19	71.98	28.02	16.84
32	0.00	15.62	56.05	71.67	28.33	16.82
30	0.00	15.75	55.82	71.57	28.43	16.84
28	0.00	15.34	56.20	71.54	28.46	16.89
26	0.00	15.32	56.05	71.37	28.63	16.90
24	0.00	15.39	55.63	71.02	28.98	16.86
22	0.00	15.40	55.38	70.78	29.22	16.85
20	0.00	15.81	54.59	70.40	29.60	16.80
18	0.00	16.00	54.07	70.07	29.93	16.76
16	0.00	16.08	53.63	69.71	30.29	16.71
14	0.00	16.09	53.20	69.29	30.71	16.64
12	0.00	16.01	52.86	68.87	31.13	16.57
10	0.00	16.24	51.55	67.79	32.21	16.30
8	0.00	16.38	51.22	67.60	32.40	16.27
6	0.00	16.36	51.40	67.76	32.24	16.33
4	0.00	16.32	51.69	68.01	31.99	16.42
2	0.00	16.60	51.56	68.16	31.84	16.47
0	0.00	16.61	51.51	68.12	31.88	16.47

Table A.30 DOP Availability Vs. South Latitude for Constellation C52, DR Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	0.00	0.00	100.00	Inf
88	0.00	0.00	0.00	0.00	100.00	Inf
86	0.00	0.00	0.00	0.00	100.00	Inf
84	0.00	0.00	0.00	0.00	100.00	Inf
82	0.00	0.00	0.00	0.00	100.00	Inf
80	0.00	0.00	0.00	0.00	100.00	Inf
78	0.00	0.00	0.00	0.00	100.00	Inf
76	0.00	0.00	0.00	0.00	100.00	Inf
74	0.00	0.00	0.00	0.00	100.00	Inf
72	0.00	0.00	0.00	0.00	100.00	Inf
70	0.00	0.00	0.00	0.00	100.00	Inf
68	0.00	0.00	0.00	0.00	100.00	Inf
66	0.00	0.00	0.00	0.00	100.00	Inf
64	0.00	0.00	0.00	0.00	100.00	Inf
62	0.00	0.00	0.00	0.00	100.00	Inf
60	0.00	0.00	0.00	0.00	100.00	Inf
58	0.00	0.00	0.00	0.00	100.00	Inf
56	0.00	0.00	0.00	0.00	100.00	Inf
54	0.00	0.00	0.00	0.00	100.00	Inf
52	0.00	0.00	0.00	0.00	100.00	Inf
50	0.00	0.00	0.00	0.00	100.00	Inf
48	0.00	0.00	0.00	0.00	100.00	Inf
46	0.00	0.00	0.00	0.00	100.00	Inf
44	0.00	0.00	0.00	0.00	100.00	Inf
42	0.00	0.00	0.00	0.00	100.00	Inf
40	0.00	0.00	0.00	0.00	100.00	Inf
38	0.00	0.00	0.00	0.00	100.00	Inf
36	0.00	0.00	0.00	0.00	100.00	Inf
34	0.00	0.00	0.00	0.00	100.00	Inf
32	0.00	0.00	0.00	0.00	100.00	Inf
30	0.00	0.00	0.00	0.00	100.00	Inf
28	0.00	0.00	0.00	0.00	100.00	Inf
26	0.00	0.00	0.00	0.00	100.00	Inf
24	0.00	0.00	0.00	0.00	100.00	Inf
22	0.00	0.00	0.00	0.00	100.00	Inf
20	0.00	0.00	0.00	0.00	100.00	Inf
18	0.00	0.00	0.00	0.00	100.00	Inf
16	0.00	0.00	0.00	0.00	100.00	Inf
14	0.00	0.00	0.00	0.00	100.00	Inf
12	0.00	0.00	0.00	0.00	100.00	Inf
10	0.00	0.00	0.00	0.00	100.00	Inf
8	0.00	0.00	0.00	0.00	100.00	Inf
6	0.00	0.00	0.00	0.00	100.00	Inf
4	0.00	0.00	0.00	0.00	100.00	Inf
2	0.00	0.00	0.00	0.00	100.00	Inf
0	0.00	0.00	0.00	0.00	100.00	Inf

Table A.31 DOP Availability Vs. South Latitude for Constellation C52, TDOA Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	0.00	0.00	100.00	Inf
88	0.00	0.00	0.00	0.00	100.00	Inf
86	0.00	0.00	0.00	0.00	100.00	Inf
84	0.00	0.00	0.00	0.00	100.00	Inf
82	0.00	0.00	0.00	0.00	100.00	Inf
80	0.00	0.00	0.00	0.00	100.00	Inf
78	0.00	0.00	0.00	0.00	100.00	Inf
76	0.00	0.00	0.00	0.00	100.00	Inf
74	0.00	0.00	0.00	0.00	100.00	Inf
72	0.00	0.00	0.00	0.00	100.00	Inf
70	0.00	0.00	0.00	0.00	100.00	Inf
68	0.00	0.00	0.00	0.00	100.00	Inf
66	0.00	0.00	0.00	0.00	100.00	Inf
64	0.00	0.00	0.00	0.00	100.00	Inf
62	0.00	0.00	0.00	0.00	100.00	Inf
60	0.00	0.00	0.00	0.00	100.00	Inf
58	0.00	0.00	0.00	0.00	100.00	Inf
56	0.00	0.00	0.00	0.00	100.00	Inf
54	0.00	0.00	0.00	0.00	100.00	Inf
52	0.00	0.00	0.00	0.00	100.00	Inf
50	0.00	0.00	0.00	0.00	100.00	Inf
48	0.00	0.00	0.00	0.00	100.00	Inf
46	0.00	0.00	0.00	0.00	100.00	Inf
44	0.00	0.00	0.00	0.00	100.00	Inf
42	0.00	0.00	0.00	0.00	100.00	Inf
40	0.00	0.00	0.00	0.00	100.00	Inf
38	0.00	0.00	0.00	0.00	100.00	Inf
36	0.00	0.00	0.00	0.00	100.00	Inf
34	0.00	0.00	0.00	0.00	100.00	Inf
32	0.00	0.00	0.00	0.00	100.00	Inf
30	0.00	0.00	0.00	0.00	100.00	Inf
28	0.00	0.00	0.00	0.00	100.00	Inf
26	0.00	0.00	0.00	0.00	100.00	Inf
24	0.00	0.00	0.00	0.00	100.00	Inf
22	0.00	0.00	0.00	0.00	100.00	Inf
20	0.00	0.00	0.00	0.00	100.00	Inf
18	0.00	0.00	0.00	0.00	100.00	Inf
16	0.00	0.00	0.00	0.00	100.00	Inf
14	0.00	0.00	0.00	0.00	100.00	Inf
12	0.00	0.00	0.00	0.00	100.00	Inf
10	0.00	0.00	0.00	0.00	100.00	Inf
8	0.00	0.00	0.00	0.00	100.00	Inf
6	0.00	0.00	0.00	0.00	100.00	Inf
4	0.00	0.00	0.00	0.00	100.00	Inf
2	0.00	0.00	0.00	0.00	100.00	Inf
0	0.00	0.00	0.00	0.00	100.00	Inf

Table A.32 DOP Availability Vs. South Latitude for Constellation C53, DR and TDOA

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	17.23	17.23	82.77	23.87
88	0.00	2.73	17.74	20.48	79.52	18.71
86	0.00	12.40	50.56	62.96	37.04	15.63
84	0.00	42.69	57.31	100.00	0.00	10.32
82	0.00	43.53	56.47	100.00	0.00	10.11
80	0.00	43.57	56.43	100.00	0.00	10.10
78	0.00	43.84	56.16	100.00	0.00	10.09
76	0.00	44.05	55.95	100.00	0.00	10.08
74	0.00	44.23	55.77	100.00	0.00	10.08
72	0.00	44.32	55.68	100.00	0.00	10.07
70	0.00	44.37	55.63	100.00	0.00	10.06
68	0.00	44.45	55.55	100.00	0.00	10.05
66	0.00	44.59	55.41	100.00	0.00	10.04
64	0.00	44.73	55.27	100.00	0.00	10.04
62	0.00	44.80	55.20	100.00	0.00	10.03
60	0.00	44.84	55.16	100.00	0.00	10.02
58	0.00	44.85	55.15	100.00	0.00	10.01
56	0.00	44.87	55.13	100.00	0.00	10.01
54	0.00	44.88	55.12	100.00	0.00	10.00
52	0.00	44.87	55.13	100.00	0.00	9.99
50	0.00	44.83	55.17	100.00	0.00	9.99
48	0.00	44.83	55.17	100.00	0.00	9.98
46	0.00	44.80	55.20	100.00	0.00	9.97
44	0.00	44.79	55.21	100.00	0.00	9.97
42	0.00	44.76	55.24	100.00	0.00	9.96
40	0.00	44.71	55.29	100.00	0.00	9.96
38	0.00	44.80	55.20	100.00	0.00	9.95
36	0.00	45.06	54.94	100.00	0.00	9.95
34	0.00	45.18	54.82	100.00	0.00	9.94
32	0.00	45.11	54.89	100.00	0.00	9.94
30	0.00	44.43	55.57	100.00	0.00	9.94
28	0.00	44.47	55.53	100.00	0.00	9.93
26	0.00	44.42	55.58	100.00	0.00	9.93
24	0.00	44.56	55.44	100.00	0.00	9.92
22	0.00	44.33	55.67	100.00	0.00	9.92
20	0.00	44.23	55.77	100.00	0.00	9.92
18	0.00	44.14	55.86	100.00	0.00	9.92
16	0.00	44.26	55.74	100.00	0.00	9.91
14	0.00	44.41	55.59	100.00	0.00	9.91
12	0.00	44.62	55.38	100.00	0.00	9.91
10	0.00	44.87	55.13	100.00	0.00	9.91
8	0.00	45.06	54.94	100.00	0.00	9.91
6	0.00	45.23	54.77	100.00	0.00	9.91
4	0.00	45.40	54.60	100.00	0.00	9.91
2	0.00	45.50	54.50	100.00	0.00	9.91
0	0.00	45.59	54.41	100.00	0.00	9.91

Table A.33 DOP Availability Vs. South Latitude for Constellation C53, DR Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	0.00	0.00	100.00	Inf
88	0.00	0.00	0.00	0.00	100.00	Inf
86	0.00	0.00	28.85	28.85	71.15	19.38
84	0.00	0.00	100.00	100.00	0.00	19.36
82	0.00	0.00	100.00	100.00	0.00	19.34
80	0.00	0.00	100.00	100.00	0.00	19.32
78	0.00	0.00	100.00	100.00	0.00	19.30
76	0.00	0.00	100.00	100.00	0.00	19.28
74	0.00	0.00	100.00	100.00	0.00	19.26
72	0.00	0.00	100.00	100.00	0.00	19.24
70	0.00	0.00	100.00	100.00	0.00	19.22
68	0.00	0.00	100.00	100.00	0.00	19.20
66	0.00	0.00	100.00	100.00	0.00	19.18
64	0.00	0.00	100.00	100.00	0.00	19.16
62	0.00	0.00	100.00	100.00	0.00	19.14
60	0.00	0.00	100.00	100.00	0.00	19.12
58	0.00	0.00	100.00	100.00	0.00	19.11
56	0.00	0.00	100.00	100.00	0.00	19.09
54	0.00	0.00	100.00	100.00	0.00	19.07
52	0.00	0.00	100.00	100.00	0.00	19.06
50	0.00	0.00	100.00	100.00	0.00	19.04
48	0.00	0.00	100.00	100.00	0.00	19.02
46	0.00	0.00	100.00	100.00	0.00	19.01
44	0.00	0.00	100.00	100.00	0.00	18.99
42	0.00	0.00	100.00	100.00	0.00	18.98
40	0.00	0.00	100.00	100.00	0.00	18.97
38	0.00	0.00	100.00	100.00	0.00	18.95
36	0.00	0.00	100.00	100.00	0.00	18.94
34	0.00	0.00	100.00	100.00	0.00	18.93
32	0.00	0.00	100.00	100.00	0.00	18.92
30	0.00	0.00	100.00	100.00	0.00	18.91
28	0.00	0.00	100.00	100.00	0.00	18.90
26	0.00	0.00	100.00	100.00	0.00	18.89
24	0.00	0.00	100.00	100.00	0.00	18.88
22	0.00	0.00	100.00	100.00	0.00	18.87
20	0.00	0.00	100.00	100.00	0.00	18.86
18	0.00	0.00	100.00	100.00	0.00	18.86
16	0.00	0.00	100.00	100.00	0.00	18.85
14	0.00	0.00	100.00	100.00	0.00	18.84
12	0.00	0.00	100.00	100.00	0.00	18.84
10	0.00	0.00	100.00	100.00	0.00	18.84
8	0.00	0.00	100.00	100.00	0.00	18.83
6	0.00	0.00	100.00	100.00	0.00	18.83
4	0.00	0.00	100.00	100.00	0.00	18.83
2	0.00	0.00	100.00	100.00	0.00	18.83
0	0.00	0.00	100.00	100.00	0.00	18.83

