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Dilution-of-Precision-Based Lunar Surface Navigation System Analysis Utilizing Earth-Based Assets

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Summary

The NASA Vision for Space Exploration is focused on the return of astronauts to the Moon (ref. 1). Although navigation systems have already been proven in the Apollo missions to the Moon, the current exploration campaign will involve more extensive and extended missions requiring new concepts for lunar navigation. In contrast to Apollo missions, which were limited to the near-side equatorial region of the Moon, those under the Exploration Systems Initiative will require navigation on the Moon's limb and far side. These regions are known to have poor Earth visibility, but unknown is the extent to which a navigation system comprised solely of Earth-based tracking stations will provide adequate navigation solutions in these areas. This report presents a dilution-of-precision (DoP)-based analysis of the performance of a network of Earth-based assets. This analysis extends a previous analysis of a lunar network (LN) of navigation satellites by providing an assessment of the capability associated with a variety of assumptions. These assumptions pertain to the minimum provider elevation angle, nadir and zenith beam widths, and a total single failure in one of the Earth-based assets. The assessment is accomplished by making appropriately formed estimates of DoP. Different adaptations of DoP, such as geometrical DoP and positional DoP (GDoP and PDoP), are associated with a different set of assumptions regarding augmentations to the navigation receiver or transceiver.

Introduction

In support of NASA's Vision for Space Exploration (ref. 1), an extension of the position-fixing capability provided by the GPS constellation (ref. 2) to the Moon is being analyzed. This extension would be provided by introducing multiple representations of a network of Earth-based assets. This study provides a dilution-of-precision (DoP)-based analysis of the navigation performance associated with the Earth-based assets for a user located on the lunar surface. The current study is similar to a prior study on the subject (ref. 3) with two main differences: use of the newly developed DoP technique referred to as "generalized DoP" (R. Carpenter, 2005, Generalized Dilution of Precision, unpublished manuscript) and its extension to multiple minimum provider elevation angles, multiple nadir and zenith beam widths, and a total single asset failure (ref. 4).

Generalized DoP provides the ability to assess the navigational performance associated with a receiver that is able to integrate radiometric measurements over time. Such an analysis method allows one to directly compare the navigational capability associated with sparse constellations with that provided by constellations which support full coverage of an appropriate fold. Estimates of a user state derived from multiple radiometric measurements collected over a period of time are referred to herein as being "dynamic," whereas those provided by full constellations that do not employ integration over time in the receiver are referred to as being "kinematic." As opposed to standard measures of DoP that are restricted to kinematic position-fixing capabilities, the use of generalized DoP further allows assessment of the constellation to be performed in terms of the latency associated with obtaining a specified level of system performance (ref. 4).

Several different options for the Earth-based assets are considered in this study and include equally distributed geostationary (GEO) satellites, deep space network (DSN) site locations, and a combination of GEO satellites and DSN locations. These constellations of assets are also studied under the possibility of the total failure of a single asset. Various minimum provider elevation angles are studied with regard to the performance of the DSN assets. For the GEO satellites, various combinations of the nadir and zenith beam widths are studied. Also included in the study are assessments of a number of augmentations to the system, such as highly stable clocks within the receiver, good knowledge of the terrain, and the integration of radiometric measurements over periods of time. Comparisons of the system performance under the different system assumptions indicate that system availability performance is significantly improved and latency is reduced by the prescribed augmentations. In particular, although using a highly stable clock for the user receiver brings about an improvement in performance, the improvement in performance brought by the knowledge of user altitude alone is significantly greater than that brought by a stable user clock. In addition, using a stable user clock together with knowledge of user altitude provides significant improvements over knowledge of user altitude alone. Further shown is that using time integration of radiometric measurements is an effective way to improve system availability to required levels. Finally, system performance is reduced with an increase in the minimum provider elevation angle as a result of the decrease in visibility.

The generalized DoP approach can be applied along with a variety of assumptions regarding navigation receiver and satellite visibility for versions of DoP, such as geometrical and positional DoP (GDoP and PDoP), with varying requirements

for the number of satellites in view to obtain a solution. For example, the basis for assessment (for a two-way mode of operation) is the PDoP, which assumes that the navigation transceiver only needs to solve for the user's position in three dimensions. Appropriate versions of DoP (or generalized DoP) are applied according to the assumptions regarding the nature of the radiometric measurements that are available in addition to assumptions regarding the availability of collateral information, such as synchronized clock or altitude above the lunar geoid. The user altitude is obtained from accurate knowledge of terrain coupled with user latitude and longitude. User latitude and longitude would be obtained from radiometric measurements. Results are derived from temporally and spatially averaged system availability numbers associated with prespecified levels of system availability. Results are also provided in terms of system latency associated with a prespecified level of system availability.

Constellations

Three categories of Earth-based asset constellations are considered: equally distributed GEO satellites (150° W, 30° W, 90° E); DSN site locations (Canberra, Madrid, and Goldstone); and the combination of GEO and DSN assets. The notation for the Earth-based assets subsequently used depends on which asset type is used. For the first asset type, such as GEO *z*/*n*, the parameters are defined as the zenith beam width *z* and the nadir beam width *n*, where the nadir beam width is the boresight beam width in the nadir direction and the zenith beam width is the boresight beam width in the zenith direction. For the second asset type, such as DSN *e*, the parameter is defined as the provider elevation angle *e*. For the third asset type, such as DSNGEO *e*/*z*/*n*, the parameters *e*, *n*, and *z* are defined in the same manner as before. Table 1 lists the parameters of the constellations considered herein.

The analysis in this report is also performed for a single failure mode of operation to determine the loss of performance if there is an asset outage. The outage is assumed to be the worst case because it is permanent. Table 2 lists the parameters of the constellations in the failure mode; note that if a constellation can have multiple failure modes due to the asymmetry in the constellation, then it will have different failure mode versions identified in table 2.

Each of the constellations in this study was considered for specific reasons. The DSN constellations were considered for their providing a focus of coverage over the front equatorial region with different minimum provider elevation angles used to simulate variable-link availability on Earth. The GEO 0/30 constellation was considered because its orientation is very close to that of the tracking and data relay satellites (TDRS), which are nearly located at 150° W, 30° W, and 90° E. Also, the beam-width pattern for the GEO 0/30 constellation is very close to the capabilities of the TDRS system. The other GEO constellations were examined to learn about the enhancements in the navigation capability if a zenith antenna were in place along with a nadir antenna having a larger beam width. The DSNGEO 10/0/30 constellation was examined because it is a combination of two previous sets of constellations that are currently feasible with the most appropriate minimum provider elevation angle. The other DSNGEO constellations were examined to learn about the effects of the combination of the DSN constellation with a new GEO constellation that has additional beam-width capabilities over those of the TDRS system. Separate images of the DSN and GEO constellations are presented in appendix A.

TABLE 1.—EARTH-BASED ASSET CONSTELLATIONS

Constellation	Number of assets		Minimum provider elevation angle, deg	Beam-width angle, deg	
	GEO	DSN		Zenith	Nadir
GEO 0/30	3	0	N/A	0	30
GEO 30/30				30	
GEO 90/30				90	
GEO 150/30				150	
GEO 90/90				90	90
GEO 150/150				150	150
DSN 5	0	3	5	N/A	N/A
DSN 10	0	3	10	N/A	N/A
DSN 15	0	3	15	N/A	N/A
DSNGEO 10/0/30	3	3	10	0	30
DSNGEO 10/30/30				30	
DSNGEO 10/90/30				90	
DSNGEO 10/150/30				150	
DSNGEO 10/90/90				90	90
DSNGEO 10/150/150				150	150

TABLE 2.—FAILURE MODE LUNAR NETWORK CONSTELLATIONS

Earth-based assets constellation	Number of assets		Minimum provider elevation angle, deg	Beam-width angle, deg	
	GEO	DSN		Zenith	Nadir
GEO 0/30	2	0	N/A	0	30
GEO 30/30				30	
GEO 90/30				90	
GEO 150/30				150	
GEO 90/90				90	90
GEO 150/150				150	150
DSN 5	0	2	5	N/A	N/A
DSN 10	0	2	10	N/A	N/A
DSN 15	0	2	15	N/A	N/A
DSNGEO 10/0/30 –v1	3	2	10	0	30
DSNGEO 10/0/30 –v2	2	3		0	
DSNGEO 10/30/30 –v1	3	2		30	
DSNGEO 10/30/30 –v2	2	3		30	
DSNGEO 10/90/30 –v1	3	2		90	
DSNGEO 10/90/30 –v2	2	3		90	
DSNGEO 10/150/30 –v1	3	2		150	
DSNGEO 10/150/30 –v2	2	3		150	
DSNGEO 10/90/90 –v1	3	2		90	90
DSNGEO 10/90/90 –v2	2	3		90	90
DSNGEO 10/150/150 –v1	3	2		150	150
DSNGEO 10/150/150 –v2	2	3		150	150

Analysis

Generalized DoP

The analysis performed is a generalized version of the DoP metric (ref. 4), of which several forms are subsequently used for analysis. The generalized DoP is derived from the observability grammian, which is obtained by using the navigation user equations of motion and the associated sequence of measurements. The equations of motion and the measurement sequence are given in reference 4. It is shown that the DoP metric takes the following form, as derived in reference 4:

$$\sqrt{\max\left\{eig\left[\left(\sum_{t_o}^{t_n}\widetilde{H}_o^T W \widetilde{H}_o\right)\right]\right\}} \tag{1}$$

where t_n is the nth time step since time step zero; t_o is time step zero; $\widetilde{H}_o^T$ is the matrix transpose of $\widetilde{H}_0$, which is the measurement partial derivative matrix; and W is the measurement weighting matrix.

Variations of Generalized DoP

To relax the constraint of satellite coverage in order to invert the observability grammian, a number of augmentations to the lunar navigation system are considered in the analysis. These augmentations constrain the navigation solution and thereby reduce the number of required satellites in view. The augmentations include clock synchronization and a good knowledge of the terrain, which result in several forms of DoP. The selected form of DoP used not only affects the required satellites in view but also affects the state transition and H-matrices used in the calculation. Also, note that throughout the analysis, both range and range-rate (Doppler) measurements are used to solve for position and time-bias (when appropriate) estimates only. No estimates were made for velocity or frequency bias, as the users are assumed to be stationary.

Geometrical dilution of precision (GDoP) is used in the global positioning system (GPS) where the solution is obtained for the position of the user in three dimensions and for the time bias, resulting in the requirement of four navigation signals. The associated H-matrices and state transition for stationary surface users are

$$\Phi_{GDoP}(t_i, t_o) = I + \begin{bmatrix} 0 & I \\ 0 & 0 \end{bmatrix} \times (t_i - t_o) \tag{2}$$

where Φ is the state transition matrix; t_i is the ith time step since time step zero; and I is the identity matrix.

$$H = \begin{bmatrix} \frac{\partial r_1}{\partial x_1} & \frac{\partial r_1}{\partial y_1} & \frac{\partial r_1}{\partial z_1} & \frac{\partial r_1}{\partial (ct_{\text{bias}_1})} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{\partial r_m}{\partial x_m} & \frac{\partial r_m}{\partial y_m} & \frac{\partial r_m}{\partial z_m} & \frac{\partial r_m}{\partial (ct_{\text{bias}_m})} \\ \frac{\partial \dot{r}_1}{\partial x_1} & \frac{\partial \dot{r}_1}{\partial y_1} & \frac{\partial \dot{r}_1}{\partial z_1} & \frac{\partial \dot{r}_1}{\partial (ct_{\text{bias}_1})} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{\partial \dot{r}_m}{\partial x_m} & \frac{\partial \dot{r}_m}{\partial y_m} & \frac{\partial \dot{r}_m}{\partial z_m} & \frac{\partial \dot{r}_m}{\partial (ct_{\text{bias}_m})} \end{bmatrix} \tag{3}$$

where r is the pseudorange/range signal (dependent on one-way/two-way navigation system); r_m is the mth observed pseudorange/range signal (dependent on one-way/two-way navigation system); and ct_{bias} is the speed of light multiplied by the clock bias.

Positional dilution of precision (PDoP) provides an estimate of user positioning accuracy for the case in which there is no time bias between orbiter clocks and user clocks, such as the case in a two-way mode of operation. PDoP results in the requirement of three navigation signals. The associated H-matrices and state transition for stationary surface users are

$$\Phi_{PDoP}(t_i, t_o) = I + \begin{bmatrix} 0 & I \\ 0 & 0 \end{bmatrix} \times (t_i - t_o) \tag{4}$$

$$H = \begin{bmatrix} \frac{\partial r_1}{\partial x_1} & \frac{\partial r_1}{\partial y_1} & \frac{\partial r_1}{\partial z_1} \\ \vdots & \vdots & \vdots \\ \frac{\partial r_m}{\partial x_m} & \frac{\partial r_m}{\partial y_m} & \frac{\partial r_m}{\partial z_m} \\ \frac{\partial \dot{r}_1}{\partial x_1} & \frac{\partial \dot{r}_1}{\partial y_1} & \frac{\partial \dot{r}_1}{\partial z_1} \\ \vdots & \vdots & \vdots \\ \frac{\partial \dot{r}_m}{\partial x_m} & \frac{\partial \dot{r}_m}{\partial y_m} & \frac{\partial \dot{r}_m}{\partial z_m} \end{bmatrix} \tag{5}$$

Horizontal/time dilution of precision (HTDoP) is applied when a user has knowledge of his altitude above the center of the Moon but a time bias exists, resulting in the requirement of three navigation signals. The associated H-matrices and state transition for stationary surface users are

$$\Phi_{HTDoP}(t_i, t_o) = I + \begin{bmatrix} 0 & I \\ 0 & 0 \end{bmatrix} \times (t_i - t_o) \tag{6}$$

$$H = \begin{bmatrix} \frac{\partial r_1}{\partial x_1} & \frac{\partial r_1}{\partial y_1} & \frac{\partial r_1}{\partial (ct_{bias_1})} \\ \vdots & \vdots & \vdots \\ \frac{\partial r_m}{\partial x_m} & \frac{\partial r_m}{\partial y_m} & \frac{\partial r_m}{\partial (ct_{bias_m})} \\ \frac{\partial \dot{r}_1}{\partial x_1} & \frac{\partial \dot{r}_1}{\partial y_1} & \frac{\partial \dot{r}_1}{\partial (ct_{bias_1})} \\ \vdots & \vdots & \vdots \\ \frac{\partial \dot{r}_m}{\partial x_m} & \frac{\partial \dot{r}_m}{\partial y_m} & \frac{\partial \dot{r}_m}{\partial (ct_{bias_m})} \end{bmatrix} \tag{7}$$

Horizontal dilution of precision (HDoP) provides an estimate of user positioning accuracy when both the time and user altitude are known, only requiring two navigation signals, such as the case of a two-way mode of operation with good knowledge of terrain. The associated H-matrices and state transition for stationary surface users are

$$\Phi_{HDoP}(t_i, t_o) = I + \begin{bmatrix} 0 & I \\ 0 & 0 \end{bmatrix} \times (t_i - t_o) \tag{8}$$

$$H = \begin{bmatrix} \frac{\partial r_1}{\partial x_1} & \frac{\partial r_1}{\partial y_1} \\ \vdots & \vdots \\ \frac{\partial r_m}{\partial x_m} & \frac{\partial r_m}{\partial y_m} \\ \frac{\partial \dot{r}_1}{\partial x_1} & \frac{\partial \dot{r}_1}{\partial y_1} \\ \vdots & \vdots \\ \frac{\partial \dot{r}_m}{\partial x_m} & \frac{\partial \dot{r}_m}{\partial y_m} \end{bmatrix} \tag{9}$$

System Availability

The underlying figure of merit (FOM) used for evaluating the performance associated with a navigation system is system availability. System availability (SA) is defined herein as the proportion of time that the navigation system is predicted to provide performance at or below a specified level of DoP. In other words, the navigation system is defined as "available" when the appropriately chosen version of DoP falls below a certain threshold. For this study, the threshold is set at 10. Furthermore, a DoP of 10 coupled with a 1-m user range error (URE) implies a user state uncertainty of 10 m, which is sometimes used as a required level of performance for lunar position fixing. System availability is calculated herein for a large number of points on the surface of the Moon. The results provided below are in terms of system availability for a given latency. Equation 10 describes how the system availability

FOM is calculated. This results in an estimate of the percentage of time that the system availability condition has been satisfied. The system availability analysis is performed for the constellations listed in table 1.

$$SA = 100 \times \frac{\sum_{m=1}^{t_n} \cos(lat_m) \times \sum_{n=1}^{t_f} (DoP_{n,m} <= \text{threshold})}{t_f \times n_{\text{long}} \times \sum_{m=1}^{n_{\text{lat}}} \cos(lat_m)} \quad (10)$$

where t_n is the total number of points in the simulation; t_f is the number of time epochs in the simulation, n_{long} is the number of longitude points in the simulation; and n_{lat} is the number of latitude points in the simulation.