Table A.34 DOP Availability Vs. South Latitude for Constellation C53, TDOA Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	2.59	2.59	97.41	21.05
88	0.00	0.00	0.00	0.00	100.00	Inf
86	0.00	0.00	0.00	0.00	100.00	Inf
84	0.00	0.00	0.00	0.00	100.00	Inf
82	0.00	0.00	0.00	0.00	100.00	Inf
80	0.00	0.00	0.00	0.00	100.00	Inf
78	0.00	0.00	0.00	0.00	100.00	Inf
76	0.00	0.00	0.00	0.00	100.00	Inf
74	0.00	0.00	0.00	0.00	100.00	Inf
72	0.00	0.00	0.00	0.00	100.00	Inf
70	0.00	0.00	0.00	0.00	100.00	Inf
68	0.00	0.00	0.00	0.00	100.00	Inf
66	0.00	0.00	0.00	0.00	100.00	Inf
64	0.00	0.00	0.00	0.00	100.00	Inf
62	0.00	0.00	0.00	0.00	100.00	Inf
60	0.00	0.00	0.00	0.00	100.00	Inf
58	0.00	0.00	0.00	0.00	100.00	Inf
56	0.00	0.00	0.00	0.00	100.00	Inf
54	0.00	0.00	0.00	0.00	100.00	Inf
52	0.00	0.00	0.00	0.00	100.00	Inf
50	0.00	0.00	0.00	0.00	100.00	Inf
48	0.00	0.00	0.00	0.00	100.00	Inf
46	0.00	0.00	0.00	0.00	100.00	Inf
44	0.00	0.00	0.00	0.00	100.00	Inf
42	0.00	0.00	0.00	0.00	100.00	Inf
40	0.00	0.00	0.00	0.00	100.00	Inf
38	0.00	0.00	0.00	0.00	100.00	Inf
36	0.00	0.00	0.00	0.00	100.00	Inf
34	0.00	0.00	0.00	0.00	100.00	Inf
32	0.00	0.00	0.00	0.00	100.00	Inf
30	0.00	0.00	0.00	0.00	100.00	Inf
28	0.00	0.00	0.00	0.00	100.00	Inf
26	0.00	0.00	0.00	0.00	100.00	Inf
24	0.00	0.00	0.00	0.00	100.00	Inf
22	0.00	0.00	0.00	0.00	100.00	Inf
20	0.00	0.00	0.00	0.00	100.00	Inf
18	0.00	0.00	0.00	0.00	100.00	Inf
16	0.00	0.00	0.00	0.00	100.00	Inf
14	0.00	0.00	0.00	0.00	100.00	Inf
12	0.00	0.00	0.00	0.00	100.00	Inf
10	0.00	0.00	0.00	0.00	100.00	Inf
8	0.00	0.00	0.00	0.00	100.00	Inf
6	0.00	0.00	0.00	0.00	100.00	Inf
4	0.00	0.00	0.00	0.00	100.00	Inf
2	0.00	0.00	0.00	0.00	100.00	Inf
0	0.00	0.00	0.00	0.00	100.00	Inf

Table A.35 DOP Availability Vs. South Latitude for Constellation C54, DR and TDOA

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	33.78	33.78	66.22	22.38
88	0.00	3.95	39.57	43.52	56.48	18.34
86	0.00	20.55	79.45	100.00	0.00	15.17
84	0.00	83.10	16.90	100.00	0.00	8.94
82	0.00	84.60	15.40	100.00	0.00	8.76
80	0.00	84.66	15.34	100.00	0.00	8.75
78	0.00	84.74	15.26	100.00	0.00	8.74
76	0.00	84.79	15.21	100.00	0.00	8.73
74	0.00	84.86	15.14	100.00	0.00	8.73
72	0.00	84.93	15.07	100.00	0.00	8.72
70	0.00	85.00	15.00	100.00	0.00	8.71
68	0.00	85.27	14.73	100.00	0.00	8.70
66	0.00	85.64	14.36	100.00	0.00	8.70
64	0.00	86.08	13.92	100.00	0.00	8.69
62	0.00	86.20	13.80	100.00	0.00	8.68
60	0.00	86.31	13.69	100.00	0.00	8.68
58	0.00	86.43	13.57	100.00	0.00	8.67
56	0.00	86.50	13.50	100.00	0.00	8.66
54	0.00	86.51	13.49	100.00	0.00	8.66
52	0.00	86.53	13.47	100.00	0.00	8.65
50	0.00	86.58	13.42	100.00	0.00	8.65
48	0.00	86.64	13.36	100.00	0.00	8.64
46	0.00	86.69	13.31	100.00	0.00	8.64
44	0.00	86.76	13.24	100.00	0.00	8.63
42	0.00	86.83	13.17	100.00	0.00	8.63
40	0.00	86.88	13.12	100.00	0.00	8.62
38	0.00	86.93	13.07	100.00	0.00	8.62
36	0.00	86.99	13.01	100.00	0.00	8.61
34	0.00	87.02	12.98	100.00	0.00	8.61
32	0.00	87.06	12.94	100.00	0.00	8.61
30	0.00	87.09	12.91	100.00	0.00	8.60
28	0.00	87.14	12.86	100.00	0.00	8.60
26	0.00	87.16	12.84	100.00	0.00	8.60
24	0.00	87.20	12.80	100.00	0.00	8.59
22	0.00	87.18	12.82	100.00	0.00	8.59
20	0.00	87.13	12.87	100.00	0.00	8.59
18	0.00	87.11	12.89	100.00	0.00	8.59
16	0.00	87.00	13.00	100.00	0.00	8.58
14	0.00	86.90	13.10	100.00	0.00	8.58
12	0.00	86.85	13.15	100.00	0.00	8.58
10	0.00	86.78	13.22	100.00	0.00	8.58
8	0.00	86.81	13.19	100.00	0.00	8.58
6	0.00	86.86	13.14	100.00	0.00	8.58
4	0.00	86.91	13.09	100.00	0.00	8.58
2	0.00	86.95	13.05	100.00	0.00	8.58
0	0.00	86.93	13.07	100.00	0.00	8.58

Table A.36 DOP Availability Vs. South Latitude for Constellation C54, DR Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	0.00	0.00	100.00	Inf
88	0.00	0.00	18.42	18.42	81.58	23.73
86	0.00	0.00	100.00	100.00	0.00	23.47
84	0.00	0.00	100.00	100.00	0.00	16.76
82	0.00	0.00	100.00	100.00	0.00	16.74
80	0.00	0.00	100.00	100.00	0.00	16.73
78	0.00	0.00	100.00	100.00	0.00	16.71
76	0.00	0.00	100.00	100.00	0.00	16.69
74	0.00	0.00	100.00	100.00	0.00	16.68
72	0.00	0.00	100.00	100.00	0.00	16.66
70	0.00	0.00	100.00	100.00	0.00	16.64
68	0.00	0.00	100.00	100.00	0.00	16.63
66	0.00	0.00	100.00	100.00	0.00	16.61
64	0.00	0.00	100.00	100.00	0.00	16.59
62	0.00	0.00	100.00	100.00	0.00	16.58
60	0.00	0.00	100.00	100.00	0.00	16.56
58	0.00	0.00	100.00	100.00	0.00	16.55
56	0.00	0.00	100.00	100.00	0.00	16.53
54	0.00	0.00	100.00	100.00	0.00	16.52
52	0.00	0.00	100.00	100.00	0.00	16.50
50	0.00	0.00	100.00	100.00	0.00	16.49
48	0.00	0.00	100.00	100.00	0.00	16.48
46	0.00	0.00	100.00	100.00	0.00	16.46
44	0.00	0.00	100.00	100.00	0.00	16.45
42	0.00	0.00	100.00	100.00	0.00	16.44
40	0.00	0.00	100.00	100.00	0.00	16.43
38	0.00	0.00	100.00	100.00	0.00	16.41
36	0.00	0.00	100.00	100.00	0.00	16.40
34	0.00	0.00	100.00	100.00	0.00	16.39
32	0.00	0.00	100.00	100.00	0.00	16.38
30	0.00	0.00	100.00	100.00	0.00	16.37
28	0.00	0.00	100.00	100.00	0.00	16.37
26	0.00	0.00	100.00	100.00	0.00	16.36
24	0.00	0.00	100.00	100.00	0.00	16.35
22	0.00	0.00	100.00	100.00	0.00	16.34
20	0.00	0.00	100.00	100.00	0.00	16.34
18	0.00	0.00	100.00	100.00	0.00	16.33
16	0.00	0.00	100.00	100.00	0.00	16.32
14	0.00	0.00	100.00	100.00	0.00	16.32
12	0.00	0.00	100.00	100.00	0.00	16.32
10	0.00	0.00	100.00	100.00	0.00	16.31
8	0.00	0.00	100.00	100.00	0.00	16.31
6	0.00	0.00	100.00	100.00	0.00	16.31
4	0.00	0.00	100.00	100.00	0.00	16.31
2	0.00	0.00	100.00	100.00	0.00	16.30
0	0.00	0.00	100.00	100.00	0.00	16.30

Table A.37 DOP Availability Vs. South Latitude for Constellation C54, TDOA Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	13.69	13.69	86.31	20.06
88	0.00	0.00	0.00	0.00	100.00	Inf
86	0.00	0.00	0.00	0.00	100.00	Inf
84	0.00	0.00	0.00	0.00	100.00	Inf
82	0.00	0.00	0.00	0.00	100.00	Inf
80	0.00	0.00	0.00	0.00	100.00	Inf
78	0.00	0.00	0.00	0.00	100.00	Inf
76	0.00	0.00	0.00	0.00	100.00	Inf
74	0.00	0.00	0.00	0.00	100.00	Inf
72	0.00	0.00	0.00	0.00	100.00	Inf
70	0.00	0.00	0.00	0.00	100.00	Inf
68	0.00	0.00	0.00	0.00	100.00	Inf
66	0.00	0.00	0.00	0.00	100.00	Inf
64	0.00	0.00	0.00	0.00	100.00	Inf
62	0.00	0.00	0.00	0.00	100.00	Inf
60	0.00	0.00	0.00	0.00	100.00	Inf
58	0.00	0.00	0.00	0.00	100.00	Inf
56	0.00	0.00	0.00	0.00	100.00	Inf
54	0.00	0.00	0.00	0.00	100.00	Inf
52	0.00	0.00	0.00	0.00	100.00	Inf
50	0.00	0.00	0.00	0.00	100.00	Inf
48	0.00	0.00	0.00	0.00	100.00	Inf
46	0.00	0.00	0.00	0.00	100.00	Inf
44	0.00	0.00	0.00	0.00	100.00	Inf
42	0.00	0.00	0.00	0.00	100.00	Inf
40	0.00	0.00	0.00	0.00	100.00	Inf
38	0.00	0.00	0.00	0.00	100.00	Inf
36	0.00	0.00	0.00	0.00	100.00	Inf
34	0.00	0.00	0.00	0.00	100.00	Inf
32	0.00	0.00	0.00	0.00	100.00	Inf
30	0.00	0.00	0.00	0.00	100.00	Inf
28	0.00	0.00	0.00	0.00	100.00	Inf
26	0.00	0.00	0.00	0.00	100.00	Inf
24	0.00	0.00	0.00	0.00	100.00	Inf
22	0.00	0.00	0.00	0.00	100.00	Inf
20	0.00	0.00	0.00	0.00	100.00	Inf
18	0.00	0.00	0.00	0.00	100.00	Inf
16	0.00	0.00	0.00	0.00	100.00	Inf
14	0.00	0.00	0.00	0.00	100.00	Inf
12	0.00	0.00	0.00	0.00	100.00	Inf
10	0.00	0.00	0.00	0.00	100.00	Inf
8	0.00	0.00	0.00	0.00	100.00	Inf
6	0.00	0.00	0.00	0.00	100.00	Inf
4	0.00	0.00	0.00	0.00	100.00	Inf
2	0.00	0.00	0.00	0.00	100.00	Inf
0	0.00	0.00	0.00	0.00	100.00	Inf

Table A.38 DOP Availability Vs. South Latitude for Constellation C61, DR and TDOA

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	0.00	0.00	100.00	Inf
88	0.00	0.00	0.00	0.00	100.00	Inf
86	0.00	0.00	0.00	0.00	100.00	Inf
84	0.00	0.00	0.00	0.00	100.00	Inf
82	0.00	0.00	0.00	0.00	100.00	Inf
80	0.00	0.00	0.00	0.00	100.00	Inf
78	0.00	0.00	0.00	0.00	100.00	Inf
76	0.00	0.00	0.00	0.00	100.00	Inf
74	0.00	0.00	0.00	0.00	100.00	Inf
72	0.00	0.00	0.00	0.00	100.00	Inf
70	0.00	0.00	0.00	0.00	100.00	Inf
68	0.00	0.00	0.00	0.00	100.00	Inf
66	0.00	0.00	0.00	0.00	100.00	Inf
64	0.00	0.00	0.00	0.00	100.00	Inf
62	0.00	0.00	0.00	0.00	100.00	Inf
60	0.00	0.00	0.00	0.00	100.00	Inf
58	0.00	0.00	0.00	0.00	100.00	Inf
56	0.00	0.00	0.00	0.00	100.00	Inf
54	0.00	0.00	0.00	0.00	100.00	Inf
52	0.00	0.00	0.00	0.00	100.00	Inf
50	0.00	0.00	0.00	0.00	100.00	Inf
48	0.00	0.00	0.00	0.00	100.00	Inf
46	0.00	0.00	0.00	0.00	100.00	Inf
44	0.00	0.00	0.00	0.00	100.00	Inf
42	0.00	0.00	0.00	0.00	100.00	Inf
40	0.00	0.00	0.00	0.00	100.00	Inf
38	0.00	0.00	0.00	0.00	100.00	Inf
36	0.00	0.00	0.00	0.00	100.00	Inf
34	0.00	0.00	0.00	0.00	100.00	Inf
32	0.00	0.00	0.00	0.00	100.00	Inf
30	0.00	0.00	0.00	0.00	100.00	Inf
28	0.00	0.00	0.00	0.00	100.00	Inf
26	0.00	0.00	0.00	0.00	100.00	Inf
24	0.00	0.00	0.00	0.00	100.00	Inf
22	0.00	0.00	0.00	0.00	100.00	Inf
20	0.00	0.00	0.00	0.00	100.00	Inf
18	0.00	0.00	0.00	0.00	100.00	Inf
16	0.00	0.00	0.00	0.00	100.00	Inf
14	0.00	0.00	0.00	0.00	100.00	Inf
12	0.00	0.00	0.00	0.00	100.00	Inf
10	0.00	0.00	0.00	0.00	100.00	Inf
8	0.00	0.00	0.00	0.00	100.00	Inf
6	0.00	0.00	0.00	0.00	100.00	Inf
4	0.00	0.00	0.00	0.00	100.00	Inf
2	0.00	0.00	0.00	0.00	100.00	Inf
0	0.00	0.00	0.00	0.00	100.00	Inf

Table A.39 DOP Availability Vs. South Latitude for Constellation C62, DR and TDOA