Failure System Availability

The failure system availability analysis simulates the event of a total outage of one node of the navigation system for the entire sidereal lunar month duration of the analysis. For the Earth-based assets, any one of the assets in the constellation can be dropped out if the constellation is symmetric. If the constellation is not symmetric, such as the DSNGEO, the failure analysis is performed for each of the sets of nodes (i.e., DSN and GEO). The failure system availability analysis is otherwise identical in procedures and presentation of results to the system availability analysis. This analysis is performed for the constellations listed in table 2.

System Latency

A secondary FOM used for evaluating the performance associated with a navigation system is system latency (SL), which is defined as the latency that is required to obtain the minimum global system availability. For the Global region to meet this minimum system availability, the most appropriate method would be for each point on the surface to also meet this minimum system availability. Therefore, latency is determined at each point on the surface as the amount of integration time in the generalized DoP measurements until the minimum system availability criterion is met. For the analysis presented herein, the minimum system availability used to determine the system latency is 90 percent. Also, it is important to state that the system latency analysis does not include the augmentation of "free-wheeling" (i.e., open-loop clock synchronization) the user clock for 3 hr before the next time synchronization. One final comment is that a maximum system latency of 1440 min (1 day) is allowed in the simulation.

Failure System Latency

The failure system latency analysis simulates the same type of outage as that in the failure system availability analysis, but the type of analysis differs from that performed for the system latency analysis. The failure system latency analysis is otherwise identical in procedures and presentation of results to the system latency analysis. This analysis is performed for the constellations listed in table 2.

Assumptions

Navigation signal.—The navigation signal requirements used in this study are outlined in table 3.

TABLE 3.—NAVIGATION SIGNAL ASSUMPTIONS

Doppler measurements frequency (GPS L1), GHz	1.57545
User range error (URE), m	1
User range rate error (URRE), mm/sec	0.1
Minimum user elevation angle, deg	5

Simulation.—The lunar surface is taken as a set of 600 points on the surface, spaced evenly in latitude and longitude. The longitudes for the points go from −180° to 180° in 15° increments, and the latitudes of the points go from −90° to 90° in 7.5° increments. Technically, this grid of points results in 625 points of interest, but the points at 180° longitude are at the same location as the points at −180° longitude, so one set of the 25 points is removed for the sake of not duplicating and not biasing the results. The analysis is performed over the duration of 1 lunar sidereal month (27.3 Earth days) where DoPs are calculated at an epoch rate of 5 min. The starting epoch for the simulations is July 15, 2009 00:00:00.000 GMT. Visibility to the constellations from the surface points is computed based on a 5° minimum user elevation angle.

User burden.—Receivers that support a reduced number of satellites will have associated with them an increased level of processing or other sensing equipment. This situation leads to increased user burden in terms of the mass and power the host platform must provide to the navigation receiver. To provide knowledge sufficient to infer user altitude given a horizontal location, a large digital elevation map would have to be available to the user. To provide an error comparable to the 1-m URE assumed for the system, the user is required to store approximately 1 TB of terrain data for global coverage. For the user to have knowledge of terrain within a 30-km radius of a starting point, approximately 100 MB is required for storage.

For a navigation system using one-way radiometric signals as a mode of operation, the clock synchronization assumption implies that the clocks would have to be stable enough to have the ability to free-wheel for a number of hours after synchronization. User clocks would then require periodic synchronization with orbiting clocks. The threshold used to synchronize the clock is a GDoP ≤ 5 with no knowledge of the terrain or an HTDoP ≤ 5 with good knowledge of terrain. Therefore, a requirement would be imposed of four and three measurements, respectively. The reduced DoP value from 10 to < 5 is assuming that the transfer of time would require a more

accurate solution than is nominally needed. The availability analyses are performed assuming a clock resynchronization period of 3 hr. The low mass, volume, and power expected for highly stable oscillators will make this system a viable option. The clock synchronization is not a requirement when using two-way radiometric navigation signals for the system's mode of operation. Table 4 lists the forms of DoP used in the analysis together with their corresponding assumed system requirements.

TABLE 4.—DoP ASSUMPTIONS SUMMARY

Knowledge of terrain	Synchronized clock	DoP requirement	Number of measurements required
No	No	GDoP 10	4
Yes	No	HTDoP 10	[a]3
No	Yes/(two way)	PDoP [b]10	3
Yes	Yes/(two way)	HDoP [c]10	[a]2

[a]Terrain knowledge of latitude and longitude.
[b]If one-way GDoP, five required to synchronize clock.
[c]If one-way HTDoP, five required to synchronize clock.

Results

Results are reported as the four system analyses (system availability, failure system availability, system latency, and failure system latency) and are presented in tabular form for selected areas on the face of the Moon:

1. Global: all latitudes and longitudes; entire lunar surface coverage
2. South pole: latitudes within 10° of the lunar south pole; all longitudes
3. Front equatorial: latitudes from 45° N to 45° S; longitudes from 90° W to 90° E (near side)
4. Backside: all latitudes and longitudes pertaining to the far side of the Moon
5. Apollo: Latitudes and longitudes within the bounds of the landed Apollo missions

The south pole analysis is performed to determine the system availability in the context of Lunar Outpost missions that are expected to focus on concentrated exploration of the south pole. The front equatorial analysis is provided in the context of extended Apollo-like missions. The backside analysis illustrates the problems (due to lack of visibility) of using only Earth-based assets. Finally, the Apollo region gives information about the actual Apollo landing sites.

The term "no terrain" indicates that there is no detailed cartography of the terrain that would allow determining the altitude of the user. The term "good terrain" indicates that there is such knowledge and that an accurate estimate of user altitude above the lunar datum is available to the navigation receiver. The term "no clock" indicates that the user clocks and orbiter clocks are not synchronized, and the term "good clock" indicates that the clocks are synchronized and remain so for a specific number of hours (indicated by τ), given a GDoP or HTDoP less than or equal to 5. If the system is operating in a two-way mode, then the concepts associated with GDoP or HTDoP do not apply.

For the system availability and failure system availability analyses, results are summarized in stoplight charts, which show the performance of each of the constellations proposed herein in terms of the latency required to achieve 90-percent system availability over a specified region of the surface of the Moon. Table 5 shows the correlation between color and latency. Note that a box shaded gray indicates that the constellation does not meet the 90-percent system availability within 12 hr. It does not mean that the system does not meet the 90-percent system availability at all; it indicates that it will take more than 12 hr to do so.

TABLE 5.—STOPLIGHT CHART COLOR TO LATENCY CONVERSION

Color	Sample	Latency
Dark green		0 min
Light green		15 min
Light yellow		1 hr
Dark yellow		2 hr
Orange		4 hr
Pink		8 hr
Red		12 hr
Grey		>12 hr

Appendix B illustrates the performance of the various constellations given the various DoPs and integration periods. The images shown in this appendix are the system availabilities for the 15 Earth-based asset constellations. Each constellation on each image is superimposed over a gray-scale image of the Moon's surface with the center of the image being the latitude-longitude pair of (0° N, 0° E). The black colors on the superimposed system availabilities imply 0 percent. However, as the colors move from black, to red, to yellow, to white, the system availabilities go up to 100 percent. Below each figure is a table that lists the system availabilities for the five regions identified above. A second table is presented for the failure system availability analysis and lists the losses in system availability from the nonfailure mode analysis.

For the system latency and failure system latency analyses, results cannot be summarized in a stoplight chart as they were for the system availability analyses. The reason is that the variable in the system latency analyses is the integration time, unlike the system availability analyses in which set latencies were in place. However, results can be plotted and tabulated similarly to the system availability analyses and are done so in appendix C. Again, the results of the system latency analysis are superimposed over a gray-scale image of the Moon's surface with the center of the image being the latitude-longitude pair of (0° N, 0° E). However, the superimposed system latencies are dependent on the overall system latency range for the set of plots. The longest latency will be identified and will be shaded black. As the latencies decrease to 0 min (kinematic position fixes), the shading will go from black, to

red, to yellow, and then to white. Below each figure is a table that lists the system latencies for the five regions identified earlier in this section. A second table is given for the failure system latency analysis and lists the increases in system latency from the nonfailure mode analysis.

System Availability Results

Figure 1 shows the stoplight chart of the performance of each of the systems proposed in this report in terms of the latency required to achieve a 90-percent system availability over a specified region of the surface of the Moon. Inspection of the latency result summary provided in figure 1 reveals three overall general trends apparent in each of the identified lunar regions. The first general trend is that latency improves for a given constellation as the augmentations are added. In particular, the improvement in performance brought by knowledge of user altitude alone is significantly greater than that brought by a highly stable user clock alone. Using a highly stable user clock together with knowledge of user altitude provides significant improvements over knowledge of user altitude alone. The second general trend observed for each identified region is that the system performance improves with an increase in visibility to the constellation. This means that for the DSN constellations, the system availability increases when a lower minimum provider elevation angle is required; for the GEO constellations, the system availability increases with an increase in the overall beam width from each satellite. One notable exception to this trend is the apparent decrease in system availability when going from the GEO 150/30 to the GEO 90/90. Both constellations have 180° of beam width; however, because the zenith beam width is larger in the first constellation, there are fewer blockages due to the Earth of the overall beam width.

The third general trend for the one-way and two-way modes of operation is that the two-way mode is better able to provide a navigation solution in all the regions. The results in appendix B show improvements in system availability above the

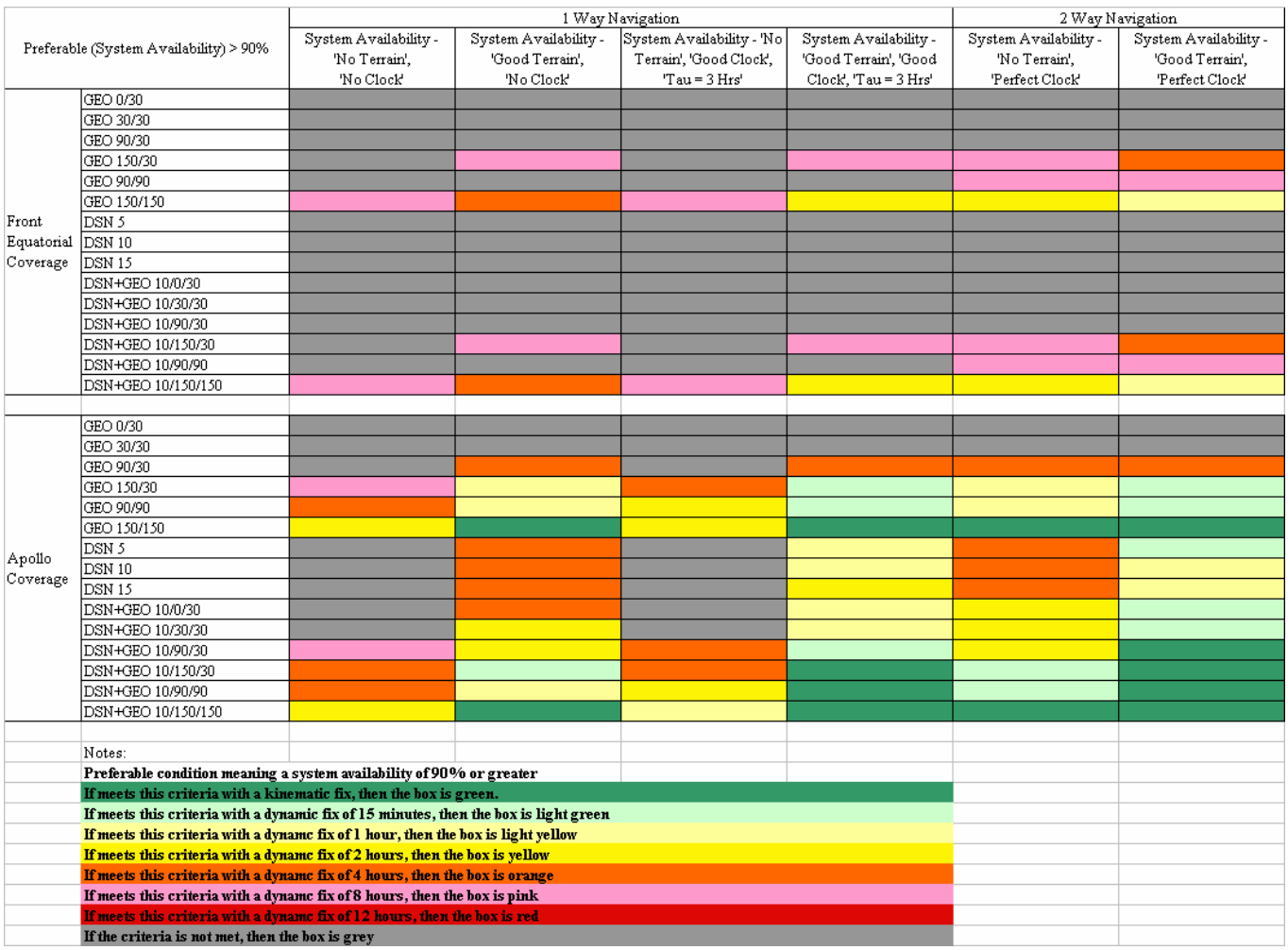

Figure 1.—Stoplight chart for system availability results.

90-percent threshold in the stoplight chart for the two-way system over that of the one-way system. The analysis shows that when using a two-way system without terrain information, the GEO 150/150 and the DSNGEO 10/150/150 constellations can give kinematic navigation solutions at or above 90 percent of the time over the Apollo region, whereas the DSNGEO 10/90/30, DSNGEO 10/150/30, and DSNGEO 10/90/90 require terrain information. No constellations can provide kinematic position fixes 90 percent of the time over the front equatorial region.

Another interesting result is that of the constellations currently in place, DSN and GEO 0/30 do not meet the 90-percent system availability in the front equatorial region within 12 hr, and only the DSN 5 and DSNGEO 10/0/30 can meet the 90-percent system availability in the Apollo region with a 15-min integration period. The DSN 10 and DSN 15 constellations meet the 90-percent system availability with a 1-hr integration period. The GEO 0/30 does not meet the 90-percent system availability within the 12-hr integration period.

It is important to note that the global, south pole, and backside regions are not shown in the stoplight chart because none of the constellations reached the 90-percent system availability after the 12-hr integration period. The reason for this result is that the lack of visibility on the lunar far side prevents this side from reaching the 90-percent system availability. However, the global and south pole regions can almost reach a 50-percent system availability, which corresponds to that of the lunar near side. It should also be noted that the sensitivity of latency to the overall visibility is higher for the kinematic solutions than for the dynamic solutions up to 12 hr.

Failure System Availability Results

Figure 2 shows the stoplight chart of the performance of each of the systems proposed in this report in terms of the latency required to achieve a 90-percent system availability over a specified region of the surface of the Moon for the single-mode failure constellations.

The total loss of one asset resulted in all constellations (except the DSNGEO 10/150/150) losing significant performance in the Apollo region. In the front equatorial region, all constellations suffer degradation in performance. However, there is still sensitivity to the overall beam width within each constellation, just as there was in the nonfailure mode of operation. For the front equatorial region, there are no constellations with any augmentation scheme that can provide the 90-percent system availability with latency less than 2 hr. For the Apollo region, the constellations that can provide the 90-percent system availability kinematically in the one-way mode with both augmentations or in the two-way mode with terrain information are the GEO 150/150, DSNGEO 10/150/30–v1, DSNGEO 10/90/90–v1, and DSNGEO 10/150/150–v1 constellations. Additional comparisons can be made from the data presented in appendix B.

System Latency Results

The results provided in appendix C for the 90-percent system availability requirement reveal the same trends that were seen in the system availability analysis. In general, the latency to reach the minimum system availability decreases for a given constellation as the various augmentations are added. These results are similar to the way the augmentations affected the system availability results. The other general trend observed for each identified region is that the system latency decreases with an increase in the overall beam width in the constellation. One notable exception to this trend is seen for the DSNGEO 10/90/90, which provides lower performance than the DSNGEO 10/150/30.

The general trend seen in a comparison of the one-way and two-way modes of operation is that the two-way mode of operation provides lower system latencies than does the one-way mode. This result is again consistent with the those of the system availability analysis. Also, the general trend relating to having and not having terrain information is that having terrain information improves system latency in the same manner as it improves system availability.

It is important to note the difference between the system availability analysis and the system latency analysis. In the system availability analysis, the DSNGEO 10/150/150 could provide 90.24-percent system availability for the front equatorial region using a one-way system without terrain information or clock synchronization if the latency were 8 hr. This 90.24-percent availability does not mean that every point on the surface has an availability of 90.24 percent, but that the spatially weighted availability for all points in the region is 90.24 percent. However, for the system latency analysis, there is a strict requirement that all points on the surface have a 90-percent system availability, and then the latency to achieve such availability is determined for all points in each region. This results in a spatially weighted system latency of 327.7 min (roughly 6.5 hr). However, this 327.7-min latency is not a multiple of the measurement epoch, so it is apparent that some of the surface points have a higher latency whereas others have a lower latency. More comparisons that are similar to these can be made from the data in appendix C.

Failure System Latency Results

Results for the failure system latency analysis to meet the 90-percent system availability requirement are also shown in appendix C. The tables in appendix C show the weighted system latency increases due to the total loss of one asset. It should be noted that for any region, increases in weighted system latency do not appear to have a correlation to beam width for the constellation. The reason is that the limit on the latency is set at 1440 min (1 day). If the simulations were allowed to run for longer durations, it is expected that the correlation with beam width would become apparent.

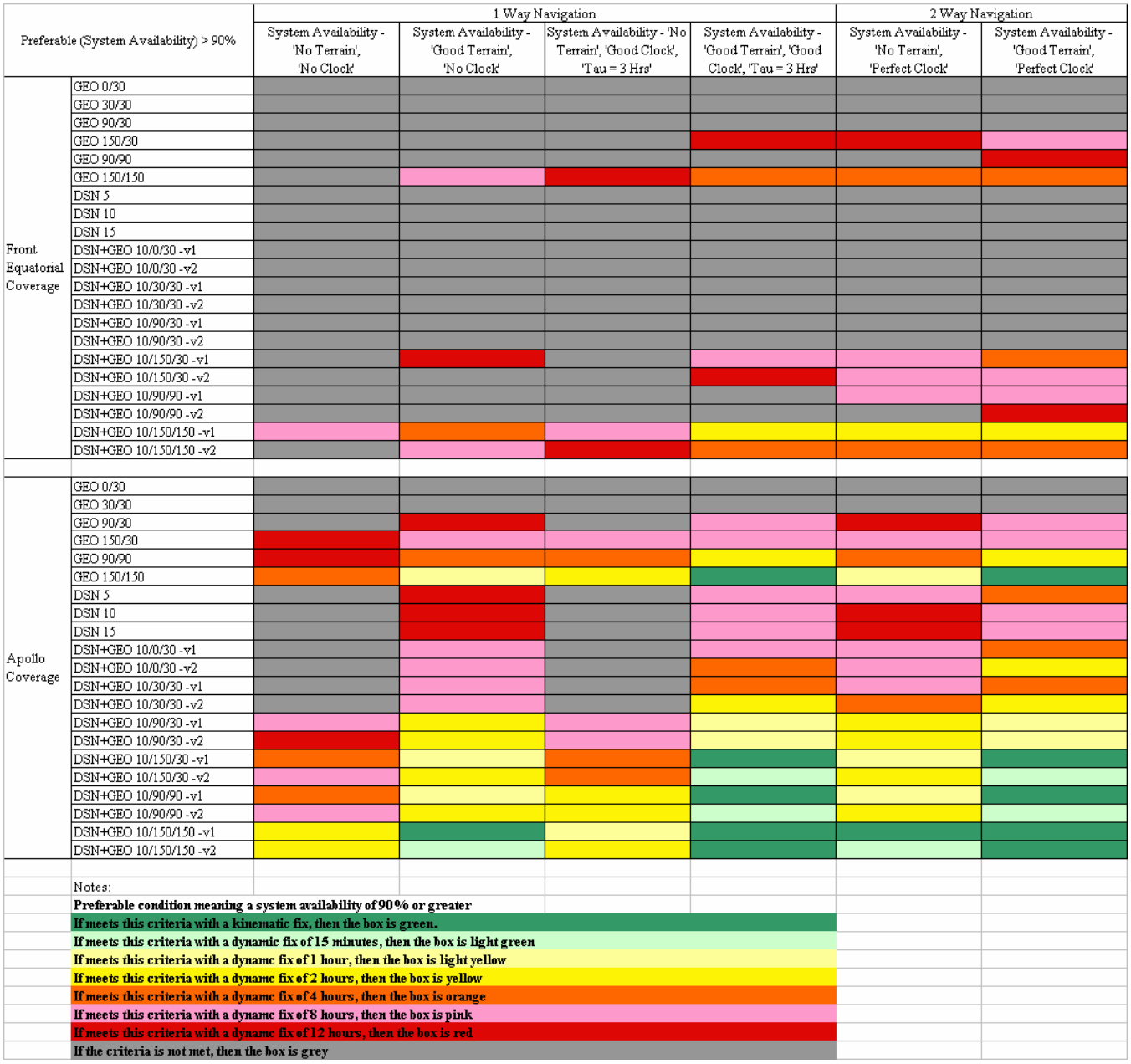

Figure 2.—Stoplight chart for failure system availability results.

Increases in weighted system latency for the one-way mode of operation without terrain information in the Apollo region ranged from 0 to about 354 min (GEO 90/90). However, for the front equatorial region, increases in weighted system latency ranged from 0 to about 286 min (GEO 90/90). With the system in a two-way mode of operation with terrain information for the Apollo region, constellations had weighted system latency increases from 0 to about 326 min. However, for the front equatorial region, increases in weighted system latency ranged from 0 to up to 259 min. Many more comparisons similar to these can be made from the data in appendix C.

Conclusions

Generalized DoP allows the effects of multiple radiometric measurements to be assessed in the same manner that standard measures of DoP are used. In the current case, the effect of integrating multiple radiometric measurements in time is assessed to allow the performance of sparse constellations around the Moon to be compared with fully populated constellations that provide only kinematic solutions. With this innovation, the basis of comparison can be changed to a domain that is more closely aligned with user requirements, namely,

the latency associated with achieving a particular level of precision in the state estimate.

A restriction to the use of kinematic solutions, as is done with analysis based on static DoP, biases the selection of a constellation to those with more satellites. The use of dynamic solutions allows for integrating radiometric signals over a period of time to improve the system availability and thus allows for the consideration of constellations with fewer satellites. The application of generalized DoP for the evaluation of inherent navigation capability of constellations of Earth-based assets has thereby eliminated this bias. The analysis method described herein has thus resulted in a set of recommendations for the use of Earth-based assets to perform lunar surface navigation.

Inspection of the result summaries reveals a general trend in the front equatorial and the Apollo regions: the performance of the kinematic system is significantly improved by the prescribed augmentations. In general, system latency decreases for a given constellation as the augmentations are added. In particular, although using a highly stable clock for the user receiver brings about an improvement in performance, the improvement in performance brought by the knowledge of user altitude alone is significantly greater than that brought by a stable user clock. Additionally, note that using a stable user clock together with knowledge of user altitude provides significant improvements over knowledge of user altitude alone. Thus, the two pieces of information appear to be uncorrelated. Increasing the beam width for the GEO satellites had a greater impact for the zenith angle than for the nadir angle. Also, increasing the minimum provider elevation angle requirement degraded the performance of the DSN constellations. Finally, changing the mode of operation of the constellation into failure mode also severely degraded the performance of the constellations, with the DSNGEO constellations having better performance in the first version (with a DSN asset removed) compared with the second version (with a GEO asset removed).

The DSNGEO 10/150/150 Com/Nav constellation offered very good performance (two-way-mode kinematic position fixes) from a navigation-only perspective, although over specified when communication considerations were taken into account. When both navigation and communications considerations were taken into account, however, the GEO 150/150 was the desired constellation. These statements are only true in the Apollo region, as in the front equatorial region, the latency to meet the 90-percent system availability threshold is 2 hr without terrain information and 1 hr with terrain information. If the solution is based on global coverage, then none of these constellations would be acceptable because of the lack of coverage on the lunar far side and the limited coverage near the lunar poles.

Based on using currently available assets, the best performance was in the Apollo region operating in two-way mode with terrain information coming from the DSN 5 with a latency of 8 hr to reach the 90-percent system availability criterion. For the front equatorial region, none of the currently available Earth-based assets could reach the 90-percent system availability. It is not recommended that any of these constellations be evaluated any further because their performance is limited to the Apollo regions.

Appendix A—Earth-Based Assets

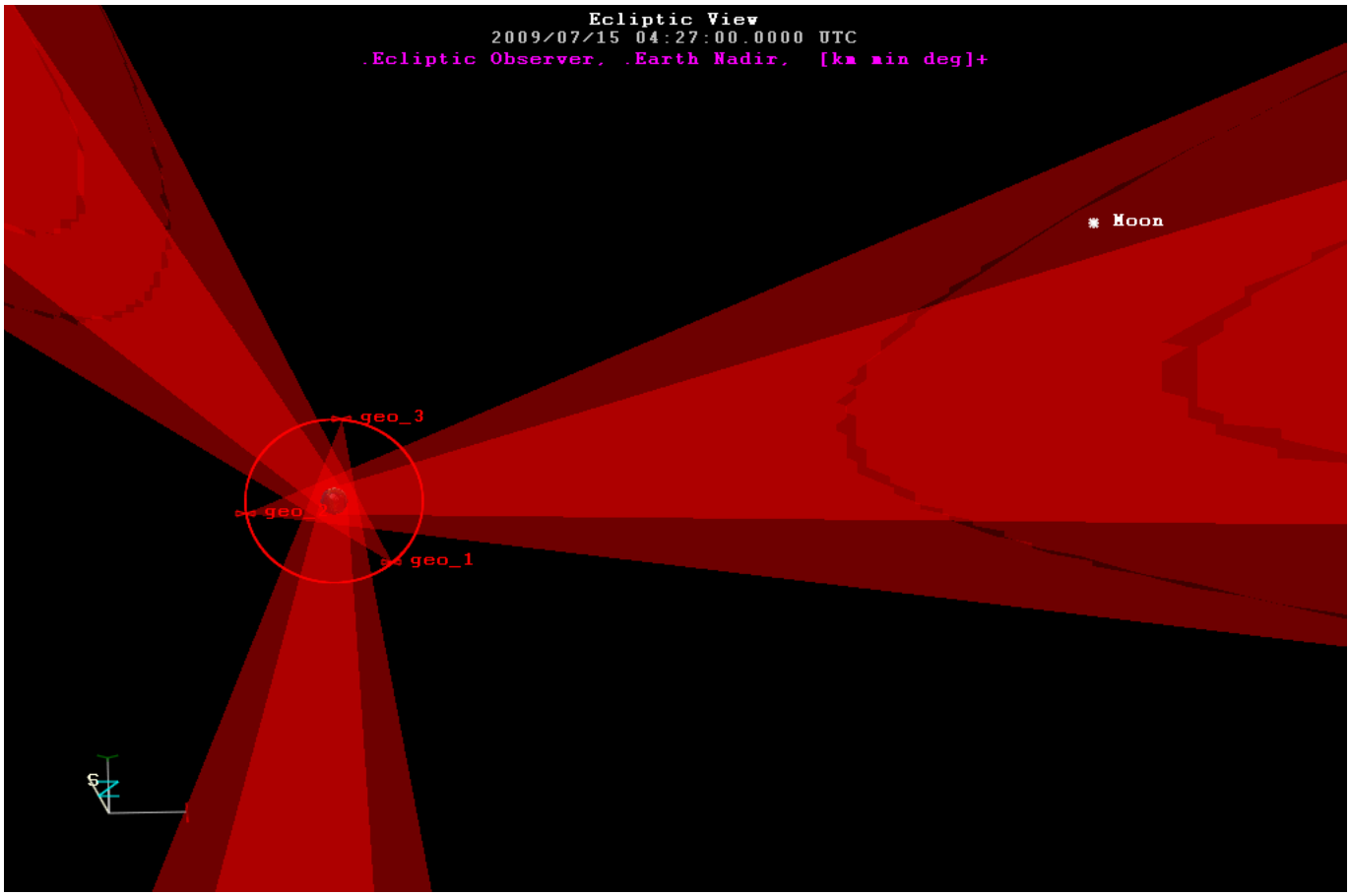

Figure A.1.—GEO 0/30.

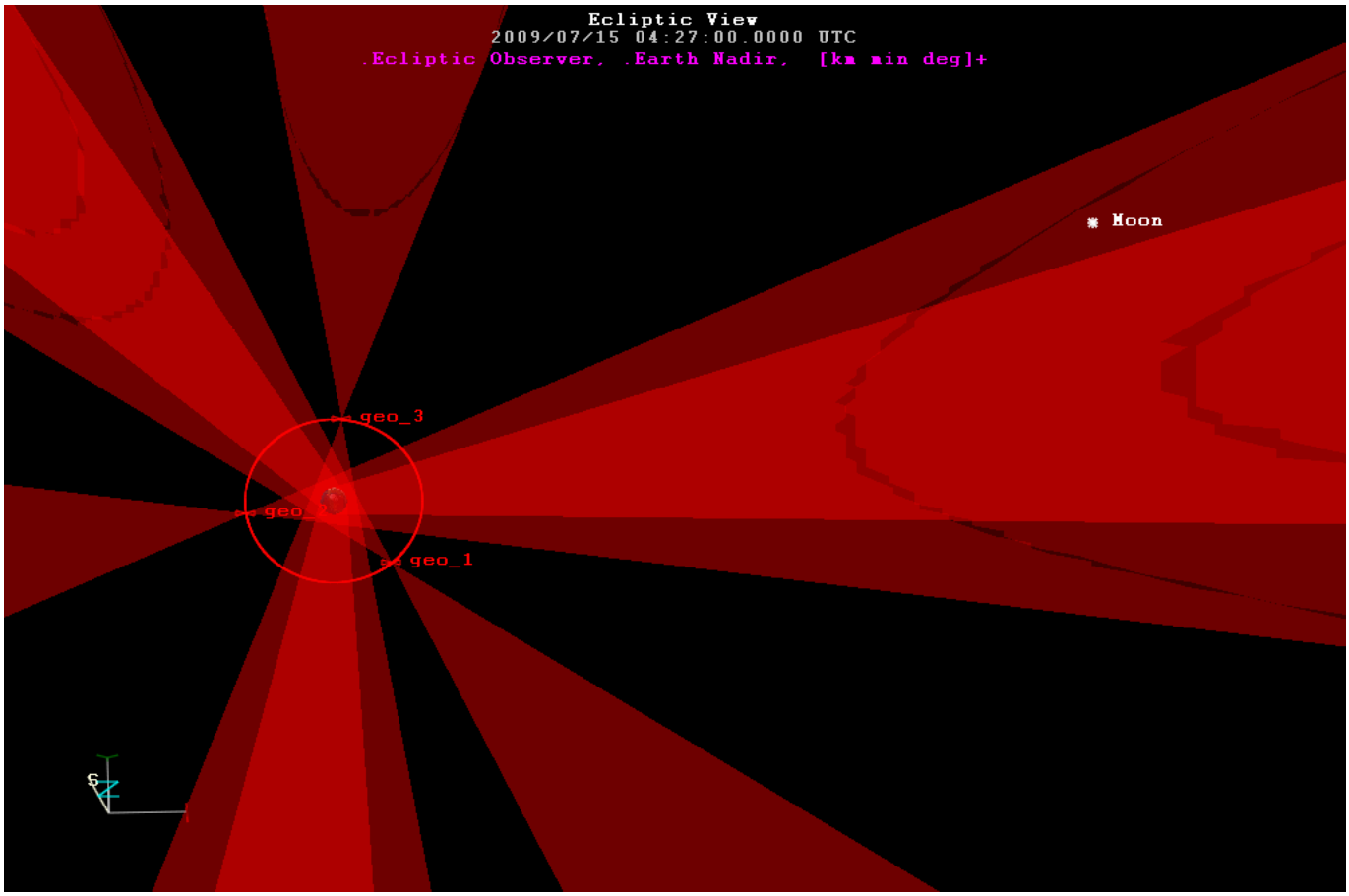

Figure A.2.—GEO 30/30.