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.24	21.09	16.80	38.13	61.87	12.52
88	0.51	25.64	19.98	46.12	53.88	11.90
86	2.81	24.30	25.67	52.78	47.22	12.75
84	5.10	23.74	24.22	53.06	46.94	12.76
82	6.24	24.52	16.26	47.01	52.99	11.56
80	7.24	25.67	9.77	42.69	57.31	10.21
78	8.67	24.17	5.36	38.21	61.79	8.71
76	4.69	14.13	20.13	38.96	61.04	14.17
74	6.14	16.90	25.47	48.51	51.49	13.94
72	9.42	23.64	30.47	63.52	36.48	13.40
70	12.67	30.83	35.89	79.40	20.60	13.22
68	12.66	30.72	36.03	79.41	20.59	13.25
66	12.65	30.59	36.13	79.37	20.63	13.27
64	12.62	30.50	36.17	79.30	20.70	13.28
62	12.60	30.81	35.61	79.02	20.98	13.21
60	12.56	30.82	35.70	79.08	20.92	13.27
58	12.53	30.69	35.90	79.13	20.87	13.33
56	12.51	30.66	35.92	79.08	20.92	13.35
54	12.48	30.62	35.97	79.07	20.93	13.39
52	12.44	30.62	35.99	79.05	20.95	13.44
50	12.38	30.66	36.01	79.04	20.96	13.49
48	12.29	30.63	35.90	78.83	21.17	13.47
46	12.20	30.63	35.79	78.62	21.38	13.46
44	12.19	30.31	35.90	78.41	21.59	13.46
42	12.13	30.08	35.98	78.19	21.81	13.45
40	12.05	29.99	35.97	78.01	21.99	13.46
38	11.96	29.91	35.87	77.73	22.27	13.44
36	11.88	29.84	35.80	77.53	22.47	13.45
34	11.83	29.88	35.63	77.34	22.66	13.47
32	11.81	29.96	35.40	77.16	22.84	13.50
30	11.82	29.96	35.18	76.96	23.04	13.52
28	11.82	29.68	35.38	76.88	23.12	13.60
26	11.81	29.63	35.32	76.75	23.25	13.67
24	11.78	29.66	35.28	76.73	23.27	13.78
22	11.78	29.60	35.22	76.60	23.40	13.86
20	11.77	29.61	35.07	76.45	23.55	13.93
18	11.86	29.35	34.98	76.18	23.82	13.97
16	11.99	29.04	34.53	75.56	24.44	13.89
14	12.07	28.83	34.25	75.15	24.85	13.87
12	12.11	28.62	34.01	74.75	25.25	13.83
10	12.16	28.33	34.44	74.94	25.06	13.98
8	12.19	28.02	35.00	75.22	24.78	14.14
6	12.16	27.00	36.01	75.17	24.83	14.19
4	12.11	26.54	35.92	74.57	25.43	14.04
2	12.07	26.42	35.28	73.78	26.22	13.78
0	11.99	26.45	35.32	73.75	26.25	13.78

Table A.40 DOP Availability Vs. South Latitude for Constellation C62, DR Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	0.00	0.00	100.00	Inf
88	0.00	1.39	0.00	1.39	98.61	6.48
86	0.00	7.88	0.00	7.88	92.12	6.58
84	0.00	15.21	0.00	15.21	84.79	6.87
82	0.00	22.94	0.00	22.94	77.06	7.44
80	0.00	24.22	6.90	31.13	68.87	8.74
78	0.00	24.25	7.51	31.76	68.24	8.89
76	0.00	0.00	0.00	0.00	100.00	Inf
74	0.00	0.00	0.00	0.00	100.00	Inf
72	0.00	0.00	0.00	0.00	100.00	Inf
70	0.00	0.00	0.00	0.00	100.00	Inf
68	0.00	0.00	0.00	0.00	100.00	Inf
66	0.00	0.00	0.00	0.00	100.00	Inf
64	0.00	0.00	0.00	0.00	100.00	Inf
62	0.00	0.00	0.00	0.00	100.00	Inf
60	0.00	0.00	0.00	0.00	100.00	Inf
58	0.00	0.00	0.00	0.00	100.00	Inf
56	0.00	0.00	0.00	0.00	100.00	Inf
54	0.00	0.00	0.00	0.00	100.00	Inf
52	0.00	0.00	0.00	0.00	100.00	Inf
50	0.00	0.00	0.00	0.00	100.00	Inf
48	0.00	0.00	0.00	0.00	100.00	Inf
46	0.00	0.00	0.00	0.00	100.00	Inf
44	0.00	0.00	0.00	0.00	100.00	Inf
42	0.00	0.00	0.00	0.00	100.00	Inf
40	0.00	0.00	0.00	0.00	100.00	Inf
38	0.00	0.00	0.00	0.00	100.00	Inf
36	0.00	0.00	0.00	0.00	100.00	Inf
34	0.00	0.00	0.00	0.00	100.00	Inf
32	0.00	0.00	0.00	0.00	100.00	Inf
30	0.00	0.00	0.00	0.00	100.00	Inf
28	0.00	0.00	0.00	0.00	100.00	Inf
26	0.00	0.00	0.00	0.00	100.00	Inf
24	0.00	0.00	0.00	0.00	100.00	Inf
22	0.00	0.00	0.00	0.00	100.00	Inf
20	0.00	0.00	0.00	0.00	100.00	Inf
18	0.00	0.00	0.00	0.00	100.00	Inf
16	0.00	0.00	0.00	0.00	100.00	Inf
14	0.00	0.00	0.00	0.00	100.00	Inf
12	0.00	0.00	0.00	0.00	100.00	Inf
10	0.00	0.00	0.00	0.00	100.00	Inf
8	0.00	0.00	0.00	0.00	100.00	Inf
6	0.00	0.00	0.00	0.00	100.00	Inf
4	0.00	0.00	0.00	0.00	100.00	Inf
2	0.00	0.00	0.00	0.00	100.00	Inf
0	0.00	0.00	0.00	0.00	100.00	Inf

Table A.41 DOP Availability Vs. South Latitude for Constellation C62, TDOA Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	0.00	0.00	100.00	Inf
88	0.13	0.38	0.72	1.23	98.77	16.27
86	0.84	2.69	2.06	5.59	94.41	12.94
84	1.09	5.87	6.22	13.18	86.82	13.51
82	1.32	7.69	8.95	17.96	82.04	13.13
80	2.15	9.85	13.42	25.42	74.58	13.97
78	2.24	9.98	13.71	25.93	74.07	13.97
76	0.00	0.00	0.00	0.00	100.00	Inf
74	0.00	0.00	0.00	0.00	100.00	Inf
72	0.00	0.00	0.00	0.00	100.00	Inf
70	0.00	0.00	0.00	0.00	100.00	Inf
68	0.00	0.00	0.00	0.00	100.00	Inf
66	0.00	0.00	0.00	0.00	100.00	Inf
64	0.00	0.00	0.00	0.00	100.00	Inf
62	0.00	0.00	0.00	0.00	100.00	Inf
60	0.00	0.00	0.00	0.00	100.00	Inf
58	0.00	0.00	0.00	0.00	100.00	Inf
56	0.00	0.00	0.00	0.00	100.00	Inf
54	0.00	0.00	0.00	0.00	100.00	Inf
52	0.00	0.00	0.00	0.00	100.00	Inf
50	0.00	0.00	0.00	0.00	100.00	Inf
48	0.00	0.00	0.00	0.00	100.00	Inf
46	0.00	0.00	0.00	0.00	100.00	Inf
44	0.00	0.00	0.00	0.00	100.00	Inf
42	0.00	0.00	0.00	0.00	100.00	Inf
40	0.00	0.00	0.00	0.00	100.00	Inf
38	0.00	0.00	0.00	0.00	100.00	Inf
36	0.00	0.00	0.00	0.00	100.00	Inf
34	0.00	0.00	0.00	0.00	100.00	Inf
32	0.00	0.00	0.00	0.00	100.00	Inf
30	0.00	0.00	0.00	0.00	100.00	Inf
28	0.00	0.00	0.00	0.00	100.00	Inf
26	0.00	0.00	0.00	0.00	100.00	Inf
24	0.00	0.00	0.00	0.00	100.00	Inf
22	0.00	0.00	0.00	0.00	100.00	Inf
20	0.00	0.00	0.00	0.00	100.00	Inf
18	0.00	0.00	0.00	0.00	100.00	Inf
16	0.00	0.00	0.00	0.00	100.00	Inf
14	0.00	0.00	0.00	0.00	100.00	Inf
12	0.00	0.00	0.00	0.00	100.00	Inf
10	0.00	0.00	0.00	0.00	100.00	Inf
8	0.00	0.00	0.00	0.00	100.00	Inf
6	0.00	0.00	0.00	0.00	100.00	Inf
4	0.00	0.00	0.00	0.00	100.00	Inf
2	0.00	0.00	0.00	0.00	100.00	Inf
0	0.00	0.00	0.00	0.00	100.00	Inf

Table A.42 DOP Availability Vs. South Latitude for Constellation C63, DR and TDOA

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	68.65	17.73	3.48	89.86	10.14	5.82
88	70.36	14.97	4.38	89.72	10.28	5.50
86	68.58	16.03	7.77	92.37	7.63	6.95
84	67.58	19.40	8.77	95.74	4.26	7.01
82	72.86	11.35	2.72	86.93	13.07	4.81
80	76.40	17.26	0.00	93.66	6.34	4.22
78	78.70	15.28	0.00	93.98	6.02	4.06
76	63.98	23.54	6.91	94.43	5.57	6.78
74	72.50	17.77	6.99	97.25	2.75	6.46
72	85.74	8.68	4.99	99.42	0.58	5.04
70	100.00	0.00	0.00	100.00	0.00	2.51
68	100.00	0.00	0.00	100.00	0.00	2.51
66	100.00	0.00	0.00	100.00	0.00	2.51
64	100.00	0.00	0.00	100.00	0.00	2.50
62	100.00	0.00	0.00	100.00	0.00	2.50
60	100.00	0.00	0.00	100.00	0.00	2.50
58	100.00	0.00	0.00	100.00	0.00	2.50
56	100.00	0.00	0.00	100.00	0.00	2.50
54	100.00	0.00	0.00	100.00	0.00	2.50
52	100.00	0.00	0.00	100.00	0.00	2.49
50	100.00	0.00	0.00	100.00	0.00	2.49
48	100.00	0.00	0.00	100.00	0.00	2.49
46	100.00	0.00	0.00	100.00	0.00	2.49
44	100.00	0.00	0.00	100.00	0.00	2.49
42	100.00	0.00	0.00	100.00	0.00	2.49
40	100.00	0.00	0.00	100.00	0.00	2.48
38	100.00	0.00	0.00	100.00	0.00	2.48
36	100.00	0.00	0.00	100.00	0.00	2.48
34	100.00	0.00	0.00	100.00	0.00	2.48
32	100.00	0.00	0.00	100.00	0.00	2.48
30	100.00	0.00	0.00	100.00	0.00	2.48
28	100.00	0.00	0.00	100.00	0.00	2.48
26	100.00	0.00	0.00	100.00	0.00	2.48
24	100.00	0.00	0.00	100.00	0.00	2.48
22	100.00	0.00	0.00	100.00	0.00	2.47
20	100.00	0.00	0.00	100.00	0.00	2.47
18	100.00	0.00	0.00	100.00	0.00	2.47
16	100.00	0.00	0.00	100.00	0.00	2.47
14	100.00	0.00	0.00	100.00	0.00	2.47
12	100.00	0.00	0.00	100.00	0.00	2.47
10	100.00	0.00	0.00	100.00	0.00	2.47
8	100.00	0.00	0.00	100.00	0.00	2.47
6	100.00	0.00	0.00	100.00	0.00	2.47
4	100.00	0.00	0.00	100.00	0.00	2.47
2	100.00	0.00	0.00	100.00	0.00	2.47
0	100.00	0.00	0.00	100.00	0.00	2.47

Table A.43 DOP Availability Vs. South Latitude for Constellation C63, DR Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	54.92	28.74	0.00	83.66	16.34	4.92
88	54.93	26.65	0.00	81.58	18.42	5.00
86	45.89	32.74	0.00	78.63	21.37	5.42
84	31.70	38.12	6.02	75.84	24.16	6.51
82	28.90	38.09	17.97	84.96	15.04	8.87
80	28.99	38.09	2.19	69.27	30.73	6.18
78	40.70	18.34	0.00	59.04	40.96	4.81
76	27.26	0.00	0.00	27.26	72.74	3.93
74	45.78	0.00	0.00	45.78	54.22	3.93
72	72.64	0.00	0.00	72.64	27.36	3.92
70	100.00	0.00	0.00	100.00	0.00	3.92
68	100.00	0.00	0.00	100.00	0.00	3.91
66	100.00	0.00	0.00	100.00	0.00	3.91
64	100.00	0.00	0.00	100.00	0.00	3.91
62	100.00	0.00	0.00	100.00	0.00	3.90
60	100.00	0.00	0.00	100.00	0.00	3.90
58	100.00	0.00	0.00	100.00	0.00	3.90
56	100.00	0.00	0.00	100.00	0.00	3.89
54	100.00	0.00	0.00	100.00	0.00	3.89
52	100.00	0.00	0.00	100.00	0.00	3.89
50	100.00	0.00	0.00	100.00	0.00	3.88
48	100.00	0.00	0.00	100.00	0.00	3.88
46	100.00	0.00	0.00	100.00	0.00	3.88
44	100.00	0.00	0.00	100.00	0.00	3.88
42	100.00	0.00	0.00	100.00	0.00	3.87
40	100.00	0.00	0.00	100.00	0.00	3.87
38	100.00	0.00	0.00	100.00	0.00	3.87
36	100.00	0.00	0.00	100.00	0.00	3.87
34	100.00	0.00	0.00	100.00	0.00	3.86
32	100.00	0.00	0.00	100.00	0.00	3.86
30	100.00	0.00	0.00	100.00	0.00	3.86
28	100.00	0.00	0.00	100.00	0.00	3.86
26	100.00	0.00	0.00	100.00	0.00	3.86
24	100.00	0.00	0.00	100.00	0.00	3.85
22	100.00	0.00	0.00	100.00	0.00	3.85
20	100.00	0.00	0.00	100.00	0.00	3.85
18	100.00	0.00	0.00	100.00	0.00	3.85
16	100.00	0.00	0.00	100.00	0.00	3.85
14	100.00	0.00	0.00	100.00	0.00	3.85
12	100.00	0.00	0.00	100.00	0.00	3.85
10	100.00	0.00	0.00	100.00	0.00	3.85
8	100.00	0.00	0.00	100.00	0.00	3.85
6	100.00	0.00	0.00	100.00	0.00	3.84
4	100.00	0.00	0.00	100.00	0.00	3.84
2	100.00	0.00	0.00	100.00	0.00	3.84
0	100.00	0.00	0.00	100.00	0.00	3.84