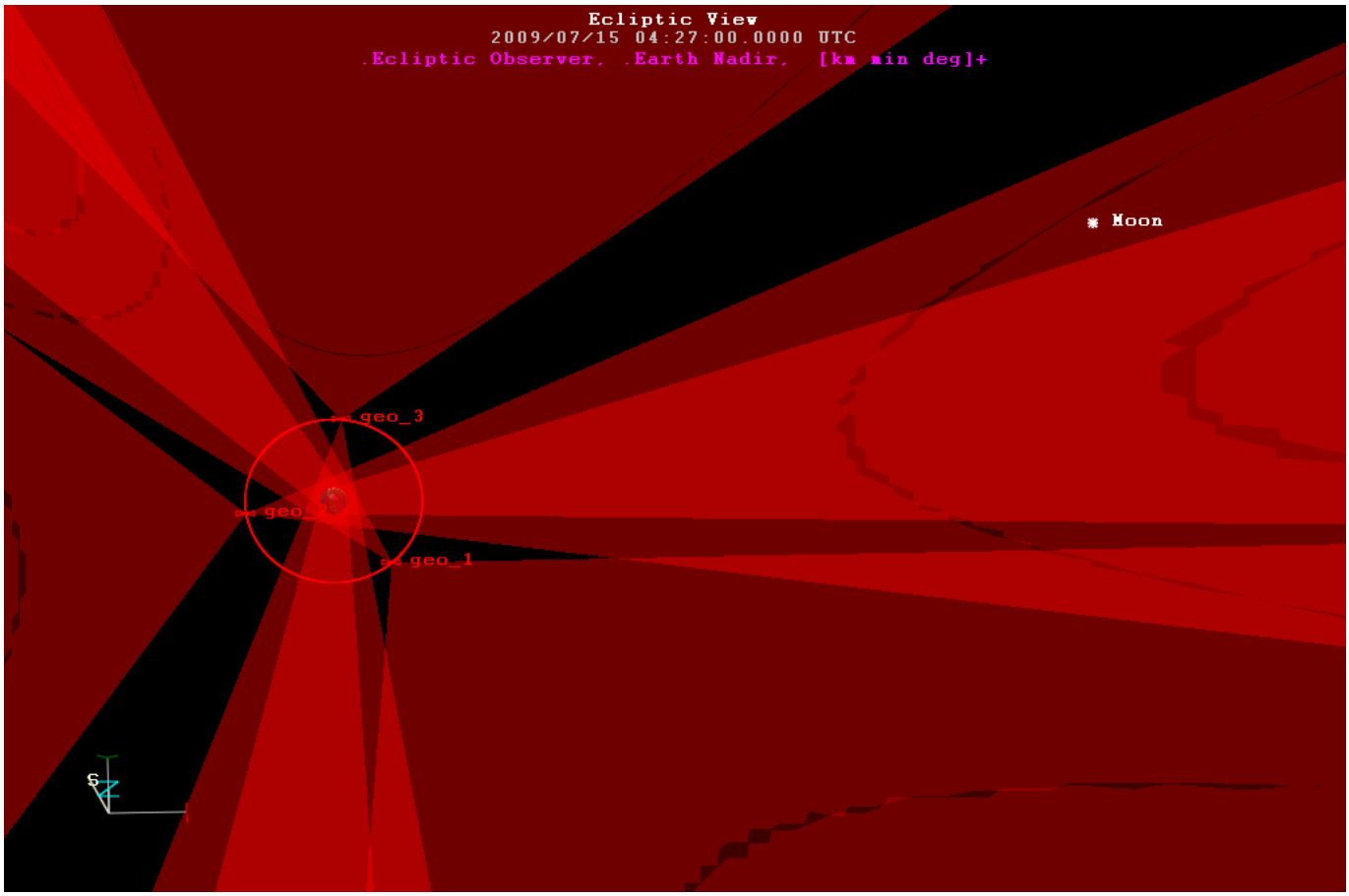

Figure A.3.—GEO 90/30.

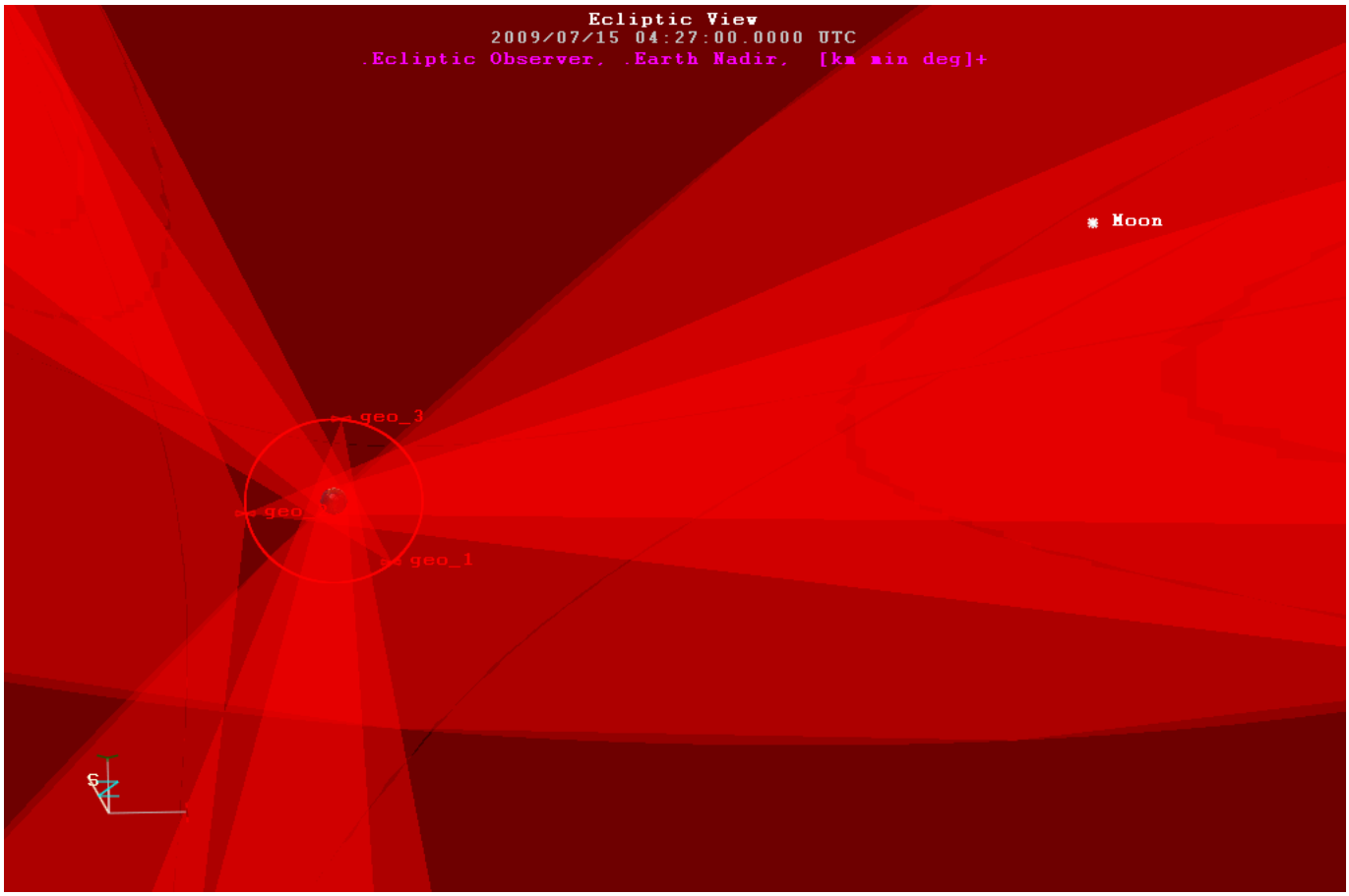

Figure A.4.—GEO 150/30.

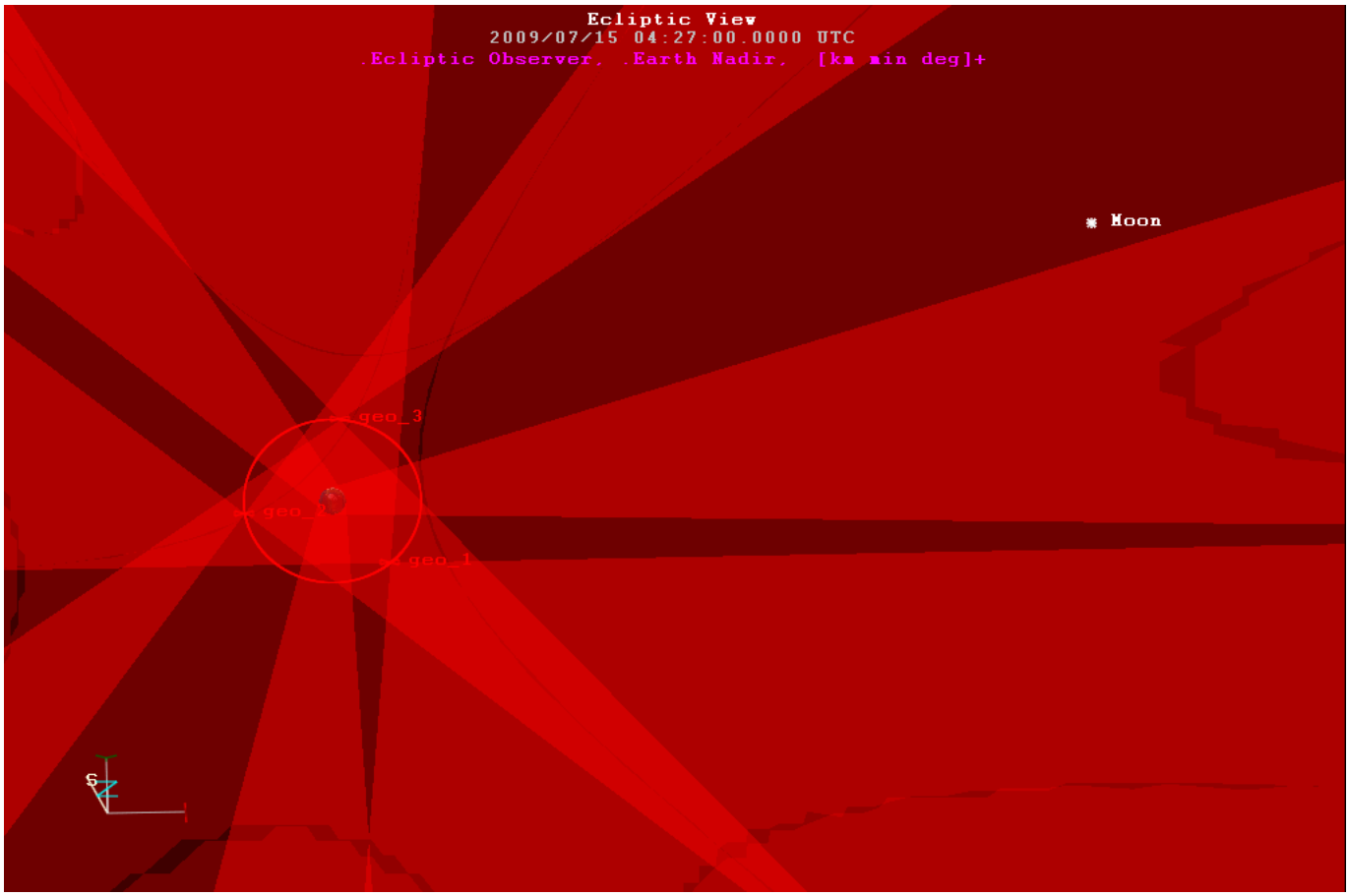

Figure A.5.—GEO 90/90.

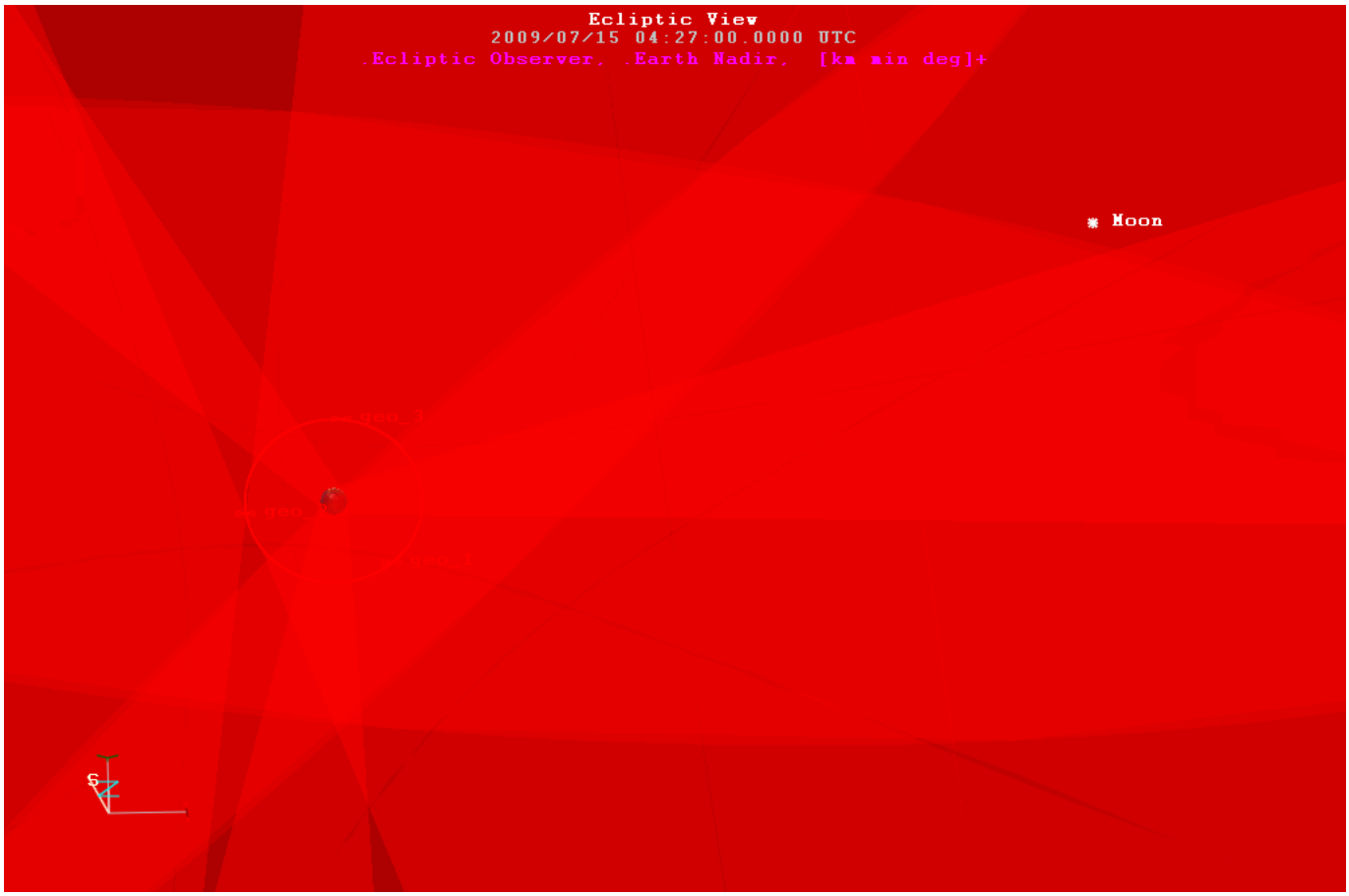

Figure A.6.—GEO 150/150.