Table A.44 DOP Availability Vs. South Latitude for Constellation C63, TDOA Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	6.47	23.13	9.42	39.02	60.98	10.01
88	11.41	27.36	7.71	46.49	53.51	8.86
86	20.58	27.40	7.70	55.68	44.32	8.36
84	27.66	31.83	8.17	67.65	32.35	8.23
82	29.96	38.28	8.10	76.33	23.67	7.91
80	25.70	29.21	7.82	62.72	37.28	8.11
78	17.17	20.26	18.17	55.60	44.40	10.28
76	0.00	1.13	26.13	27.26	72.74	15.55
74	0.00	2.52	43.26	45.78	54.22	15.55
72	0.00	5.86	66.78	72.64	27.36	15.39
70	0.00	8.03	91.97	100.00	0.00	15.44
68	0.00	8.32	91.68	100.00	0.00	15.40
66	0.00	8.50	91.50	100.00	0.00	15.36
64	0.00	8.72	91.28	100.00	0.00	15.32
62	0.00	8.87	91.13	100.00	0.00	15.28
60	0.00	9.06	90.94	100.00	0.00	15.24
58	0.00	9.32	90.68	100.00	0.00	15.20
56	0.00	9.72	90.28	100.00	0.00	15.16
54	0.00	10.09	89.91	100.00	0.00	15.12
52	0.00	10.21	89.79	100.00	0.00	15.08
50	0.00	10.36	89.64	100.00	0.00	15.04
48	0.00	10.50	89.50	100.00	0.00	15.00
46	0.00	10.65	89.35	100.00	0.00	14.97
44	0.00	10.80	89.20	100.00	0.00	14.93
42	0.00	10.96	89.04	100.00	0.00	14.90
40	0.00	11.10	88.90	100.00	0.00	14.87
38	0.00	11.27	88.73	100.00	0.00	14.84
36	0.00	11.31	88.69	100.00	0.00	14.81
34	0.00	11.34	88.66	100.00	0.00	14.78
32	0.00	11.36	88.64	100.00	0.00	14.75
30	0.00	11.40	88.60	100.00	0.00	14.72
28	0.00	11.40	88.60	100.00	0.00	14.70
26	0.00	11.43	88.57	100.00	0.00	14.68
24	0.00	11.45	88.55	100.00	0.00	14.66
22	0.00	11.53	88.47	100.00	0.00	14.64
20	0.00	11.60	88.40	100.00	0.00	14.62
18	0.00	11.76	88.24	100.00	0.00	14.60
16	0.00	11.87	88.13	100.00	0.00	14.59
14	0.00	11.97	88.03	100.00	0.00	14.58
12	0.00	12.14	87.86	100.00	0.00	14.57
10	0.00	12.35	87.65	100.00	0.00	14.56
8	0.00	12.52	87.48	100.00	0.00	14.56
6	0.00	12.62	87.38	100.00	0.00	14.55
4	0.00	12.74	87.26	100.00	0.00	14.55
2	0.00	12.81	87.19	100.00	0.00	14.55
0	0.00	12.82	87.18	100.00	0.00	14.55

Table A.45 DOP Availability Vs. South Latitude for Constellation C64, DR and TDOA

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	89.32	2.06	3.39	94.78	5.22	4.90
88	100.00	0.00	0.00	100.00	0.00	3.41
86	100.00	0.00	0.00	100.00	0.00	3.11
84	100.00	0.00	0.00	100.00	0.00	2.75
82	100.00	0.00	0.00	100.00	0.00	2.72
80	98.26	1.74	0.00	100.00	0.00	2.89
78	94.75	5.25	0.00	100.00	0.00	3.15
76	100.00	0.00	0.00	100.00	0.00	2.89
74	100.00	0.00	0.00	100.00	0.00	2.73
72	100.00	0.00	0.00	100.00	0.00	2.48
70	100.00	0.00	0.00	100.00	0.00	2.17
68	100.00	0.00	0.00	100.00	0.00	2.17
66	100.00	0.00	0.00	100.00	0.00	2.17
64	100.00	0.00	0.00	100.00	0.00	2.17
62	100.00	0.00	0.00	100.00	0.00	2.17
60	100.00	0.00	0.00	100.00	0.00	2.16
58	100.00	0.00	0.00	100.00	0.00	2.16
56	100.00	0.00	0.00	100.00	0.00	2.16
54	100.00	0.00	0.00	100.00	0.00	2.16
52	100.00	0.00	0.00	100.00	0.00	2.16
50	100.00	0.00	0.00	100.00	0.00	2.16
48	100.00	0.00	0.00	100.00	0.00	2.16
46	100.00	0.00	0.00	100.00	0.00	2.15
44	100.00	0.00	0.00	100.00	0.00	2.15
42	100.00	0.00	0.00	100.00	0.00	2.15
40	100.00	0.00	0.00	100.00	0.00	2.15
38	100.00	0.00	0.00	100.00	0.00	2.15
36	100.00	0.00	0.00	100.00	0.00	2.15
34	100.00	0.00	0.00	100.00	0.00	2.15
32	100.00	0.00	0.00	100.00	0.00	2.15
30	100.00	0.00	0.00	100.00	0.00	2.15
28	100.00	0.00	0.00	100.00	0.00	2.14
26	100.00	0.00	0.00	100.00	0.00	2.14
24	100.00	0.00	0.00	100.00	0.00	2.14
22	100.00	0.00	0.00	100.00	0.00	2.14
20	100.00	0.00	0.00	100.00	0.00	2.14
18	100.00	0.00	0.00	100.00	0.00	2.14
16	100.00	0.00	0.00	100.00	0.00	2.14
14	100.00	0.00	0.00	100.00	0.00	2.14
12	100.00	0.00	0.00	100.00	0.00	2.14
10	100.00	0.00	0.00	100.00	0.00	2.14
8	100.00	0.00	0.00	100.00	0.00	2.14
6	100.00	0.00	0.00	100.00	0.00	2.14
4	100.00	0.00	0.00	100.00	0.00	2.14
2	100.00	0.00	0.00	100.00	0.00	2.14
0	100.00	0.00	0.00	100.00	0.00	2.14

Table A.46 DOP Availability Vs. South Latitude for Constellation C64, DR Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	89.22	0.18	0.00	89.40	10.60	4.04
88	100.00	0.00	0.00	100.00	0.00	4.17
86	100.00	0.00	0.00	100.00	0.00	4.08
84	100.00	0.00	0.00	100.00	0.00	4.05
82	100.00	0.00	0.00	100.00	0.00	4.11
80	90.85	3.34	0.00	94.19	5.81	4.18
78	81.16	0.00	0.00	81.16	18.84	4.07
76	100.00	0.00	0.00	100.00	0.00	4.77
74	100.00	0.00	0.00	100.00	0.00	4.46
72	100.00	0.00	0.00	100.00	0.00	3.96
70	100.00	0.00	0.00	100.00	0.00	3.39
68	100.00	0.00	0.00	100.00	0.00	3.39
66	100.00	0.00	0.00	100.00	0.00	3.39
64	100.00	0.00	0.00	100.00	0.00	3.38
62	100.00	0.00	0.00	100.00	0.00	3.38
60	100.00	0.00	0.00	100.00	0.00	3.38
58	100.00	0.00	0.00	100.00	0.00	3.37
56	100.00	0.00	0.00	100.00	0.00	3.37
54	100.00	0.00	0.00	100.00	0.00	3.37
52	100.00	0.00	0.00	100.00	0.00	3.37
50	100.00	0.00	0.00	100.00	0.00	3.36
48	100.00	0.00	0.00	100.00	0.00	3.36
46	100.00	0.00	0.00	100.00	0.00	3.36
44	100.00	0.00	0.00	100.00	0.00	3.36
42	100.00	0.00	0.00	100.00	0.00	3.35
40	100.00	0.00	0.00	100.00	0.00	3.35
38	100.00	0.00	0.00	100.00	0.00	3.35
36	100.00	0.00	0.00	100.00	0.00	3.35
34	100.00	0.00	0.00	100.00	0.00	3.35
32	100.00	0.00	0.00	100.00	0.00	3.34
30	100.00	0.00	0.00	100.00	0.00	3.34
28	100.00	0.00	0.00	100.00	0.00	3.34
26	100.00	0.00	0.00	100.00	0.00	3.34
24	100.00	0.00	0.00	100.00	0.00	3.34
22	100.00	0.00	0.00	100.00	0.00	3.34
20	100.00	0.00	0.00	100.00	0.00	3.34
18	100.00	0.00	0.00	100.00	0.00	3.33
16	100.00	0.00	0.00	100.00	0.00	3.33
14	100.00	0.00	0.00	100.00	0.00	3.33
12	100.00	0.00	0.00	100.00	0.00	3.33
10	100.00	0.00	0.00	100.00	0.00	3.33
8	100.00	0.00	0.00	100.00	0.00	3.33
6	100.00	0.00	0.00	100.00	0.00	3.33
4	100.00	0.00	0.00	100.00	0.00	3.33
2	100.00	0.00	0.00	100.00	0.00	3.33
0	100.00	0.00	0.00	100.00	0.00	3.33

Table A.47 DOP Availability Vs. South Latitude for Constellation C64, TDOA Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	28.91	16.01	0.01	44.94	55.06	4.97
88	39.59	22.65	0.74	62.98	37.02	5.23
86	53.70	23.81	1.61	79.12	20.88	5.13
84	74.67	21.94	1.91	98.51	1.49	4.86
82	81.25	17.81	0.94	100.00	0.00	4.61
80	81.77	12.14	0.28	94.19	5.81	4.30
78	64.63	0.00	15.96	80.59	19.41	8.00
76	0.00	0.08	98.30	98.37	1.63	17.36
74	0.00	4.04	94.79	98.83	1.17	16.37
72	0.00	13.98	86.02	100.00	0.00	15.04
70	0.00	19.57	80.43	100.00	0.00	13.36
68	0.00	19.73	80.27	100.00	0.00	13.32
66	0.00	19.76	80.24	100.00	0.00	13.29
64	0.00	19.85	80.15	100.00	0.00	13.25
62	0.00	19.90	80.10	100.00	0.00	13.22
60	0.00	19.92	80.08	100.00	0.00	13.18
58	0.00	19.93	80.07	100.00	0.00	13.15
56	0.00	19.99	80.01	100.00	0.00	13.11
54	0.00	20.09	79.91	100.00	0.00	13.08
52	0.00	20.25	79.75	100.00	0.00	13.04
50	0.00	20.49	79.51	100.00	0.00	13.01
48	0.00	20.89	79.11	100.00	0.00	12.98
46	0.00	21.23	78.77	100.00	0.00	12.95
44	0.00	21.43	78.57	100.00	0.00	12.92
42	0.00	21.66	78.34	100.00	0.00	12.89
40	0.00	21.91	78.09	100.00	0.00	12.86
38	0.00	22.09	77.91	100.00	0.00	12.84
36	0.00	22.17	77.83	100.00	0.00	12.81
34	0.00	22.23	77.77	100.00	0.00	12.78
32	0.00	22.31	77.69	100.00	0.00	12.76
30	0.00	22.39	77.61	100.00	0.00	12.74
28	0.00	22.47	77.53	100.00	0.00	12.72
26	0.00	22.57	77.43	100.00	0.00	12.70
24	0.00	22.75	77.25	100.00	0.00	12.68
22	0.00	22.99	77.01	100.00	0.00	12.66
20	0.00	23.39	76.61	100.00	0.00	12.65
18	0.00	23.54	76.46	100.00	0.00	12.64
16	0.00	23.63	76.37	100.00	0.00	12.62
14	0.00	23.69	76.31	100.00	0.00	12.61
12	0.00	23.70	76.30	100.00	0.00	12.61
10	0.00	23.68	76.32	100.00	0.00	12.60
8	0.00	23.67	76.33	100.00	0.00	12.59
6	0.00	23.70	76.30	100.00	0.00	12.59
4	0.00	23.78	76.22	100.00	0.00	12.59
2	0.00	23.91	76.09	100.00	0.00	12.59
0	0.00	24.01	75.99	100.00	0.00	12.59

Table A.48 DOP Availability Vs. South Latitude for Constellation C7L, DR and TDOA

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	10.78	26.37	37.15	62.85	14.63
88	1.64	19.32	36.20	57.16	42.84	14.50
86	3.32	30.81	43.24	77.36	22.64	14.23
84	7.28	57.51	31.33	96.12	3.88	10.63
82	7.28	61.82	28.16	97.27	2.73	10.25
80	7.28	63.83	26.14	97.25	2.75	10.10
78	7.28	64.03	25.92	97.23	2.77	10.05
76	7.27	65.05	24.87	97.19	2.81	10.00
74	7.27	65.09	24.81	97.17	2.83	10.00
72	7.27	65.14	24.72	97.13	2.87	9.99
70	7.27	65.30	24.52	97.09	2.91	9.99
68	7.26	65.30	24.49	97.05	2.95	9.98
66	7.26	65.28	24.48	97.01	2.99	9.98
64	7.24	65.26	24.45	96.96	3.04	9.98
62	7.21	65.29	24.44	96.94	3.06	9.99
60	7.21	65.23	24.45	96.89	3.11	9.99
58	7.18	65.18	24.48	96.84	3.16	9.98
56	7.14	65.10	24.53	96.77	3.23	9.98
54	7.12	65.00	24.58	96.70	3.30	9.97
52	7.10	64.84	24.68	96.63	3.37	9.97
50	7.07	64.77	24.73	96.57	3.43	9.96
48	7.03	64.50	24.94	96.47	3.53	9.95
46	6.96	64.25	25.22	96.43	3.57	9.95
44	6.94	64.04	25.42	96.40	3.60	9.97
42	6.90	63.97	25.53	96.40	3.60	9.99
40	6.85	63.96	25.58	96.39	3.61	10.01
38	6.80	63.71	25.89	96.40	3.60	10.04
36	6.75	63.52	26.13	96.40	3.60	10.07
34	6.69	63.32	26.44	96.44	3.56	10.11
32	6.62	63.27	26.59	96.48	3.52	10.15
30	6.56	63.13	26.84	96.53	3.47	10.19
28	6.46	63.08	27.05	96.58	3.42	10.24
26	6.41	62.95	27.26	96.62	3.38	10.28
24	6.30	62.90	27.48	96.68	3.32	10.33
22	6.20	62.94	27.61	96.75	3.25	10.38
20	6.08	62.68	28.05	96.81	3.19	10.43
18	5.87	62.20	28.75	96.82	3.18	10.46
16	5.58	62.00	29.05	96.63	3.37	10.41
14	5.40	61.83	29.17	96.40	3.60	10.33
12	5.03	62.02	29.27	96.33	3.67	10.31
10	4.97	61.91	29.41	96.29	3.71	10.30
8	4.87	62.06	29.32	96.25	3.75	10.29
6	4.80	62.32	29.11	96.23	3.77	10.28
4	4.73	62.32	29.14	96.19	3.81	10.26
2	4.64	62.38	29.16	96.17	3.83	10.25
0	4.50	62.13	29.58	96.20	3.80	10.26