Figure A.7.—DSN 5.

Figure A.8.—DSN 10.

Figure A.9.—DSN 15.

Appendix B—System Availability/Failure System Availability Results

B.1 No Terrain, No Clock, One-Way Mode

B.1.1 Kinematic.—Figures B.1.1.1 to B.1.1.3 show the system availability results for the 15 Earth-based constellations when the system is operating in one-way mode without terrain information or clock synchronization (solving with kinematic measurements). Table B.1.1.1 tabulates the weighted system availabilities from figures B.1.1.1 to B.1.1.3. Table B.1.1.2 tabulates the losses in system availability that occur as the result of losing a single asset (derived from the failure system availability analysis).

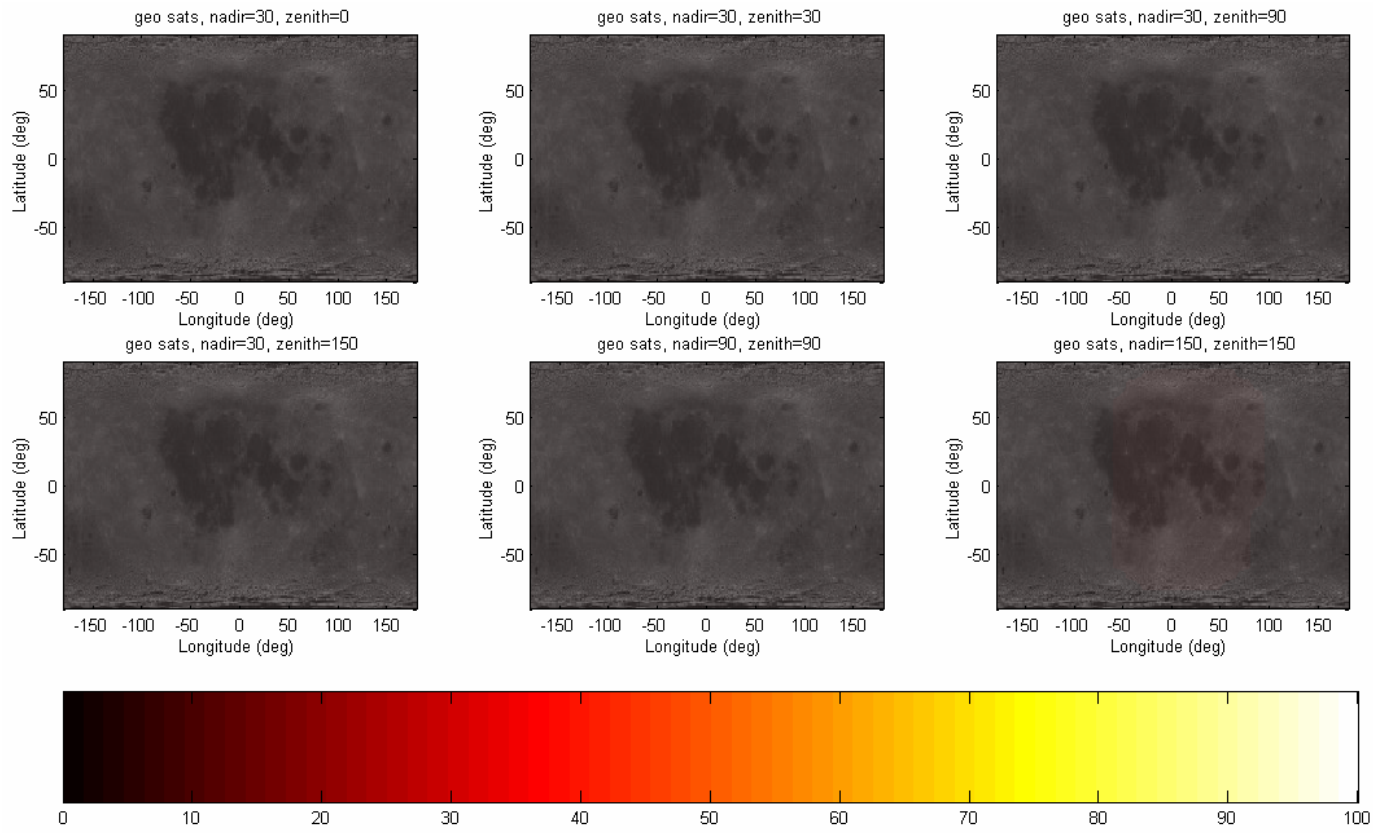

Figure B.1.1.1.—GEO system availability results.

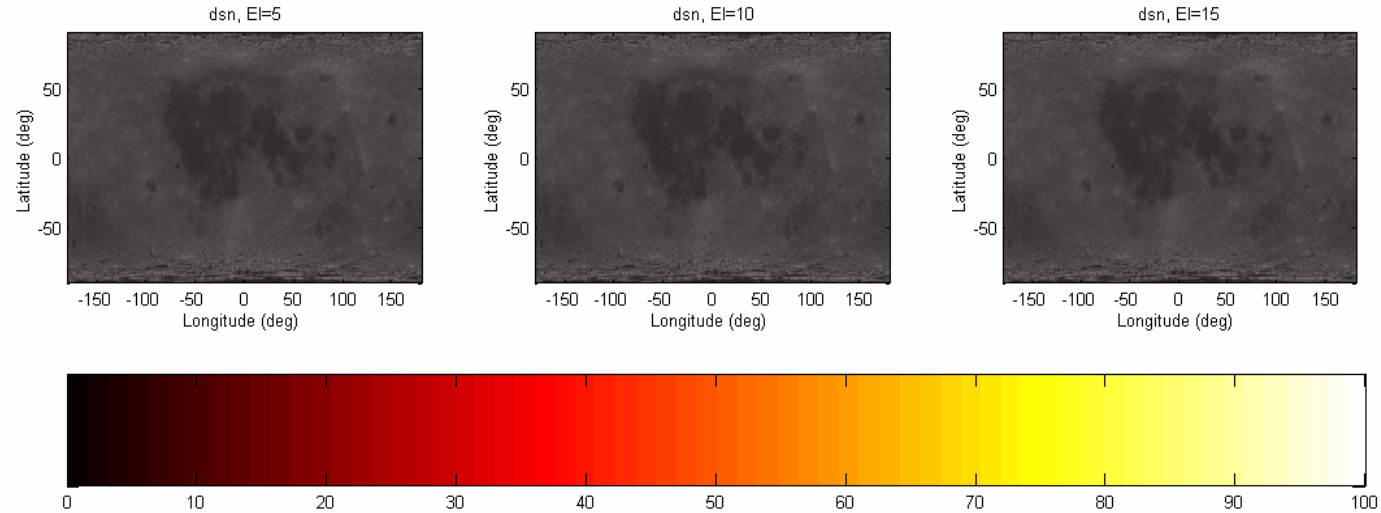

Figure B.1.1.2.—DSN system availability results.

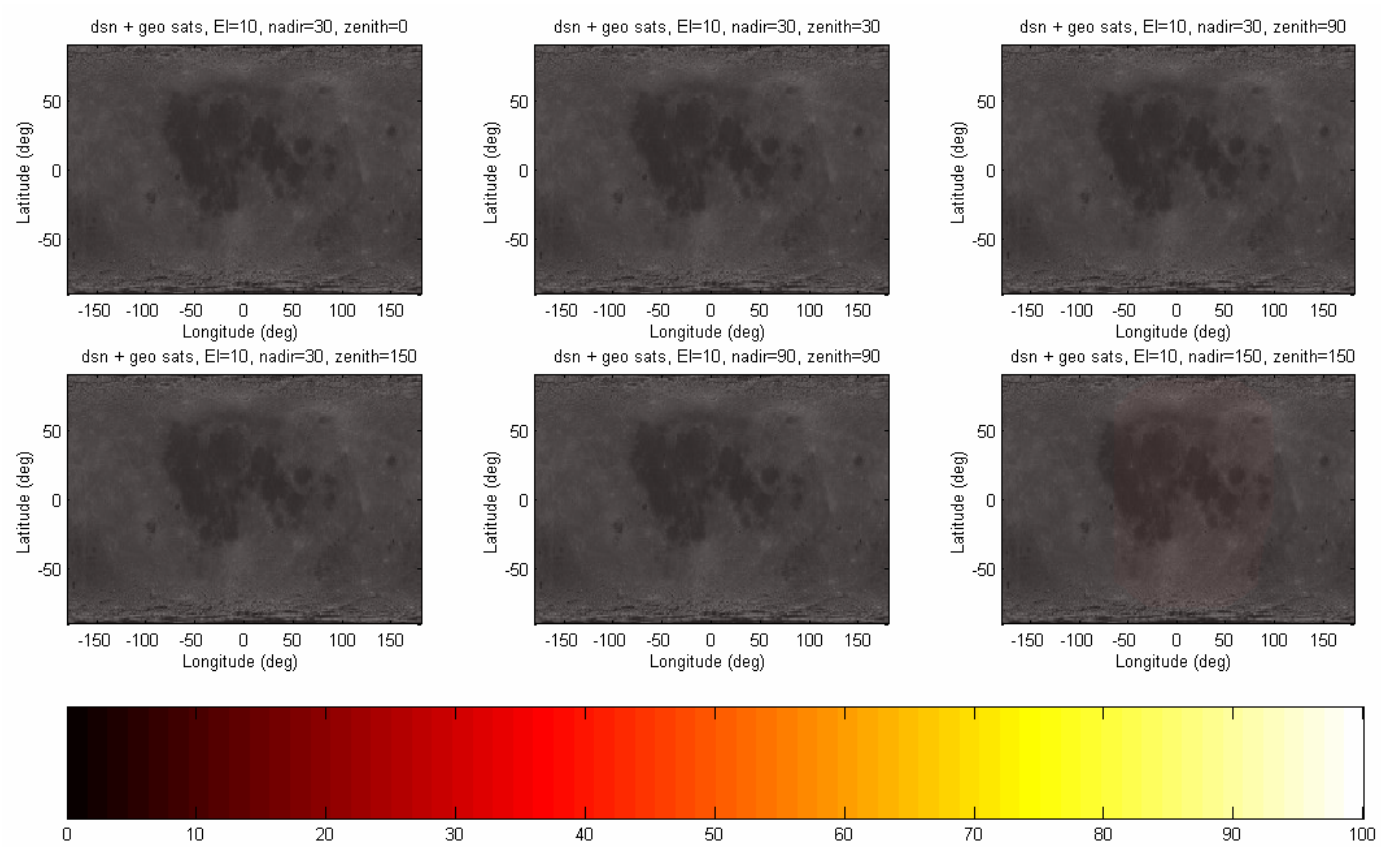

Figure B.1.1.3.—DSNGEO system availability results.

TABLE B.1.1.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	0.00	0.00	0.00	0.00	0.00
GEO 90/30	0.00	0.00	0.00	0.00	0.00
GEO 150/30	0.00	0.00	0.00	0.00	0.00
GEO 90/90	0.00	0.00	0.00	0.00	0.00
GEO 150/150	0.83	0.00	1.59	0.00	1.93
DSN 5	0.00	0.00	0.00	0.00	0.00
DSN 10	0.00	0.00	0.00	0.00	0.00
DSN 15	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/30/30	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/90/30	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/150/30	0.07	0.00	0.13	0.00	0.15
DSN+GEO 10/90/90	0.01	0.00	0.02	0.00	0.03
DSN+GEO 10/150/150	1.18	0.01	2.25	0.00	2.71

TABLE B.1.1.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	0.00	0.00	0.00	0.00	0.00
GEO 90/30	0.00	0.00	0.00	0.00	0.00
GEO 150/30	0.00	0.00	0.00	0.00	0.00
GEO 90/90	0.00	0.00	0.00	0.00	0.00
GEO 150/150	0.83	0.00	1.59	0.00	1.93
DSN 5	0.00	0.00	0.00	0.00	0.00
DSN 10	0.00	0.00	0.00	0.00	0.00
DSN 15	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30 -v2	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/30/30 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/30/30 -v2	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/90/30 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/90/30 -v2	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/150/30 -v1	0.04	0.00	0.07	0.00	0.07
DSN+GEO 10/150/30 -v2	0.07	0.00	0.13	0.00	0.15
DSN+GEO 10/90/90 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/90/90 -v2	0.01	0.00	0.02	0.00	0.03
DSN+GEO 10/150/150 -v1	0.14	0.01	0.25	0.00	0.29
DSN+GEO 10/150/150 -v2	0.75	0.01	1.44	0.00	1.73

B.1.2 Dynamic (15 min).—Figures B.1.2.1 to B.1.2.3 show the system availability results for the 15 Earth-based constellations when the system is operating in one-way mode without terrain information or clock synchronization (solving with 15-min dynamic measurements). Table B.1.2.1 tabulates the weighted system availabilities from figures B.1.2.1 to B.1.2.3. Table B.1.2.2 tabulates the losses in system availability that occurred as the result of losing a single asset (derived from the failure system availability analysis.

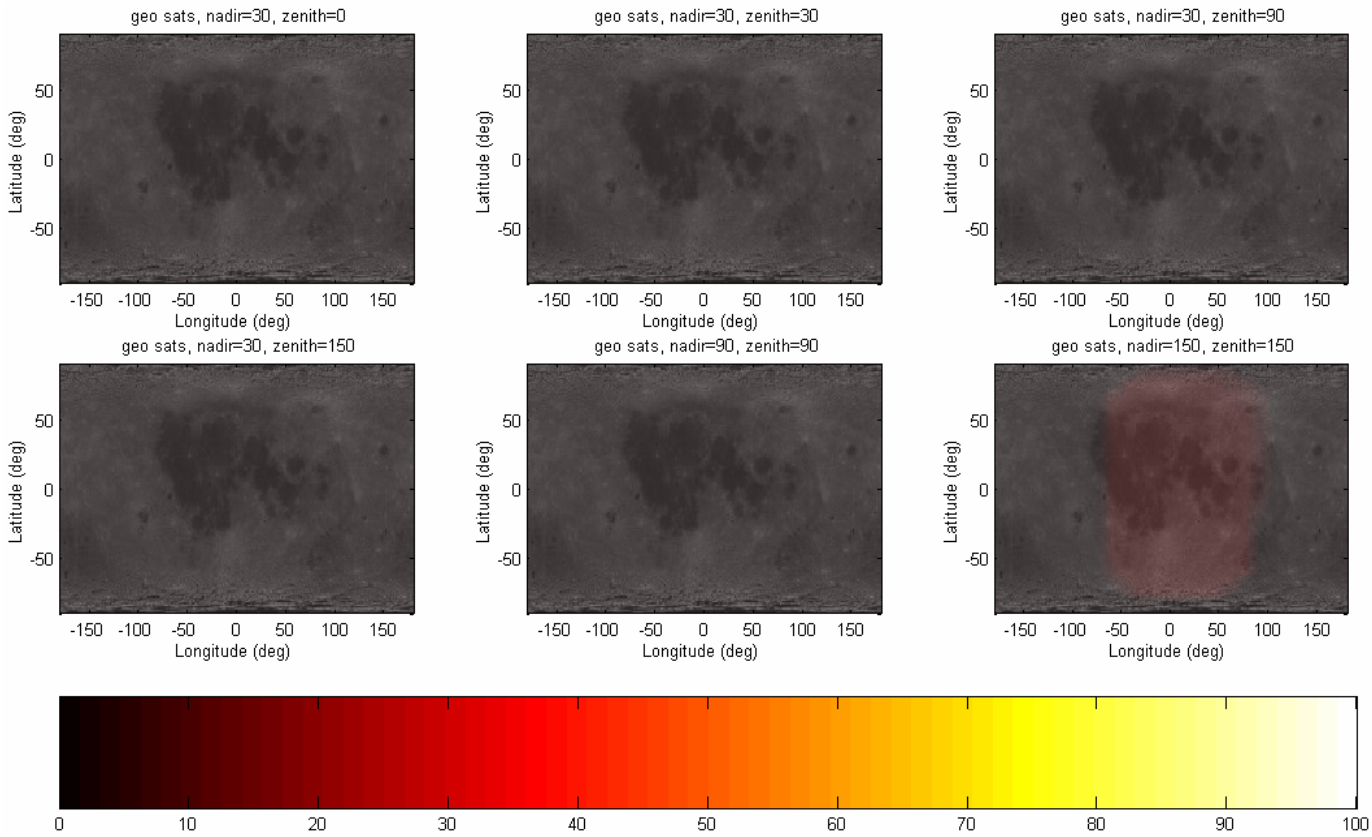

Figure B.1.2.1.—GEO system availability results.

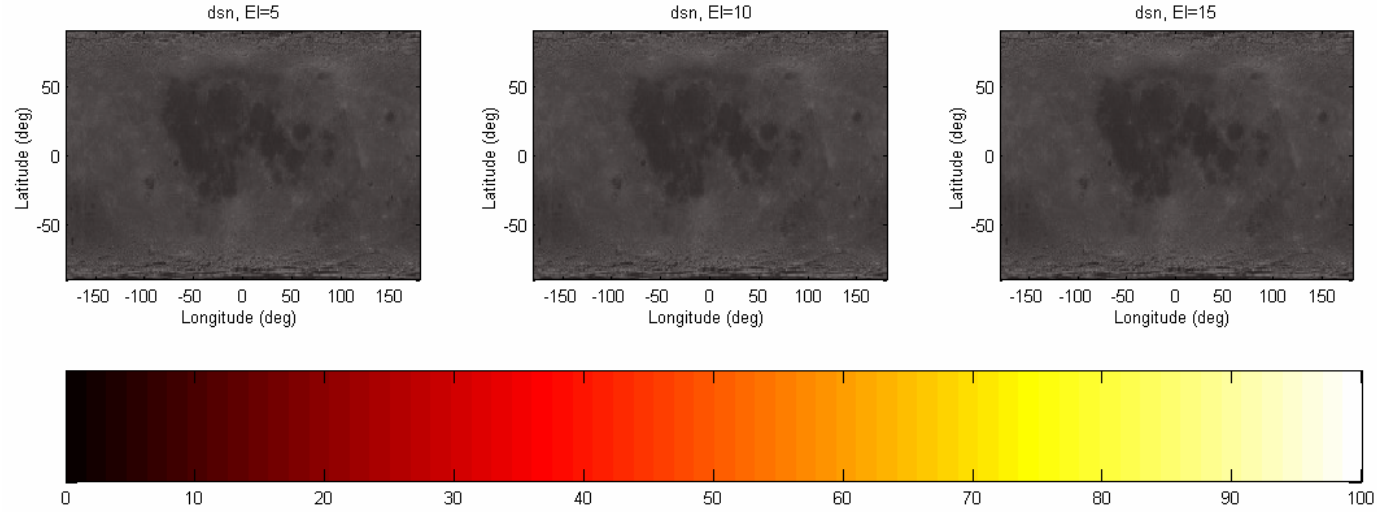

Figure B.1.2.2.—DSN system availability results.

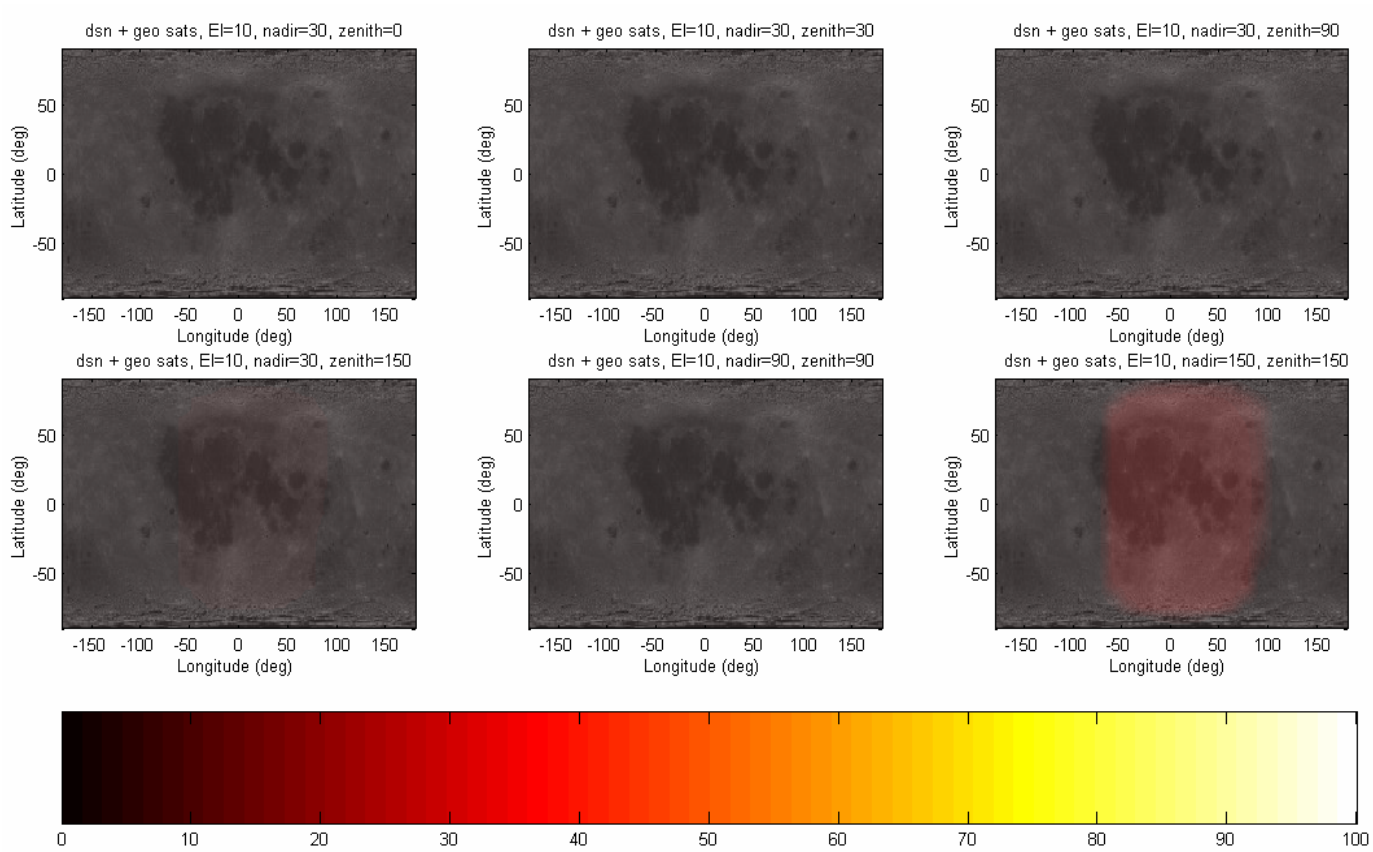

Figure B.1.2.3.—DSNGEO system availability results.

TABLE B.1.2.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	0.00	0.00	0.00	0.00	0.00
GEO 90/30	0.00	0.00	0.00	0.00	0.00
GEO 150/30	0.24	0.00	0.45	0.00	0.56
GEO 90/90	0.00	0.00	0.00	0.00	0.00
GEO 150/150	2.83	0.20	5.40	0.00	6.72
DSN 5	0.00	0.00	0.00	0.00	0.00
DSN 10	0.00	0.00	0.00	0.00	0.00
DSN 15	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/30/30	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/90/30	0.01	0.00	0.01	0.00	0.01
DSN+GEO 10/150/30	0.80	0.00	1.52	0.00	1.87
DSN+GEO 10/90/90	0.49	0.02	0.94	0.00	1.13
DSN+GEO 10/150/150	4.51	0.61	8.61	0.00	10.58

TABLE B.1.2.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES
FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	0.00	0.00	0.00	0.00	0.00
GEO 90/30	0.00	0.00	0.00	0.00	0.00
GEO 150/30	0.24	0.00	0.45	0.00	0.56
GEO 90/90	0.00	0.00	0.00	0.00	0.00
GEO 150/150	2.83	0.20	5.40	0.00	6.72
DSN 5	0.00	0.00	0.00	0.00	0.00
DSN 10	0.00	0.00	0.00	0.00	0.00
DSN 15	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30 -v2	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/30/30 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/30/30 -v2	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/90/30 -v1	0.01	0.00	0.01	0.00	0.01
DSN+GEO 10/90/30 -v2	0.01	0.00	0.01	0.00	0.01
DSN+GEO 10/150/30 -v1	0.18	0.00	0.33	0.00	0.41
DSN+GEO 10/150/30 -v2	0.56	0.00	1.06	0.00	1.32
DSN+GEO 10/90/90 -v1	0.17	0.02	0.33	0.00	0.41
DSN+GEO 10/90/90 -v2	0.35	0.02	0.67	0.00	0.81
DSN+GEO 10/150/150 -v1	0.61	0.17	1.17	0.00	1.40
DSN+GEO 10/150/150 -v2	2.77	0.56	5.30	0.00	6.55

B.1.3 Dynamic (1 hr).—Figures B.1.3.1 to B.1.3.3 show the system availability results for the 15 Earth-based constellations when the system is operating in one-way mode without terrain information or clock synchronization (solving with 1-hr dynamic measurements). Table B.1.3.1 tabulates the weighted system availabilities from figures B.1.3.1 to B.1.3.3. Table B.1.3.2 tabulates the losses in system availability that occurred as the result of losing a single asset (derived from the failure system availability analysis).

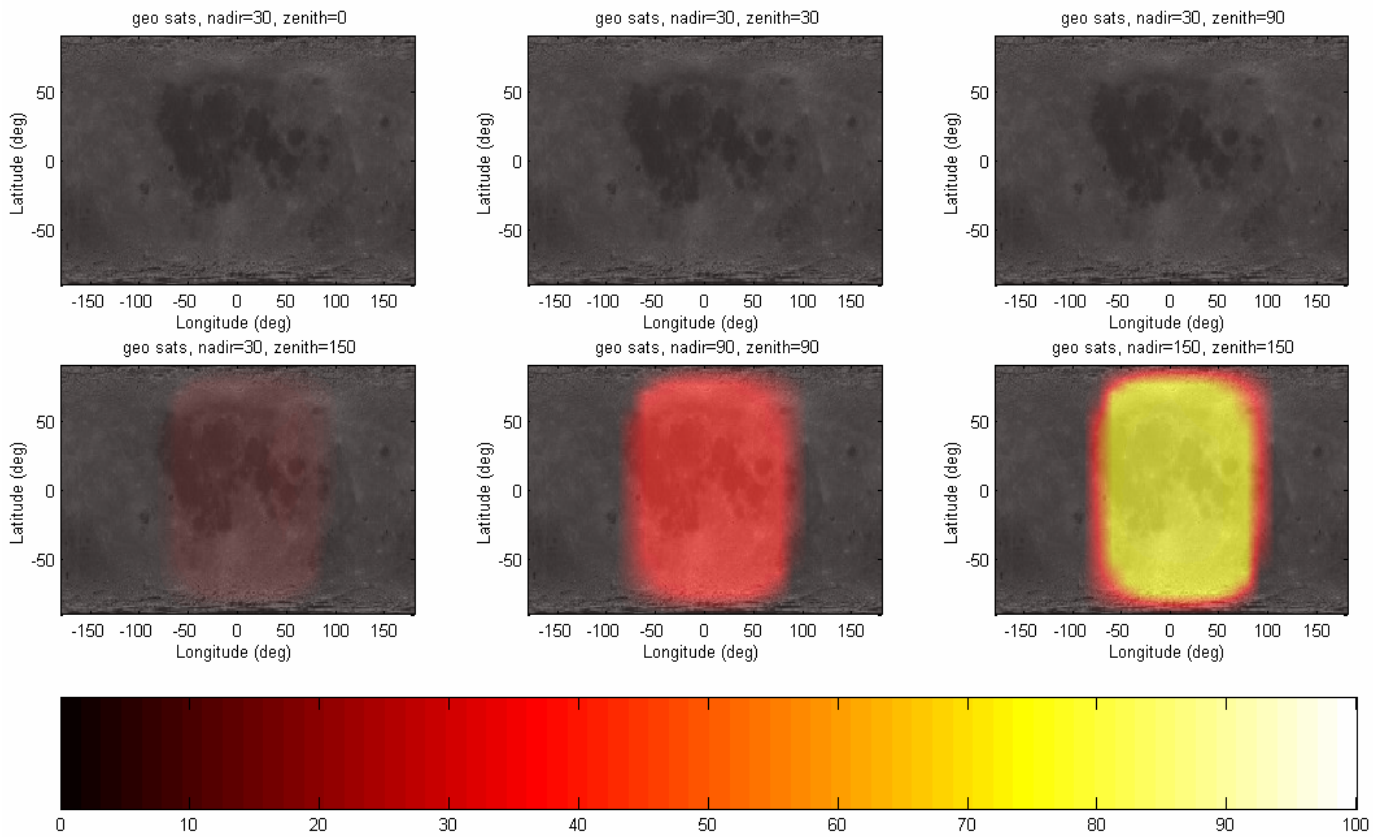

Figure B.1.3.1.—GEO system availability results.

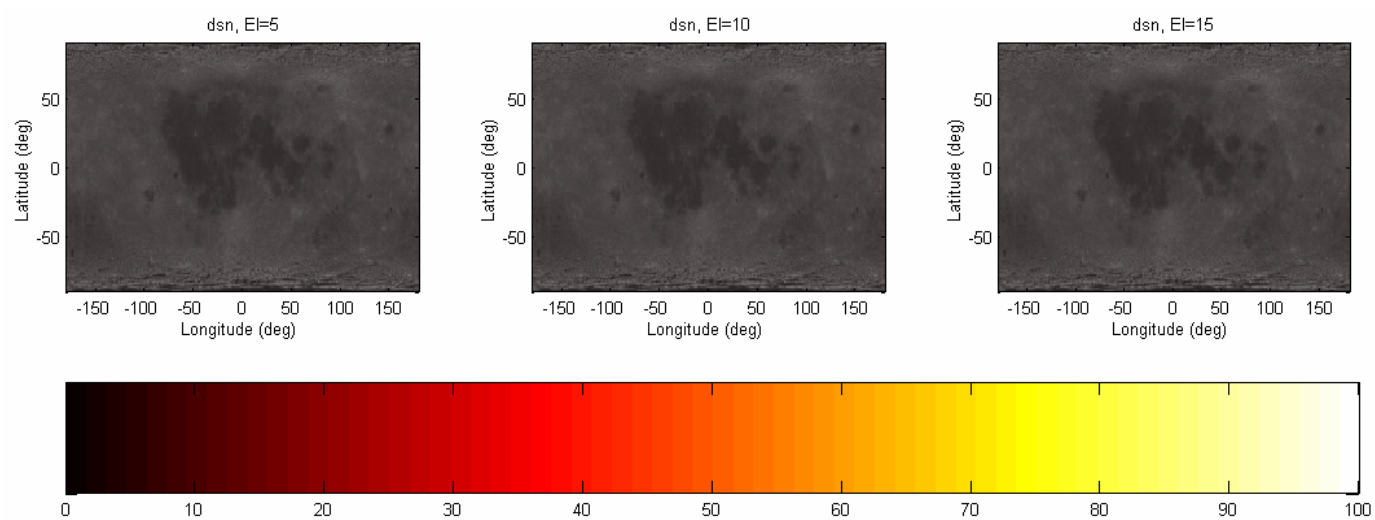

Figure B.1.3.2.—DSN system availability results.