Table A.49 DOP Availability Vs. South Latitude for Constellation C7L, DR Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	27.11	27.11	72.89	18.49
88	0.00	3.34	41.81	45.16	54.84	17.94
86	0.00	11.15	51.93	63.08	36.92	17.10
84	0.00	22.59	62.46	85.04	14.96	14.74
82	0.00	22.59	68.15	90.73	9.27	14.27
80	0.00	23.58	68.75	92.32	7.68	13.90
78	0.00	24.29	68.05	92.34	7.66	13.67
76	0.00	24.78	67.55	92.34	7.66	13.59
74	0.00	24.76	67.58	92.34	7.66	13.59
72	0.00	24.75	67.56	92.31	7.69	13.59
70	0.00	24.71	67.60	92.31	7.69	13.60
68	0.00	24.67	67.63	92.30	7.70	13.61
66	0.00	24.64	67.50	92.15	7.85	13.58
64	0.00	24.57	67.45	92.02	7.98	13.55
62	0.00	24.56	67.35	91.90	8.10	13.53
60	0.00	24.50	67.34	91.84	8.16	13.53
58	0.00	24.43	67.34	91.76	8.24	13.52
56	0.00	24.31	67.37	91.69	8.31	13.52
54	0.00	24.25	67.39	91.64	8.36	13.52
52	0.00	24.14	67.40	91.54	8.46	13.51
50	0.00	24.02	67.45	91.47	8.53	13.51
48	0.00	23.95	67.46	91.41	8.59	13.51
46	0.00	23.79	67.54	91.33	8.67	13.51
44	0.00	23.64	67.62	91.26	8.74	13.51
42	0.00	23.53	67.68	91.20	8.80	13.51
40	0.00	23.36	67.77	91.13	8.87	13.51
38	0.00	22.99	68.06	91.05	8.95	13.51
36	0.00	22.70	68.30	91.00	9.00	13.52
34	0.00	22.31	68.62	90.93	9.07	13.51
32	0.00	21.78	69.06	90.85	9.15	13.51
30	0.00	21.42	69.34	90.76	9.24	13.51
28	0.00	21.03	69.61	90.65	9.35	13.49
26	0.00	20.77	69.71	90.48	9.52	13.46
24	0.00	20.42	70.07	90.49	9.51	13.49
22	0.00	20.07	70.42	90.49	9.51	13.50
20	0.00	19.66	70.84	90.51	9.49	13.53
18	0.00	19.08	71.45	90.53	9.47	13.55
16	0.00	18.54	71.99	90.53	9.47	13.57
14	0.00	18.38	72.17	90.54	9.46	13.59
12	0.00	18.30	72.27	90.57	9.43	13.62
10	0.00	18.14	72.43	90.57	9.43	13.63
8	0.00	17.88	72.71	90.59	9.41	13.66
6	0.00	17.68	72.95	90.63	9.37	13.68
4	0.00	17.51	73.16	90.67	9.33	13.71
2	0.00	17.36	73.34	90.70	9.30	13.73
0	0.00	17.22	73.50	90.72	9.28	13.76

Table A.50 DOP Availability Vs. South Latitude for Constellation C7L, TDOA Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	0.00	0.00	100.00	Inf
88	0.00	0.00	0.00	0.00	100.00	Inf
86	0.00	0.00	0.00	0.00	100.00	Inf
84	0.00	0.00	0.00	0.00	100.00	Inf
82	0.00	0.00	0.00	0.00	100.00	Inf
80	0.00	0.00	0.00	0.00	100.00	Inf
78	0.00	0.00	0.29	0.29	99.71	26.00
76	0.00	0.00	0.29	0.29	99.71	25.98
74	0.00	0.00	0.29	0.29	99.71	25.97
72	0.00	0.00	0.29	0.29	99.71	25.96
70	0.00	0.00	0.29	0.29	99.71	25.95
68	0.00	0.00	0.29	0.29	99.71	25.94
66	0.00	0.00	0.36	0.36	99.64	26.70
64	0.00	0.00	0.41	0.41	99.59	27.12
62	0.00	0.00	0.44	0.44	99.56	27.35
60	0.00	0.00	0.47	0.47	99.53	27.47
58	0.00	0.00	0.50	0.50	99.50	27.58
56	0.00	0.00	0.52	0.52	99.48	27.67
54	0.00	0.00	0.55	0.55	99.45	27.74
52	0.00	0.00	0.57	0.57	99.43	27.81
50	0.00	0.00	0.60	0.60	99.40	27.87
48	0.00	0.00	0.61	0.61	99.39	27.88
46	0.00	0.00	0.64	0.64	99.36	27.93
44	0.00	0.00	0.65	0.65	99.35	27.93
42	0.00	0.00	0.67	0.67	99.33	27.97
40	0.00	0.00	0.69	0.69	99.31	27.97
38	0.00	0.00	0.70	0.70	99.30	27.96
36	0.00	0.00	0.72	0.72	99.28	28.00
34	0.00	0.00	0.74	0.74	99.26	28.00
32	0.00	0.00	0.75	0.75	99.25	27.99
30	0.00	0.00	0.76	0.76	99.24	27.99
28	0.00	0.00	0.78	0.78	99.22	27.99
26	0.00	0.00	0.79	0.79	99.21	27.99
24	0.00	0.00	0.80	0.80	99.20	27.99
22	0.00	0.00	0.81	0.81	99.19	27.99
20	0.00	0.00	0.81	0.81	99.19	27.97
18	0.00	0.00	0.81	0.81	99.19	27.94
16	0.00	0.00	0.81	0.81	99.19	27.92
14	0.00	0.00	0.81	0.81	99.19	27.91
12	0.00	0.00	0.81	0.81	99.19	27.89
10	0.00	0.00	0.81	0.81	99.19	27.88
8	0.00	0.00	0.81	0.81	99.19	27.88
6	0.00	0.00	0.81	0.81	99.19	27.87
4	0.00	0.00	0.81	0.81	99.19	27.87
2	0.00	0.00	0.81	0.81	99.19	27.88
0	0.00	0.00	0.81	0.81	99.19	27.89

Table A.51 DOP Availability Vs. South Latitude for Constellation C7H, DR and TDOA

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	1.79	17.55	27.67	47.01	52.99	13.02
88	3.11	27.68	32.42	63.22	36.78	13.41
86	5.74	35.02	36.83	77.59	22.41	12.71
84	11.02	41.92	37.95	90.89	9.11	11.52
82	14.03	49.08	30.71	93.82	6.18	10.51
80	17.27	50.36	27.68	95.31	4.69	10.14
78	20.51	51.25	26.17	97.93	2.07	9.64
76	23.21	52.61	22.31	98.12	1.88	9.00
74	26.45	53.44	18.23	98.12	1.88	8.62
72	36.12	48.03	14.03	98.18	1.82	7.91
70	45.68	42.25	10.40	98.32	1.68	7.31
68	45.58	42.31	10.35	98.23	1.77	7.28
66	45.55	42.35	10.28	98.18	1.82	7.27
64	45.54	42.32	10.26	98.12	1.88	7.26
62	45.45	42.40	10.19	98.04	1.96	7.24
60	45.39	42.49	10.03	97.90	2.10	7.19
58	45.39	42.54	9.89	97.81	2.19	7.17
56	45.27	42.65	9.84	97.76	2.24	7.16
54	45.21	42.74	9.74	97.69	2.31	7.15
52	45.16	42.78	9.71	97.65	2.35	7.16
50	45.07	42.84	9.71	97.62	2.38	7.18
48	44.95	42.91	9.72	97.59	2.41	7.19
46	44.84	42.98	9.72	97.55	2.45	7.20
44	44.76	43.00	9.75	97.51	2.49	7.22
42	44.66	43.00	9.84	97.50	2.50	7.25
40	44.53	43.02	9.93	97.48	2.52	7.28
38	44.40	43.05	10.00	97.45	2.55	7.30
36	44.20	43.15	10.09	97.45	2.55	7.34
34	44.09	43.20	10.08	97.37	2.63	7.34
32	43.98	43.28	10.07	97.32	2.68	7.35
30	43.91	43.30	10.07	97.28	2.72	7.37
28	43.89	43.14	10.23	97.25	2.75	7.39
26	43.90	42.84	10.49	97.23	2.77	7.41
24	43.84	42.65	10.77	97.25	2.75	7.46
22	43.76	42.56	10.98	97.31	2.69	7.53
20	43.71	42.55	11.12	97.38	2.62	7.60
18	43.65	42.46	11.35	97.46	2.54	7.68
16	43.57	42.48	11.46	97.51	2.49	7.73
14	43.48	42.54	11.55	97.57	2.43	7.80
12	43.42	42.59	11.64	97.65	2.35	7.86
10	43.38	42.54	11.78	97.70	2.30	7.91
8	43.37	42.51	11.87	97.75	2.25	7.96
6	43.33	42.58	11.95	97.85	2.15	8.03
4	43.30	42.50	12.10	97.90	2.10	8.07
2	43.29	42.41	12.28	97.98	2.02	8.12
0	43.30	42.35	12.40	98.06	1.94	8.17

Table A.52 DOP Availability Vs. South Latitude for Constellation C7H, DR Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	6.74	30.64	37.38	62.62	16.28
88	0.00	12.71	40.80	53.51	46.49	15.69
86	0.00	18.72	47.48	66.20	33.80	14.93
84	0.00	25.78	51.84	77.62	22.38	14.40
82	0.00	33.21	53.95	87.16	12.84	13.54
80	0.00	40.33	50.05	90.38	9.62	12.80
78	0.00	45.26	48.31	93.57	6.43	12.47
76	0.00	49.80	44.83	94.62	5.38	11.93
74	0.32	53.67	40.59	94.59	5.41	11.48
72	1.73	60.29	33.41	95.44	4.56	10.73
70	6.02	64.20	25.56	95.78	4.22	9.98
68	6.04	64.18	25.53	95.75	4.25	9.98
66	6.08	64.10	25.57	95.74	4.26	10.00
64	6.10	64.03	25.57	95.70	4.30	10.00
62	6.13	63.96	25.60	95.68	4.32	10.01
60	6.27	63.79	25.57	95.63	4.37	10.02
58	6.32	63.68	25.61	95.60	4.40	10.03
56	6.42	63.54	25.52	95.48	4.52	10.01
54	6.49	63.38	25.39	95.27	4.73	9.95
52	6.52	63.36	25.23	95.11	4.89	9.91
50	6.61	63.19	25.19	94.99	5.01	9.89
48	6.66	63.08	25.14	94.88	5.12	9.87
46	6.72	63.01	25.03	94.76	5.24	9.85
44	6.80	62.84	25.01	94.65	5.35	9.82
42	6.84	62.75	24.95	94.53	5.47	9.80
40	6.88	62.65	24.92	94.45	5.55	9.79
38	6.95	62.54	24.85	94.34	5.66	9.78
36	7.02	62.40	24.82	94.24	5.76	9.76
34	7.04	62.33	24.80	94.17	5.83	9.75
32	7.12	62.21	24.72	94.05	5.95	9.73
30	7.21	62.06	24.69	93.96	6.04	9.71
28	7.27	61.96	24.62	93.85	6.15	9.69
26	7.35	61.86	24.54	93.75	6.25	9.67
24	7.40	61.76	24.47	93.62	6.38	9.63
22	7.45	61.64	24.36	93.45	6.55	9.58
20	7.52	61.54	24.15	93.21	6.79	9.49
18	7.60	61.41	24.21	93.23	6.77	9.51
16	7.70	61.29	24.22	93.21	6.79	9.52
14	7.82	61.15	24.25	93.21	6.79	9.53
12	7.93	60.99	24.30	93.23	6.77	9.55
10	8.11	60.75	24.36	93.23	6.77	9.57
8	8.16	60.68	24.42	93.25	6.75	9.60
6	8.24	60.57	24.43	93.24	6.76	9.61
4	8.31	60.47	24.47	93.25	6.75	9.63
2	8.36	60.41	24.50	93.28	6.72	9.65
0	8.39	60.41	24.49	93.29	6.71	9.67

Table A.53 DOP Availability Vs. South Latitude for Constellation C7H, TDOA Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	1.33	1.33	98.67	24.10
88	0.00	0.00	2.02	2.02	97.98	22.84
86	0.00	0.00	5.92	5.92	94.08	21.99
84	0.00	0.00	9.34	9.34	90.66	22.01
82	0.00	0.00	12.77	12.77	87.23	21.94
80	0.00	0.00	16.51	16.51	83.49	21.70
78	0.00	0.00	22.66	22.66	77.34	21.57
76	0.00	0.00	31.02	31.02	68.98	21.58
74	0.00	0.00	39.74	39.74	60.26	21.44
72	0.00	0.00	52.53	52.53	47.47	20.80
70	0.00	0.00	66.79	66.79	33.21	20.60
68	0.00	0.00	66.87	66.87	33.13	20.57
66	0.00	0.00	66.93	66.93	33.07	20.54
64	0.00	0.00	66.97	66.97	33.03	20.50
62	0.00	0.00	67.04	67.04	32.96	20.47
60	0.00	0.00	67.12	67.12	32.88	20.44
58	0.00	0.00	67.23	67.23	32.77	20.41
56	0.00	0.00	67.30	67.30	32.70	20.38
54	0.00	0.00	67.32	67.32	32.68	20.34
52	0.00	0.00	67.40	67.40	32.60	20.31
50	0.00	0.00	67.43	67.43	32.57	20.27
48	0.00	0.00	67.48	67.48	32.52	20.23
46	0.00	0.00	67.56	67.56	32.44	20.21
44	0.00	0.00	67.60	67.60	32.40	20.17
42	0.00	0.00	67.67	67.67	32.33	20.14
40	0.00	0.00	67.73	67.73	32.27	20.11
38	0.00	0.00	67.77	67.77	32.23	20.07
36	0.00	0.00	67.82	67.82	32.18	20.04
34	0.00	0.00	67.87	67.87	32.13	20.01
32	0.00	0.00	67.87	67.87	32.13	19.97
30	0.00	0.00	67.97	67.97	32.03	19.95
28	0.00	0.00	68.00	68.00	32.00	19.92
26	0.00	0.00	68.07	68.07	31.93	19.90
24	0.00	0.00	68.10	68.10	31.90	19.86
22	0.00	0.00	68.05	68.05	31.95	19.82
20	0.00	0.00	68.07	68.07	31.93	19.80
18	0.00	0.00	68.10	68.10	31.90	19.77
16	0.00	0.00	68.19	68.19	31.81	19.76
14	0.00	0.00	68.44	68.44	31.56	19.78
12	0.00	0.00	68.67	68.67	31.33	19.80
10	0.00	0.00	68.84	68.84	31.16	19.80
8	0.00	0.00	69.08	69.08	30.92	19.83
6	0.00	0.00	69.23	69.23	30.77	19.83
4	0.00	0.00	69.41	69.41	30.59	19.84
2	0.00	0.00	69.55	69.55	30.45	19.85
0	0.00	0.00	69.61	69.61	30.39	19.84

Table A.54 DOP Availability Vs. South Latitude for Constellation C8L, DR and TDOA

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	7.21	15.37	17.21	39.78	60.22	12.38
88	10.33	24.53	27.57	62.43	37.57	12.28
86	18.84	27.41	33.69	79.94	20.06	12.42
84	27.86	43.80	25.47	97.13	2.87	9.32
82	30.25	47.98	20.18	98.41	1.59	8.83
80	30.95	48.63	19.09	98.67	1.33	8.55
78	31.41	50.41	16.85	98.67	1.33	8.23
76	31.55	50.46	16.68	98.68	1.32	8.17
74	31.46	50.52	16.70	98.68	1.32	8.18
72	31.44	50.46	16.79	98.69	1.31	8.20
70	31.38	50.56	16.74	98.68	1.32	8.21
68	31.37	50.50	16.80	98.67	1.33	8.23
66	31.43	50.36	16.89	98.68	1.32	8.25
64	31.33	50.50	16.85	98.68	1.32	8.27
62	31.37	50.38	16.93	98.68	1.32	8.30
60	31.37	50.32	16.99	98.68	1.32	8.32
58	31.22	50.39	17.06	98.67	1.33	8.37
56	31.10	50.44	17.13	98.68	1.32	8.40
54	31.13	50.46	17.11	98.69	1.31	8.42
52	31.01	50.53	17.16	98.70	1.30	8.45
50	30.71	50.69	17.30	98.69	1.31	8.51
48	30.53	50.84	17.34	98.70	1.30	8.55
46	30.41	50.78	17.53	98.72	1.28	8.61
44	30.21	50.88	17.62	98.70	1.30	8.66
42	29.94	50.97	17.81	98.72	1.28	8.72
40	29.91	50.93	17.88	98.72	1.28	8.77
38	29.44	51.11	18.17	98.72	1.28	8.84
36	28.98	51.31	18.43	98.72	1.28	8.90
34	28.58	51.49	18.66	98.73	1.27	8.97
32	27.92	51.84	18.95	98.72	1.28	9.06
30	27.31	52.03	19.34	98.69	1.31	9.15
28	26.45	52.39	19.78	98.61	1.39	9.24
26	25.03	53.10	20.36	98.49	1.51	9.36
24	24.14	53.69	20.60	98.42	1.58	9.45
22	23.49	54.41	20.53	98.42	1.58	9.52
20	22.62	54.98	20.82	98.42	1.58	9.61
18	22.42	54.96	21.35	98.73	1.27	9.78
16	22.04	55.11	21.91	99.06	0.94	9.94
14	21.66	55.35	22.05	99.06	0.94	9.95
12	21.28	55.54	22.27	99.08	0.92	9.97
10	20.83	55.72	22.53	99.08	0.92	9.99
8	20.55	55.68	22.90	99.14	0.86	10.01
6	20.07	55.99	23.40	99.45	0.55	10.14
4	19.84	56.00	23.98	99.82	0.18	10.27
2	19.31	56.23	24.47	100.00	0.00	10.32
0	18.95	56.41	24.48	99.83	0.17	10.23

Table A.55 DOP Availability Vs. South Latitude for Constellation C8L, DR Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	2.21	8.66	17.44	28.30	71.70	14.61
88	4.09	11.40	31.04	46.53	53.47	14.95
86	5.83	20.45	35.45	61.73	38.27	14.37
84	7.88	28.15	45.67	81.70	18.30	13.34
82	9.42	30.16	46.07	85.65	14.35	12.88
80	10.28	31.79	46.38	88.45	11.55	12.76
78	11.15	33.78	45.54	90.47	9.53	12.22
76	11.57	34.61	44.42	90.59	9.41	12.06
74	11.67	34.53	44.38	90.58	9.42	12.05
72	11.76	34.38	44.41	90.54	9.46	12.06
70	11.82	34.30	44.41	90.53	9.47	12.06
68	11.85	34.20	44.46	90.51	9.49	12.07
66	11.85	34.27	44.36	90.47	9.53	12.07
64	11.87	34.20	44.37	90.44	9.56	12.09
62	11.91	34.09	44.41	90.40	9.60	12.10
60	11.83	34.10	44.43	90.37	9.63	12.11
58	11.81	34.05	44.38	90.24	9.76	12.13
56	11.87	33.91	44.41	90.19	9.81	12.14
54	11.96	33.86	44.36	90.18	9.82	12.15
52	11.97	33.68	44.56	90.21	9.79	12.20
50	11.76	33.54	44.75	90.05	9.95	12.23
48	11.81	33.36	44.85	90.02	9.98	12.26
46	11.72	33.24	44.98	89.93	10.07	12.29
44	11.68	33.15	44.94	89.77	10.23	12.31
42	11.46	33.02	45.21	89.69	10.31	12.36
40	11.39	32.89	45.34	89.62	10.38	12.39
38	11.12	32.69	45.73	89.54	10.46	12.48
36	10.96	32.68	45.83	89.46	10.54	12.53
34	10.73	32.59	46.03	89.35	10.65	12.59
32	10.38	32.44	46.39	89.21	10.79	12.68
30	9.88	32.45	46.80	89.12	10.88	12.79
28	9.35	32.28	47.28	88.92	11.08	12.91
26	8.17	32.44	48.03	88.64	11.36	13.06
24	7.59	32.45	48.36	88.40	11.60	13.16
22	7.18	32.24	49.00	88.42	11.58	13.31
20	6.69	31.27	50.48	88.43	11.57	13.46
18	6.61	30.97	51.02	88.60	11.40	13.58
16	6.44	30.83	51.50	88.78	11.22	13.71
14	6.33	30.71	51.89	88.93	11.07	13.81
12	6.29	30.30	52.76	89.35	10.65	13.98
10	6.28	29.97	53.43	89.68	10.32	14.11
8	6.23	29.84	53.75	89.82	10.18	14.17
6	6.14	29.77	54.51	90.42	9.58	14.36
4	6.14	29.77	54.31	90.21	9.79	14.31
2	6.10	29.68	54.08	89.86	10.14	14.22
0	6.14	29.58	53.86	89.58	10.42	14.14

Table A.56 DOP Availability Vs. South Latitude for Constellation C8L, TDOA Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.83	6.47	7.30	92.70	16.95
88	0.00	1.82	10.49	12.30	87.70	17.23
86	0.00	4.54	13.28	17.82	82.18	17.51
84	0.00	9.65	18.14	27.78	72.22	16.45
82	0.00	9.91	19.70	29.61	70.39	16.45
80	0.00	10.08	20.44	30.52	69.48	16.63
78	0.00	10.22	21.56	31.77	68.23	16.84
76	0.00	10.42	21.52	31.94	68.06	16.78
74	0.00	10.35	21.47	31.81	68.19	16.75
72	0.00	10.27	21.56	31.83	68.17	16.80
70	0.00	10.10	21.57	31.67	68.33	16.84
68	0.00	10.04	21.58	31.62	68.38	16.86
66	0.00	9.90	21.73	31.63	68.37	16.93
64	0.00	9.76	21.62	31.38	68.62	16.98
62	0.00	9.74	21.56	31.29	68.71	16.99
60	0.00	9.58	21.52	31.10	68.90	17.03
58	0.00	9.44	21.40	30.85	69.15	17.09
56	0.00	9.30	21.52	30.82	69.18	17.13
54	0.00	9.21	21.61	30.82	69.18	17.18
52	0.00	9.04	21.54	30.58	69.42	17.25
50	0.00	8.80	21.48	30.27	69.73	17.30
48	0.00	8.58	21.52	30.10	69.90	17.43
46	0.00	8.39	21.53	29.92	70.08	17.46
44	0.00	8.24	21.40	29.64	70.36	17.47
42	0.00	8.01	21.20	29.21	70.79	17.56
40	0.00	7.71	21.17	28.89	71.11	17.58
38	0.00	7.46	20.93	28.39	71.61	17.66
36	0.00	7.08	20.88	27.96	72.04	17.69
34	0.00	6.76	20.70	27.47	72.53	17.73
32	0.00	6.47	20.35	26.82	73.18	17.81
30	0.00	5.99	20.17	26.16	73.84	17.90
28	0.00	5.45	19.75	25.20	74.80	18.00
26	0.00	4.77	19.28	24.05	75.95	18.28
24	0.00	4.46	18.61	23.07	76.93	18.23
22	0.00	4.13	18.28	22.41	77.59	18.20
20	0.00	3.93	18.00	21.92	78.08	18.23
18	0.00	3.69	17.98	21.67	78.33	18.22
16	0.00	3.56	17.88	21.44	78.56	18.23
14	0.00	3.29	17.88	21.17	78.83	18.34
12	0.00	3.09	17.70	20.79	79.21	18.28
10	0.00	3.02	17.54	20.56	79.44	18.24
8	0.00	2.90	17.46	20.36	79.64	18.21
6	0.00	2.81	17.30	20.11	79.89	18.18
4	0.00	2.76	17.25	20.01	79.99	18.15
2	0.00	2.73	17.21	19.94	80.06	18.16
0	0.00	2.72	17.30	20.02	79.98	18.23

Table A.57 DOP Availability Vs. South Latitude for Constellation C8H, DR and TDOA

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	14.12	23.53	12.86	50.51	49.49	9.45
88	22.22	27.45	16.37	66.04	33.96	8.95
86	28.43	29.44	21.06	78.93	21.07	9.29
84	34.62	34.02	22.24	90.89	9.11	8.89
82	37.40	38.87	19.55	95.82	4.18	8.30
80	41.09	38.15	18.21	97.46	2.54	8.05
78	45.67	37.28	15.68	98.63	1.37	7.54
76	49.38	36.90	12.89	99.16	0.84	7.07
74	52.28	38.00	9.35	99.63	0.37	6.53
72	59.05	33.54	7.04	99.63	0.37	6.10
70	67.29	25.57	6.77	99.63	0.37	5.84
68	67.21	25.61	6.81	99.63	0.37	5.85
66	67.21	25.61	6.81	99.63	0.37	5.87
64	67.16	25.64	6.83	99.62	0.38	5.88
62	67.07	25.71	6.84	99.62	0.38	5.90
60	67.06	25.70	6.85	99.61	0.39	5.91
58	66.95	25.75	6.89	99.59	0.41	5.95
56	66.85	25.89	6.74	99.48	0.52	5.88
54	66.70	26.04	6.67	99.42	0.58	5.85
52	66.61	26.14	6.65	99.40	0.60	5.85
50	66.45	26.12	6.83	99.39	0.61	5.89
48	66.34	26.13	6.91	99.39	0.61	5.92
46	66.20	26.22	6.96	99.39	0.61	5.94
44	66.01	26.35	7.00	99.36	0.64	5.98
42	65.72	26.55	7.09	99.36	0.64	6.01
40	65.58	26.63	7.13	99.34	0.66	6.03
38	65.19	26.89	7.26	99.34	0.66	6.07
36	64.97	27.01	7.35	99.33	0.67	6.10
34	64.65	27.24	7.42	99.31	0.69	6.15
32	64.40	27.31	7.56	99.28	0.72	6.19
30	64.17	27.40	7.66	99.24	0.76	6.24
28	63.57	27.76	7.85	99.19	0.81	6.32
26	62.77	28.24	8.11	99.12	0.88	6.44
24	62.23	28.61	8.30	99.14	0.86	6.49
22	61.81	28.95	8.39	99.15	0.85	6.52
20	61.36	29.35	8.46	99.17	0.83	6.57
18	61.13	29.49	8.57	99.19	0.81	6.58
16	60.87	29.68	8.67	99.21	0.79	6.61
14	60.75	29.74	8.76	99.25	0.75	6.64
12	60.55	29.87	8.87	99.29	0.71	6.67
10	60.36	29.92	9.04	99.31	0.69	6.68
8	60.23	29.94	9.19	99.36	0.64	6.71
6	60.09	29.66	9.63	99.39	0.61	6.72
4	60.02	29.65	9.75	99.42	0.58	6.72
2	59.85	29.69	9.90	99.44	0.56	6.72
0	59.81	29.75	9.93	99.49	0.51	6.73