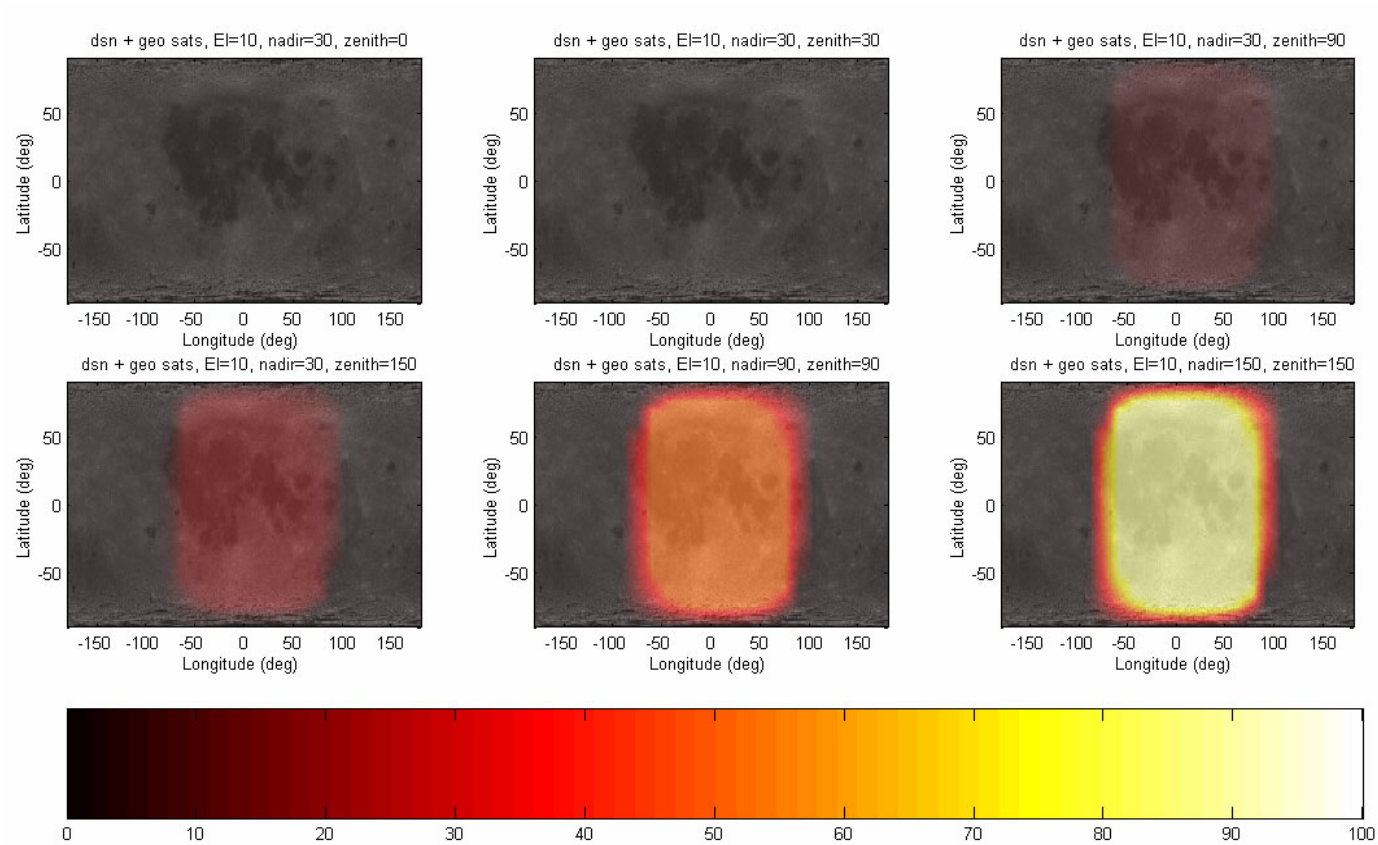

Figure B.1.3.3.—DSNGEO system availability results.

TABLE B.1.3.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	0.00	0.00	0.00	0.00	0.00
GEO 90/30	0.00	0.00	0.00	0.00	0.00
GEO 150/30	3.37	1.04	6.44	0.00	7.77
GEO 90/90	16.82	5.97	32.15	0.00	38.24
GEO 150/150	33.43	12.88	63.70	0.00	75.26
DSN 5	0.00	0.00	0.00	0.00	0.00
DSN 10	0.00	0.00	0.00	0.00	0.00
DSN 15	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/30/30	0.47	0.01	0.89	0.00	1.05
DSN+GEO 10/90/30	3.04	0.23	5.79	0.00	6.87
DSN+GEO 10/150/30	7.07	1.70	13.50	0.00	16.14
DSN+GEO 10/90/90	22.62	8.21	43.21	0.00	51.20
DSN+GEO 10/150/150	39.47	16.20	75.16	0.00	88.55

TABLE B.1.3.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	0.00	0.00	0.00	0.00	0.00
GEO 90/30	0.00	0.00	0.00	0.00	0.00
GEO 150/30	2.10	0.63	4.02	0.00	4.85
GEO 90/90	11.13	3.98	21.28	0.00	25.31
GEO 150/150	13.93	6.01	26.46	0.00	30.51
DSN 5	0.00	0.00	0.00	0.00	0.00
DSN 10	0.00	0.00	0.00	0.00	0.00
DSN 15	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30 -v2	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/30/30 -v1	0.16	0.01	0.31	0.00	0.36
DSN+GEO 10/30/30 -v2	0.17	0.01	0.31	0.00	0.37
DSN+GEO 10/90/30 -v1	1.11	0.18	2.11	0.00	2.52
DSN+GEO 10/90/30 -v2	1.44	0.19	2.73	0.00	3.23
DSN+GEO 10/150/30 -v1	1.16	0.24	2.22	0.00	2.62
DSN+GEO 10/150/30 -v2	2.68	0.97	5.14	0.00	6.06
DSN+GEO 10/90/90 -v1	2.07	0.76	3.96	0.00	4.65
DSN+GEO 10/90/90 -v2	13.82	5.22	26.40	0.00	31.26
DSN+GEO 10/150/150 -v1	2.07	1.21	3.92	0.00	4.49
DSN+GEO 10/150/150 -v2	11.74	6.35	22.21	0.00	24.88

B.1.4 Dynamic (2 hr).—Figures B.1.4.1 to B.1.4.3 show the system availability results for the 15 Earth-based constellations when the system is operating in one-way mode without terrain information or clock synchronization (solving with 2-hr dynamic measurements). Table B.1.4.1 tabulates the weighted system availabilities from figures B.1.4.1 to B.1.4.3. Table B.1.4.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

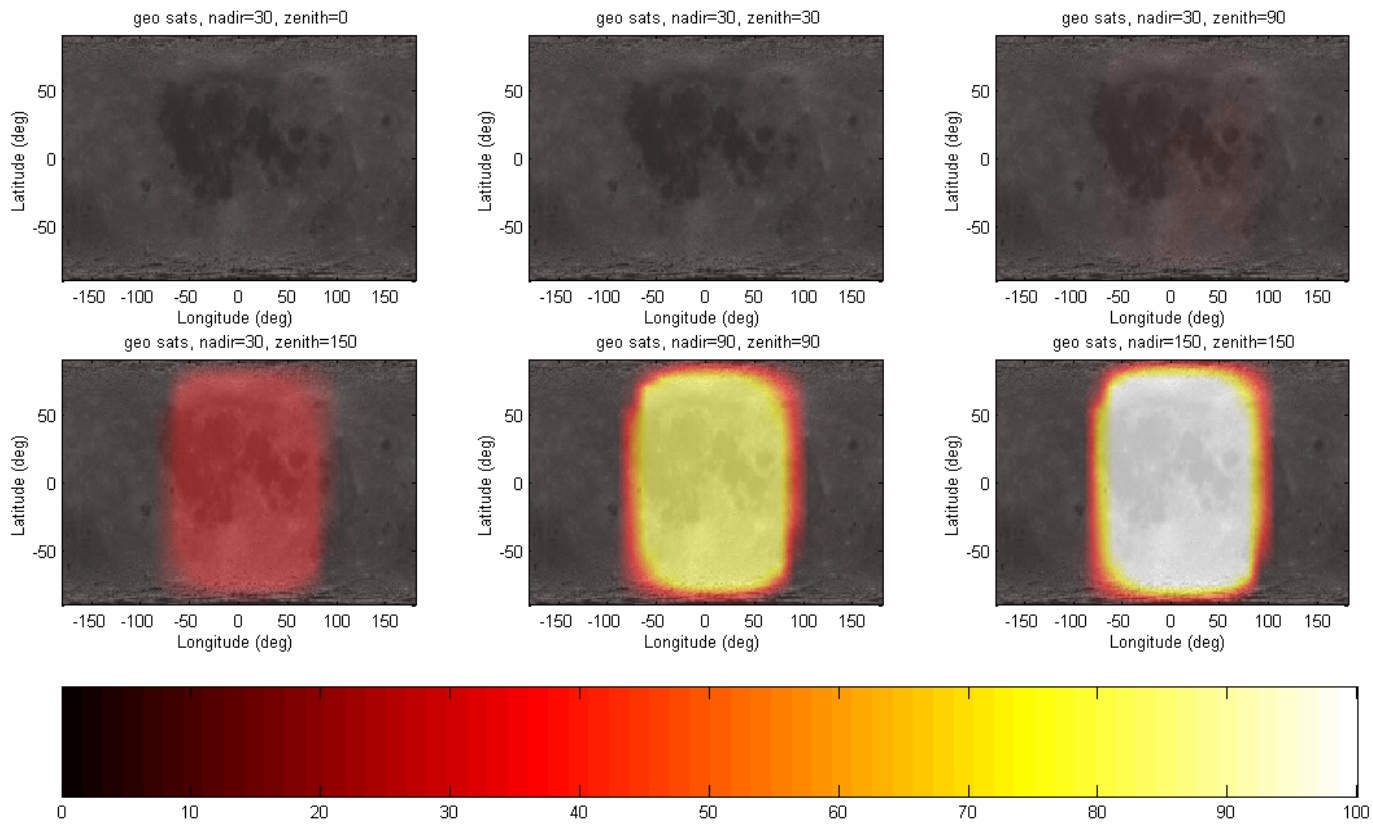

Figure B.1.4.1.—GEO system availability results.

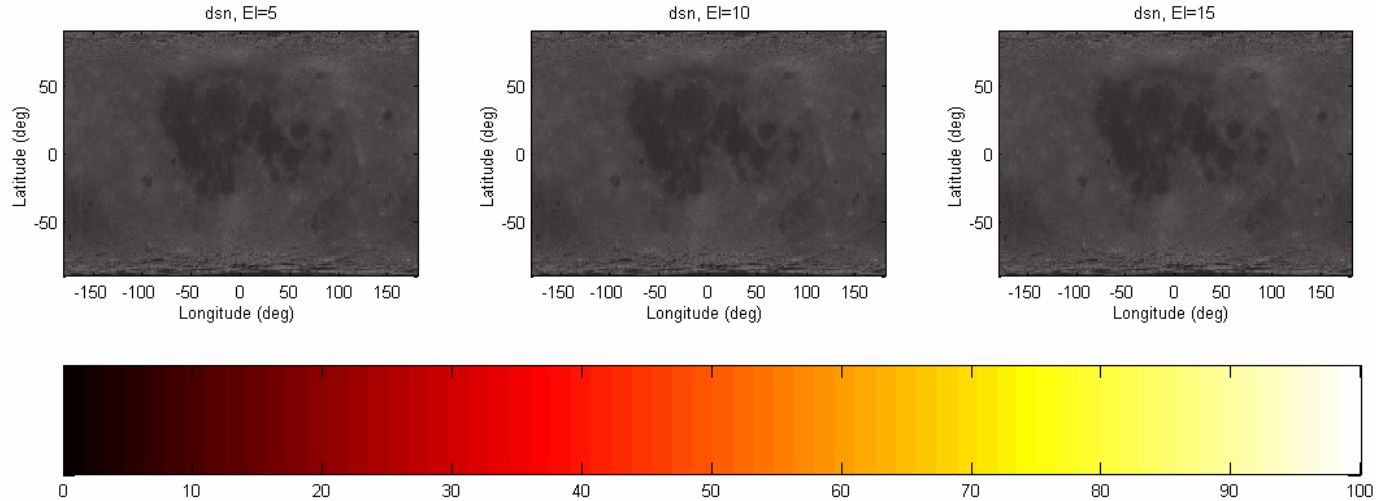

Figure B.1.4.2.—DSN system availability results.

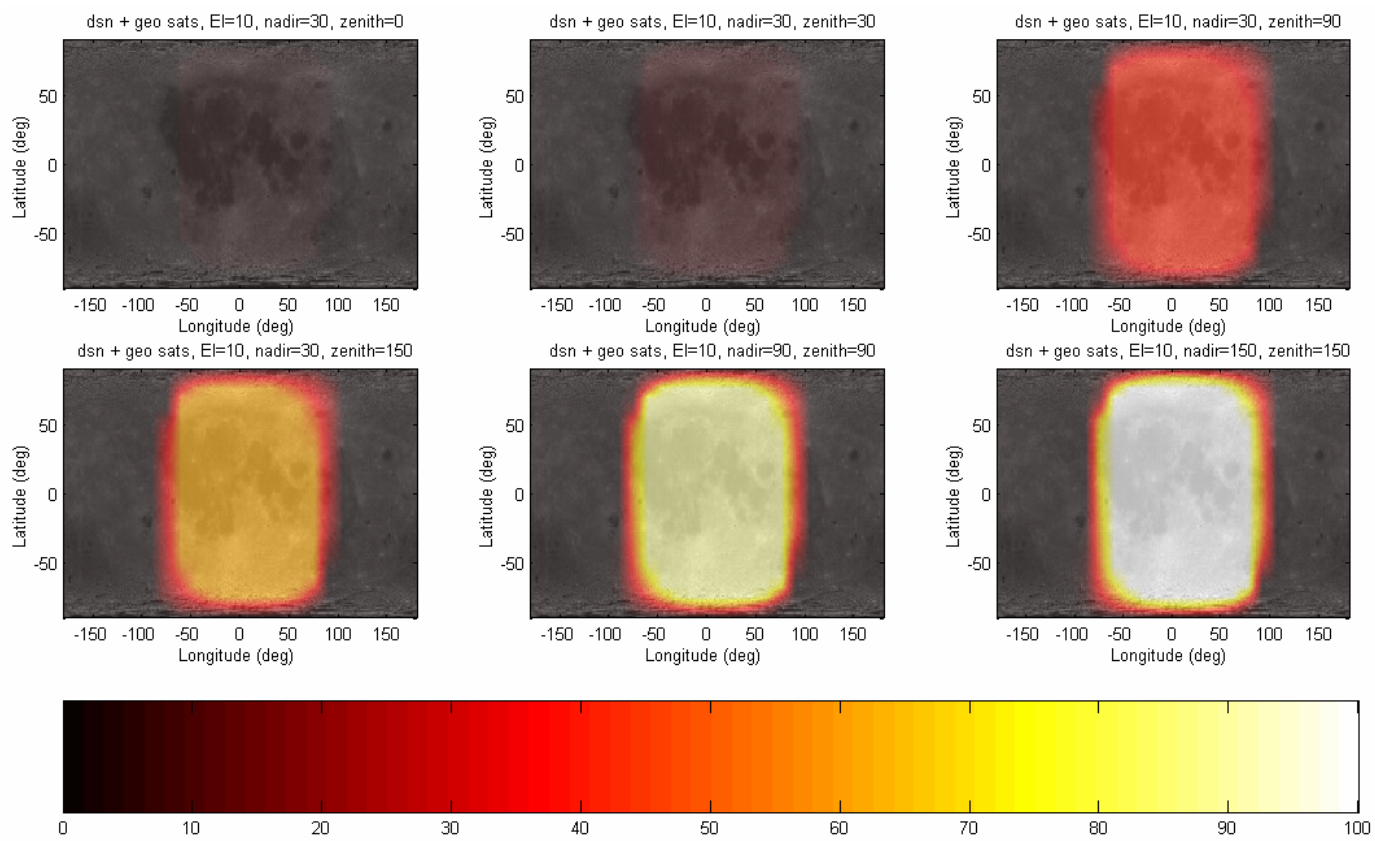

Figure B.1.4.3.—DSNGEO system availability results.