Table A.58 DOP Availability Vs. South Latitude for Constellation C8H, DR Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	4.70	13.04	18.28	36.02	63.98	13.06
88	7.89	20.56	25.69	54.14	45.86	12.58
86	10.28	23.95	29.96	64.18	35.82	12.59
84	13.01	26.36	31.23	70.60	29.40	12.43
82	16.64	28.74	33.03	78.41	21.59	12.38
80	19.09	31.24	32.98	83.31	16.69	11.99
78	22.56	34.56	31.11	88.23	11.77	11.33
76	25.67	35.78	29.17	90.62	9.38	10.45
74	28.97	37.39	27.86	94.22	5.78	9.88
72	33.27	39.88	23.09	96.25	3.75	8.97
70	39.83	36.77	20.28	96.89	3.11	8.56
68	39.79	36.65	20.42	96.87	3.13	8.55
66	39.91	36.40	20.55	96.86	3.14	8.56
64	39.86	36.30	20.69	96.85	3.15	8.56
62	39.88	36.17	20.77	96.82	3.18	8.56
60	39.73	36.24	20.84	96.81	3.19	8.57
58	39.58	36.29	20.88	96.75	3.25	8.58
56	39.57	36.26	20.89	96.72	3.28	8.58
54	39.63	36.11	20.93	96.67	3.33	8.57
52	39.51	36.12	21.02	96.66	3.34	8.57
50	39.31	36.12	21.16	96.59	3.41	8.60
48	39.17	36.17	21.19	96.53	3.47	8.59
46	39.04	36.21	21.21	96.47	3.53	8.58
44	38.85	36.22	21.38	96.45	3.55	8.62
42	38.52	36.29	21.63	96.44	3.56	8.64
40	38.32	36.44	21.66	96.42	3.58	8.67
38	37.95	36.53	21.91	96.39	3.61	8.72
36	37.72	36.62	22.03	96.37	3.63	8.75
34	37.23	36.90	22.23	96.35	3.65	8.81
32	36.67	37.19	22.48	96.34	3.66	8.89
30	36.03	37.56	22.76	96.35	3.65	8.97
28	35.02	38.13	23.13	96.28	3.72	9.07
26	33.67	38.93	23.54	96.14	3.86	9.19
24	32.96	39.31	23.95	96.21	3.79	9.30
22	32.44	39.41	24.48	96.33	3.67	9.41
20	31.90	39.60	24.97	96.48	3.52	9.53
18	31.67	39.62	25.37	96.66	3.34	9.63
16	31.51	39.43	25.78	96.71	3.29	9.68
14	31.32	39.39	26.07	96.77	3.23	9.73
12	31.04	39.34	26.45	96.82	3.18	9.77
10	30.88	38.83	27.12	96.84	3.16	9.80
8	30.58	38.75	27.50	96.84	3.16	9.82
6	30.34	38.75	27.77	96.86	3.14	9.84
4	30.31	38.64	27.96	96.91	3.09	9.86
2	30.15	38.60	28.15	96.90	3.10	9.87
0	30.15	38.56	28.15	96.86	3.14	9.85

Table A.59 DOP Availability Vs. South Latitude for Constellation C8H, TDOA Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	3.39	7.09	10.49	89.51	16.24
88	0.00	4.22	10.23	14.45	85.55	16.89
86	0.25	5.24	12.74	18.23	81.77	16.44
84	0.42	7.94	16.62	24.99	75.01	16.35
82	0.43	9.82	19.41	29.66	70.34	16.57
80	0.67	10.74	23.13	34.54	65.46	16.57
78	1.09	12.16	29.89	43.15	56.85	16.84
76	1.64	13.90	34.23	49.77	50.23	16.55
74	2.11	15.12	40.76	57.99	42.01	16.48
72	3.61	15.84	47.95	67.40	32.60	16.02
70	5.13	16.73	56.20	78.06	21.94	16.03
68	5.16	16.65	56.33	78.14	21.86	16.04
66	5.16	16.54	56.37	78.06	21.94	16.02
64	5.25	16.22	56.60	78.06	21.94	16.04
62	5.25	16.17	56.60	78.01	21.99	16.03
60	5.24	15.96	56.74	77.94	22.06	16.04
58	5.20	15.76	56.86	77.82	22.18	16.05
56	5.12	15.72	56.93	77.77	22.23	16.04
54	5.13	15.65	56.90	77.68	22.32	16.01
52	5.08	15.47	57.09	77.64	22.36	16.03
50	4.94	15.32	57.27	77.53	22.47	16.06
48	4.91	15.10	57.35	77.35	22.65	16.06
46	4.84	14.93	57.49	77.26	22.74	16.06
44	4.75	14.78	57.54	77.07	22.93	16.06
42	4.64	14.41	57.92	76.97	23.03	16.09
40	4.50	14.23	58.07	76.80	23.20	16.10
38	4.38	13.82	58.34	76.54	23.46	16.12
36	4.14	13.68	58.53	76.35	23.65	16.14
34	4.03	13.29	58.82	76.14	23.86	16.18
32	3.80	12.93	59.04	75.76	24.24	16.21
30	3.56	12.47	59.51	75.53	24.47	16.27
28	3.22	12.14	59.76	75.11	24.89	16.34
26	2.73	11.49	60.36	74.58	25.42	16.44
24	2.55	10.94	60.79	74.29	25.71	16.53
22	2.29	10.71	61.08	74.08	25.92	16.60
20	2.12	10.38	61.55	74.06	25.94	16.70
18	2.01	10.27	61.77	74.05	25.95	16.75
16	1.84	10.24	61.79	73.88	26.12	16.75
14	1.72	10.10	62.21	74.03	25.97	16.86
12	1.64	9.96	62.61	74.21	25.79	16.95
10	1.58	9.94	62.74	74.25	25.75	16.98
8	1.50	9.85	63.05	74.40	25.60	17.04
6	1.40	9.80	63.17	74.36	25.64	17.06
4	1.39	9.80	63.31	74.49	25.51	17.09
2	1.37	9.75	63.38	74.50	25.50	17.11
0	1.40	9.76	63.46	74.62	25.38	17.12

Table A.60 DOP Availability Vs. South Latitude for Constellation C9, DR and TDOA

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	1.25	29.46	30.71	69.29	18.58
88	0.00	1.25	38.49	39.73	60.27	18.52
86	0.00	1.25	45.83	47.08	52.92	19.15
84	0.00	1.25	55.13	56.38	43.62	19.09
82	0.00	1.36	61.24	62.60	37.40	18.90
80	0.00	1.92	64.84	66.76	33.24	18.72
78	0.00	1.93	66.60	68.53	31.47	18.71
76	0.00	1.93	67.32	69.26	30.74	18.64
74	0.00	1.93	67.32	69.26	30.74	18.63
72	0.00	1.93	67.34	69.27	30.73	18.63
70	0.00	1.96	67.32	69.28	30.72	18.63
68	0.00	1.98	67.31	69.29	30.71	18.63
66	0.00	2.00	67.30	69.29	30.71	18.63
64	0.00	2.01	67.30	69.31	30.69	18.63
62	0.00	2.02	67.29	69.31	30.69	18.63
60	0.00	2.05	67.25	69.29	30.71	18.63
58	0.00	2.05	67.27	69.32	30.68	18.63
56	0.00	2.05	67.27	69.32	30.68	18.62
54	0.00	2.05	67.27	69.32	30.68	18.62
52	0.00	2.07	67.23	69.31	30.69	18.62
50	0.00	2.07	67.25	69.32	30.68	18.62
48	0.00	2.07	67.23	69.31	30.69	18.61
46	0.00	2.07	67.25	69.32	30.68	18.61
44	0.00	2.10	67.25	69.34	30.66	18.62
42	0.00	2.10	67.26	69.36	30.64	18.62
40	0.00	2.10	67.27	69.37	30.63	18.62
38	0.00	2.10	67.29	69.38	30.62	18.62
36	0.00	2.10	67.29	69.38	30.62	18.62
34	0.00	2.11	67.25	69.36	30.64	18.61
32	0.00	2.12	67.26	69.38	30.62	18.62
30	0.00	2.12	67.31	69.43	30.57	18.62
28	0.00	2.12	67.32	69.45	30.55	18.62
26	0.00	2.11	67.36	69.47	30.53	18.63
24	0.00	2.11	67.41	69.52	30.48	18.64
22	0.00	2.11	67.41	69.52	30.48	18.64
20	0.00	2.11	67.40	69.51	30.49	18.63
18	0.00	2.12	67.35	69.47	30.53	18.62
16	0.00	2.12	67.37	69.50	30.50	18.63
14	0.00	2.12	67.39	69.51	30.49	18.63
12	0.00	2.12	67.37	69.50	30.50	18.63
10	0.00	2.14	67.37	69.51	30.49	18.63
8	0.00	2.15	67.35	69.50	30.50	18.63
6	0.00	2.14	67.36	69.50	30.50	18.63
4	0.00	2.12	67.39	69.51	30.49	18.63
2	0.00	2.14	67.36	69.50	30.50	18.63
0	0.00	2.14	67.36	69.50	30.50	18.63

Table A.61 DOP Availability Vs. South Latitude for Constellation C9, DR Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	19.40	19.40	80.60	22.24
88	0.00	0.00	27.77	27.77	72.23	22.06
86	0.00	0.00	32.28	32.28	67.72	21.73
84	0.00	0.00	38.83	38.83	61.17	21.71
82	0.00	0.00	44.64	44.64	55.36	21.44
80	0.00	0.00	48.95	48.95	51.05	21.18
78	0.00	0.00	50.39	50.39	49.61	21.10
76	0.00	0.00	51.21	51.21	48.79	21.02
74	0.00	0.00	51.21	51.21	48.79	21.01
72	0.00	0.00	51.21	51.21	48.79	21.01
70	0.00	0.00	51.22	51.22	48.78	21.01
68	0.00	0.00	51.23	51.23	48.77	21.01
66	0.00	0.00	51.25	51.25	48.75	21.01
64	0.00	0.00	51.25	51.25	48.75	21.01
62	0.00	0.00	51.23	51.23	48.77	21.00
60	0.00	0.00	51.21	51.21	48.79	20.99
58	0.00	0.00	51.25	51.25	48.75	21.00
56	0.00	0.00	51.22	51.22	48.78	20.99
54	0.00	0.00	51.25	51.25	48.75	20.99
52	0.00	0.00	51.25	51.25	48.75	20.99
50	0.00	0.00	51.23	51.23	48.77	20.99
48	0.00	0.00	51.23	51.23	48.77	20.98
46	0.00	0.00	51.25	51.25	48.75	20.98
44	0.00	0.00	51.23	51.23	48.77	20.98
42	0.00	0.00	51.25	51.25	48.75	20.98
40	0.00	0.00	51.23	51.23	48.77	20.97
38	0.00	0.00	51.23	51.23	48.77	20.97
36	0.00	0.00	51.23	51.23	48.77	20.97
34	0.00	0.00	51.21	51.21	48.79	20.96
32	0.00	0.00	51.19	51.19	48.81	20.96
30	0.00	0.00	51.21	51.21	48.79	20.96
28	0.00	0.00	51.22	51.22	48.78	20.96
26	0.00	0.00	51.22	51.22	48.78	20.96
24	0.00	0.00	51.28	51.28	48.72	20.97
22	0.00	0.00	51.33	51.33	48.67	20.98
20	0.00	0.00	51.35	51.35	48.65	20.98
18	0.00	0.00	51.32	51.32	48.68	20.98
16	0.00	0.00	51.30	51.30	48.70	20.97
14	0.00	0.00	51.30	51.30	48.70	20.97
12	0.00	0.00	51.27	51.27	48.73	20.96
10	0.00	0.00	51.28	51.28	48.72	20.97
8	0.00	0.00	51.26	51.26	48.74	20.96
6	0.00	0.00	51.25	51.25	48.75	20.96
4	0.00	0.00	51.27	51.27	48.73	20.96
2	0.00	0.00	51.23	51.23	48.77	20.95
0	0.00	0.00	51.19	51.19	48.81	20.95

Table A.62 DOP Availability Vs. South Latitude for Constellation C9, TDOA Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	0.00	0.00	100.00	Inf
88	0.00	0.00	0.00	0.00	100.00	Inf
86	0.00	0.00	0.00	0.00	100.00	Inf
84	0.00	0.00	0.00	0.00	100.00	Inf
82	0.00	0.00	0.00	0.00	100.00	Inf
80	0.00	0.00	0.00	0.00	100.00	Inf
78	0.00	0.00	0.00	0.00	100.00	Inf
76	0.00	0.00	0.00	0.00	100.00	Inf
74	0.00	0.00	0.00	0.00	100.00	Inf
72	0.00	0.00	0.00	0.00	100.00	Inf
70	0.00	0.00	0.00	0.00	100.00	Inf
68	0.00	0.00	0.00	0.00	100.00	Inf
66	0.00	0.00	0.00	0.00	100.00	Inf
64	0.00	0.00	0.00	0.00	100.00	Inf
62	0.00	0.00	0.00	0.00	100.00	Inf
60	0.00	0.00	0.00	0.00	100.00	Inf
58	0.00	0.00	0.00	0.00	100.00	Inf
56	0.00	0.00	0.00	0.00	100.00	Inf
54	0.00	0.00	0.00	0.00	100.00	Inf
52	0.00	0.00	0.00	0.00	100.00	Inf
50	0.00	0.00	0.00	0.00	100.00	Inf
48	0.00	0.00	0.00	0.00	100.00	Inf
46	0.00	0.00	0.00	0.00	100.00	Inf
44	0.00	0.00	0.00	0.00	100.00	Inf
42	0.00	0.00	0.00	0.00	100.00	Inf
40	0.00	0.00	0.00	0.00	100.00	Inf
38	0.00	0.00	0.00	0.00	100.00	Inf
36	0.00	0.00	0.00	0.00	100.00	Inf
34	0.00	0.00	0.00	0.00	100.00	Inf
32	0.00	0.00	0.00	0.00	100.00	Inf
30	0.00	0.00	0.00	0.00	100.00	Inf
28	0.00	0.00	0.00	0.00	100.00	Inf
26	0.00	0.00	0.00	0.00	100.00	Inf
24	0.00	0.00	0.00	0.00	100.00	Inf
22	0.00	0.00	0.00	0.00	100.00	Inf
20	0.00	0.00	0.00	0.00	100.00	Inf
18	0.00	0.00	0.00	0.00	100.00	Inf
16	0.00	0.00	0.00	0.00	100.00	Inf
14	0.00	0.00	0.00	0.00	100.00	Inf
12	0.00	0.00	0.00	0.00	100.00	Inf
10	0.00	0.00	0.00	0.00	100.00	Inf
8	0.00	0.00	0.00	0.00	100.00	Inf
6	0.00	0.00	0.00	0.00	100.00	Inf
4	0.00	0.00	0.00	0.00	100.00	Inf
2	0.00	0.00	0.00	0.00	100.00	Inf
0	0.00	0.00	0.00	0.00	100.00	Inf

Table A.63 DOP Availability Vs. South Latitude for Constellation C10, DR and TDOA

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	6.27	8.17	17.27	31.71	68.29	13.85
88	8.08	10.00	24.76	42.84	57.16	14.08
86	9.86	12.54	29.73	52.14	47.86	14.12
84	11.76	13.88	38.14	63.78	36.22	14.66
82	13.36	15.53	41.37	70.26	29.74	14.63
80	14.16	16.54	42.90	73.59	26.41	14.44
78	14.74	18.70	45.14	78.58	21.42	14.21
76	15.00	18.98	46.29	80.26	19.74	14.14
74	15.07	18.80	46.33	80.20	19.80	14.14
72	15.18	18.61	46.38	80.16	19.84	14.14
70	15.30	18.45	46.35	80.11	19.89	14.15
68	15.34	18.47	46.24	80.05	19.95	14.14
66	15.39	18.47	46.14	79.99	20.01	14.14
64	15.49	18.24	46.20	79.93	20.07	14.15
62	15.51	18.11	46.16	79.78	20.22	14.14
60	15.53	18.01	46.12	79.66	20.34	14.14
58	15.63	17.77	46.10	79.50	20.50	14.15
56	15.58	17.72	46.17	79.47	20.53	14.16
54	15.76	17.55	46.10	79.41	20.59	14.15
52	15.73	17.46	46.15	79.35	20.65	14.16
50	15.61	17.30	46.29	79.19	20.81	14.20
48	15.57	17.13	46.34	79.04	20.96	14.20
46	15.56	17.01	46.33	78.89	21.11	14.23
44	15.49	16.90	46.31	78.71	21.29	14.24
42	15.21	16.75	46.45	78.42	21.58	14.27
40	15.12	16.68	46.43	78.23	21.77	14.28
38	14.87	16.41	46.67	77.95	22.05	14.35
36	14.63	16.33	46.67	77.63	22.37	14.37
34	14.36	16.19	46.71	77.26	22.74	14.41
32	13.98	15.79	46.99	76.75	23.25	14.49
30	13.54	15.52	47.10	76.16	23.84	14.57
28	12.86	15.05	47.38	75.29	24.71	14.69
26	11.59	14.74	47.70	74.03	25.97	14.83
24	11.11	14.45	47.85	73.41	26.59	14.93
22	10.61	14.43	47.90	72.94	27.06	15.00
20	10.22	14.04	48.37	72.64	27.36	15.08
18	10.12	14.01	48.27	72.39	27.61	15.11
16	9.74	13.96	48.61	72.31	27.69	15.15
14	9.60	13.79	48.77	72.15	27.85	15.18
12	9.43	13.75	48.91	72.09	27.91	15.22
10	9.30	13.73	49.01	72.04	27.96	15.24
8	9.21	13.62	49.14	71.98	28.02	15.26
6	9.09	13.60	49.24	71.92	28.08	15.27
4	9.11	13.56	49.26	71.94	28.06	15.28
2	9.10	13.54	49.26	71.90	28.10	15.29
0	9.20	13.52	49.16	71.89	28.11	15.26

Table A.64 DOP Availability Vs. South Latitude for Constellation C10, DR Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	2.00	7.84	19.41	29.25	70.75	16.43
88	3.19	9.35	26.36	38.90	61.10	16.55
86	3.79	12.24	31.32	47.34	52.66	16.40
84	4.75	13.85	37.25	55.86	44.14	16.44
82	5.64	15.53	40.06	61.24	38.76	16.10
80	6.22	16.08	42.11	64.40	35.60	16.06
78	6.75	16.43	46.07	69.26	30.74	16.10
76	6.94	16.57	47.50	71.01	28.99	16.14
74	6.96	16.60	47.38	70.95	29.05	16.14
72	7.02	16.55	47.34	70.91	29.09	16.14
70	7.03	16.54	47.24	70.81	29.19	16.12
68	7.07	16.46	47.19	70.72	29.28	16.12
66	7.16	16.40	47.14	70.69	29.31	16.12
64	7.22	16.38	47.03	70.63	29.37	16.13
62	7.23	16.31	47.03	70.56	29.44	16.16
60	7.28	16.26	46.95	70.49	29.51	16.16
58	7.32	16.05	46.98	70.35	29.65	16.19
56	7.32	15.94	47.06	70.32	29.68	16.20
54	7.28	16.09	46.91	70.28	29.72	16.19
52	7.37	15.93	46.82	70.12	29.88	16.19
50	7.40	15.75	46.73	69.88	30.12	16.22
48	7.36	15.61	46.77	69.74	30.26	16.24
46	7.33	15.57	46.61	69.51	30.49	16.25
44	7.33	15.49	46.58	69.41	30.59	16.29
42	7.17	15.26	46.67	69.10	30.90	16.35
40	7.08	15.19	46.64	68.91	31.09	16.36
38	6.99	15.01	46.53	68.53	31.47	16.43
36	6.84	14.72	46.62	68.17	31.83	16.47
34	6.72	14.50	46.54	67.77	32.23	16.52
32	6.52	14.10	46.50	67.12	32.88	16.60
30	6.22	13.71	46.57	66.50	33.50	16.71
28	5.90	13.07	46.53	65.49	34.51	16.84
26	5.27	12.18	46.73	64.18	35.82	17.05
24	4.94	11.73	46.67	63.35	36.65	17.15
22	4.80	11.38	46.61	62.79	37.21	17.23
20	4.60	10.96	46.77	62.33	37.67	17.32
18	4.54	10.87	46.71	62.11	37.89	17.37
16	4.49	10.50	46.95	61.93	38.07	17.44
14	4.42	10.37	47.03	61.82	38.18	17.49
12	4.32	10.21	47.15	61.68	38.32	17.54
10	4.27	10.08	47.27	61.62	38.38	17.58
8	4.14	10.08	47.28	61.50	38.50	17.59
6	4.12	10.02	47.42	61.55	38.45	17.64
4	4.12	10.02	47.38	61.51	38.49	17.64
2	4.16	9.94	47.42	61.51	38.49	17.66
0	4.16	9.96	47.46	61.58	38.42	17.67

Table A.65 DOP Availability Vs. South Latitude for Constellation C10, TDOA Only

User South Latitude	Percent Time DOP≤5	Percent Time 5<DOP≤10	Percent Time 10<DOP≤30	Percent Available (DOP≤30)	Percent Unavailable (30<DOP)	RMS of DOP≤30
90	0.00	0.00	2.62	2.62	97.38	19.53
88	0.00	0.00	3.08	3.08	96.92	20.06
86	0.00	0.00	3.74	3.74	96.26	20.00
84	0.00	0.00	4.40	4.40	95.60	19.86
82	0.00	0.00	5.16	5.16	94.84	19.64
80	0.00	0.00	5.24	5.24	94.76	19.72
78	0.00	0.00	6.08	6.08	93.92	19.47
76	0.00	0.00	6.55	6.55	93.45	19.22
74	0.00	0.00	6.58	6.58	93.42	19.28
72	0.00	0.00	6.60	6.60	93.40	19.25
70	0.00	0.00	6.48	6.48	93.52	19.27
68	0.00	0.00	6.56	6.56	93.44	19.37
66	0.00	0.00	6.58	6.58	93.42	19.43
64	0.00	0.00	6.52	6.52	93.48	19.48
62	0.00	0.00	6.56	6.56	93.44	19.55
60	0.00	0.00	6.58	6.58	93.42	19.66
58	0.00	0.00	6.51	6.51	93.49	19.67
56	0.00	0.00	6.49	6.49	93.51	19.66
54	0.00	0.00	6.47	6.47	93.53	19.68
52	0.00	0.00	6.37	6.37	93.63	19.57
50	0.00	0.00	6.27	6.27	93.73	19.61
48	0.00	0.00	6.18	6.18	93.82	19.62
46	0.00	0.00	6.16	6.16	93.84	19.61
44	0.00	0.00	6.11	6.11	93.89	19.68
42	0.00	0.00	6.05	6.05	93.95	19.77
40	0.00	0.00	6.00	6.00	94.00	19.73
38	0.00	0.00	5.88	5.88	94.12	19.78
36	0.00	0.00	5.81	5.81	94.19	19.80
34	0.00	0.00	5.69	5.69	94.31	19.77
32	0.00	0.00	5.63	5.63	94.37	19.79
30	0.00	0.00	5.45	5.45	94.55	19.59
28	0.00	0.00	5.29	5.29	94.71	19.51
26	0.00	0.00	5.12	5.12	94.88	19.52
24	0.00	0.00	4.93	4.93	95.07	19.31
22	0.00	0.00	4.79	4.79	95.21	19.27
20	0.00	0.00	4.73	4.73	95.27	19.18
18	0.00	0.00	4.60	4.60	95.40	19.13
16	0.00	0.00	4.49	4.49	95.51	19.01
14	0.00	0.00	4.40	4.40	95.60	18.98
12	0.00	0.00	4.28	4.28	95.72	18.94
10	0.00	0.00	4.22	4.22	95.78	18.90
8	0.00	0.00	4.11	4.11	95.89	18.81
6	0.00	0.00	4.11	4.11	95.89	18.81
4	0.00	0.00	4.08	4.08	95.92	18.89
2	0.00	0.00	4.11	4.11	95.89	18.90
0	0.00	0.00	4.07	4.07	95.93	18.84

Write the identity matrix, $\mathbf{I}$, as $\mathbf{A}\mathbf{A}^{-1}$

$$\begin{bmatrix} \mathbf{I} & \mathbf{0} \\ \mathbf{0} & \mathbf{I} \end{bmatrix} = \begin{bmatrix} \mathbf{P}^{-1} & \mathbf{H}^T \\ \mathbf{H} & -\mathbf{R} \end{bmatrix} \begin{bmatrix} \mathbf{D} & \mathbf{F} \\ \mathbf{G}^T & \mathbf{E} \end{bmatrix} = \begin{bmatrix} \mathbf{P}^{-1}\mathbf{D} + \mathbf{H}^T\mathbf{G}^T & \mathbf{P}^{-1}\mathbf{F} + \mathbf{H}^T\mathbf{E} \\ \mathbf{H}\mathbf{D} - \mathbf{R}\mathbf{G}^T & \mathbf{H}\mathbf{F} - \mathbf{R}\mathbf{E} \end{bmatrix}$$

Equation (B.1) can be written from the upper left partition, and then solved for $\mathbf{D}$ in Equation (B.2).

$$\mathbf{P}^{-1}\mathbf{D} + \mathbf{H}^T\mathbf{G}^T = \mathbf{I} \tag{B.1}$$

$$\mathbf{D} = (\mathbf{P} - \mathbf{P}\mathbf{H}^T\mathbf{G}^T) \tag{B.2}$$

Equation (B.3) can be written from the lower left partition and then solved for $\mathbf{G}^T$ in Equation (B.4).

$$\mathbf{H}\mathbf{D} - \mathbf{R}\mathbf{G}^T = \mathbf{0} \tag{B.3}$$

$$\mathbf{G}^T = \mathbf{R}^{-1}\mathbf{H}\mathbf{D} \tag{B.4}$$

Substituting Equation (B.4) into Equation (B.1) yields Equation (B.5):

$$\mathbf{P}^{-1}\mathbf{D} + \mathbf{H}^T\mathbf{R}^{-1}\mathbf{H}\mathbf{D} = \mathbf{I}$$

$$(\mathbf{P}^{-1} + \mathbf{H}^T\mathbf{R}^{-1}\mathbf{H})\mathbf{D} = \mathbf{I}$$

$$\mathbf{D} = (\mathbf{P}^{-1} + \mathbf{H}^T\mathbf{R}^{-1}\mathbf{H})^{-1} \tag{B.5}$$

Substituting Equation (B.2) into Equation (B.3) yields Equation (B.6):

$$\mathbf{H}\mathbf{P} - \mathbf{H}\mathbf{P}\mathbf{H}^T\mathbf{G}^T - \mathbf{R}\mathbf{G}^T = \mathbf{0}$$

$$\mathbf{H}\mathbf{P} - (\mathbf{H}\mathbf{P}\mathbf{H}^T + \mathbf{R})\mathbf{G}^T = \mathbf{0}$$

$$(\mathbf{HPH}^T + \mathbf{R})\mathbf{G}^T = \mathbf{HP}$$

$$\mathbf{G}^T = (\mathbf{HPH}^T + \mathbf{R})^{-1}\mathbf{HP} \tag{B.6}$$

Substituting Equation (B.6) into Equation (B.2) yields Equation (B.7):

$$\mathbf{D} = \mathbf{P} - \mathbf{PH}^T(\mathbf{HPH}^T + \mathbf{R})^{-1}\mathbf{HP} \tag{B.7}$$

Equating (B.5) and (B.7) yields the final result.

$$(\mathbf{P}^{-1} + \mathbf{H}^T\mathbf{R}^{-1}\mathbf{H})^{-1} = \mathbf{P} - \mathbf{PH}^T(\mathbf{HPH}^T + \mathbf{R})^{-1}\mathbf{HP} \tag{B.8}$$

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14. ABSTRACT

The National Aeronautics and Space Agency's Glenn Research Center is examining several approaches to meet navigational requirements for spacecraft in lunar orbit, in transit to or from the moon, and for personnel on the lunar surface requiring an accurate, real-time, on-board navigation capability. This work addresses one possible solution to the navigation problem in the vicinity of the moon using a lunar satellite navigation system.

Dilution of precision is the figure of merit used to determine if the system can meet accuracy specifications based on a given satellite constellation and the measurement types used. Ten satellite constellations, using two measurement types (direct ranging and time-difference-of-arrival), are analyzed for numerous user locations on the moon. Using terrestrial and Earth-orbiting assets to augment the lunar constellations is also investigated. Sensitivity analyses are accomplished to determine the effect on the position solution accuracy of additional measurements, reduced measurements, and different combinations of measurement types.

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