TABLE B.1.4.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	0.00	0.00	0.00	0.00	0.00
GEO 90/30	1.38	0.41	2.62	0.00	3.11
GEO 150/30	11.40	4.54	21.68	0.00	26.18
GEO 90/90	36.52	13.24	69.76	0.00	82.00
GEO 150/150	45.22	21.45	85.77	0.00	99.48
DSN 5	0.00	0.00	0.00	0.00	0.00
DSN 10	0.00	0.00	0.00	0.00	0.00
DSN 15	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30	0.82	0.04	1.55	0.00	1.85
DSN+GEO 10/30/30	2.72	0.67	5.16	0.00	6.12
DSN+GEO 10/90/30	18.47	6.22	35.24	0.00	41.67
DSN+GEO 10/150/30	27.21	10.84	51.83	0.00	61.81
DSN+GEO 10/90/90	40.20	15.86	76.56	0.00	89.57
DSN+GEO 10/150/150	45.48	22.33	86.12	0.00	99.67

TABLE B.1.4.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	0.00	0.00	0.00	0.00	0.00
GEO 90/30	0.94	0.27	1.77	0.00	2.09
GEO 150/30	5.42	2.33	10.28	0.00	12.37
GEO 90/90	23.94	8.65	45.73	0.00	53.74
GEO 150/150	8.89	7.80	16.54	0.00	16.70
DSN 5	0.00	0.00	0.00	0.00	0.00
DSN 10	0.00	0.00	0.00	0.00	0.00
DSN 15	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30 -v1	0.08	0.00	0.19	0.00	0.24
DSN+GEO 10/0/30 -v2	0.33	0.04	0.62	0.00	0.74
DSN+GEO 10/30/30 -v1	0.99	0.46	1.88	0.00	2.22
DSN+GEO 10/30/30 -v2	1.32	0.47	2.49	0.00	2.94
DSN+GEO 10/90/30 -v1	6.03	2.32	11.50	0.00	13.53
DSN+GEO 10/90/30 -v2	11.06	4.04	21.11	0.00	24.94
DSN+GEO 10/150/30 -v1	5.79	2.39	11.05	0.00	12.98
DSN+GEO 10/150/30 -v2	9.99	4.27	19.00	0.00	22.63
DSN+GEO 10/90/90 -v1	0.55	1.08	0.97	0.00	0.97
DSN+GEO 10/90/90 -v2	18.06	7.66	34.35	0.00	39.84
DSN+GEO 10/150/150 -v1	0.06	0.51	0.07	0.00	0.00
DSN+GEO 10/150/150 -v2	4.69	5.67	8.52	0.00	7.76

B.1.5 Dynamic (4 hr).—Figures B.1.5.1 to B.1.5.3 show the system availability results for the 15 Earth-based constellations when the system is operating in one-way mode without terrain information or clock synchronization (solving with 4-hr dynamic measurements). Table B.1.5.1 tabulates the weighted system availabilities from figures B.1.5.1 to B.1.5.3. Table B.1.5.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

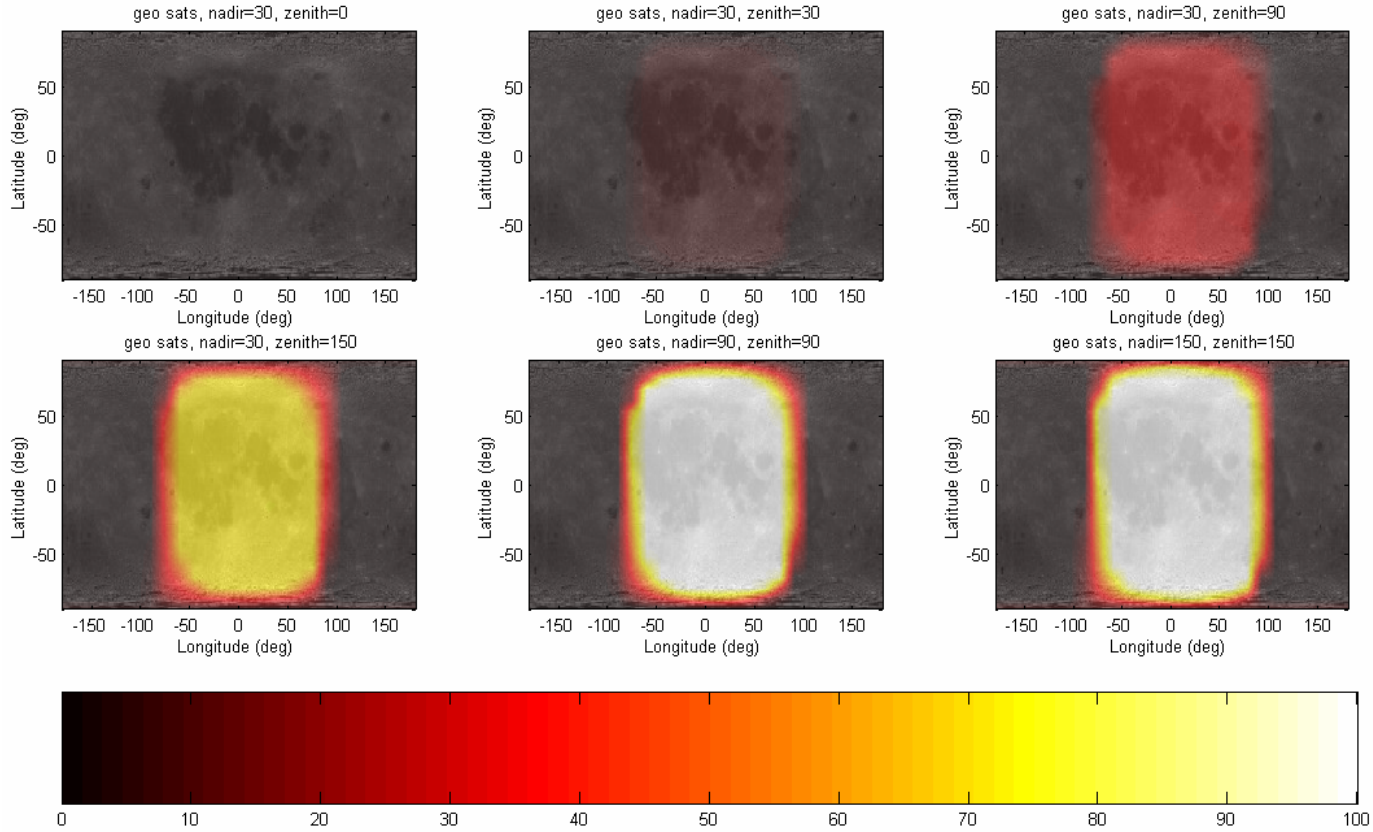

Figure B.1.5.1.—GEO system availability results.

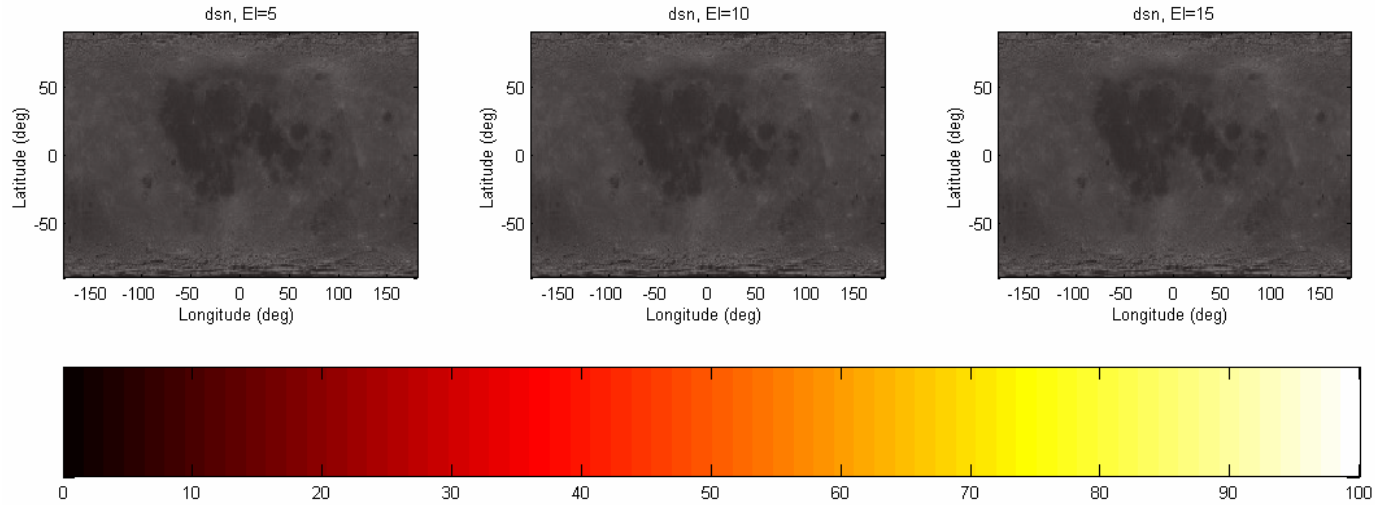

Figure B.1.5.2.—DSN system availability results.

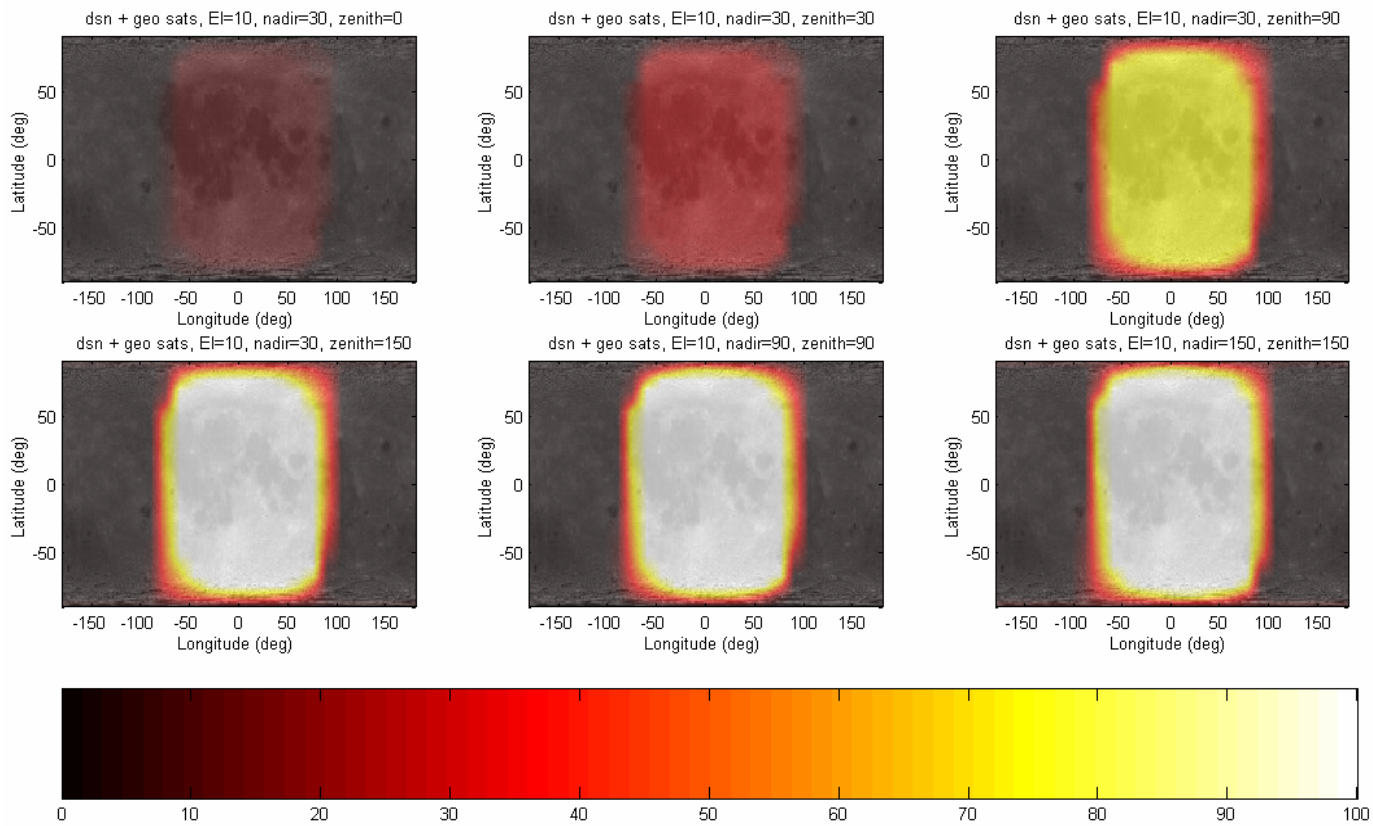

Figure B.1.5.3.—DSNGEO system availability results.

TABLE B.1.5.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	2.45	1.04	4.66	0.00	5.53
GEO 90/30	11.75	4.97	22.29	0.00	26.22
GEO 150/30	31.97	15.93	60.62	0.00	71.68
GEO 90/90	45.13	18.07	86.02	0.00	99.52
GEO 150/150	46.70	27.96	87.92	0.00	100.00
DSN 5	0.00	0.00	0.00	0.00	0.00
DSN 10	0.00	0.00	0.00	0.00	0.00
DSN 15	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30	4.44	1.49	8.44	0.00	10.01
DSN+GEO 10/30/30	10.57	4.25	20.08	0.00	23.73
DSN+GEO 10/90/30	34.02	15.27	64.82	0.00	76.25
DSN+GEO 10/150/30	44.99	21.99	85.39	0.00	99.74
DSN+GEO 10/90/90	45.65	21.26	86.57	0.00	99.78
DSN+GEO 10/150/150	46.73	28.12	87.95	0.00	100.00

TABLE B.1.5.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	1.60	0.67	3.05	0.00	3.60
GEO 90/30	6.90	2.95	13.08	0.00	15.35
GEO 150/30	10.29	5.88	49.41	0.00	22.73
GEO 90/90	25.09	10.38	47.83	0.00	54.97
GEO 150/150	1.84	7.25	2.79	0.00	0.12
DSN 5	0.00	0.00	0.00	0.00	0.00
DSN 10	0.00	0.00	0.00	0.00	0.00
DSN 15	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30 -v1	0.83	0.40	1.58	0.00	1.86
DSN+GEO 10/0/30 -v2	1.78	0.79	3.38	0.00	4.00
DSN+GEO 10/30/30 -v1	2.01	1.32	3.80	0.00	4.44
DSN+GEO 10/30/30 -v2	4.90	2.46	9.28	0.00	10.92
DSN+GEO 10/90/30 -v1	6.65	3.15	12.68	0.00	14.82
DSN+GEO 10/90/30 -v2	13.62	6.29	25.93	0.00	30.34
DSN+GEO 10/150/30 -v1	3.12	1.78	5.92	0.00	6.50
DSN+GEO 10/150/30 -v2	10.65	6.19	20.15	0.00	23.03
DSN+GEO 10/90/90 -v1	0.13	1.89	0.12	0.00	0.00
DSN+GEO 10/90/90 -v2	6.47	4.28	12.01	0.00	12.57
DSN+GEO 10/150/150 -v1	0.01	0.15	0.02	0.00	0.00
DSN+GEO 10/150/150 -v2	1.11	4.91	1.62	0.00	0.00

B.1.6 Dynamic (8 hr).—Figures B.1.6.1 to B.1.6.3 show the system availability results for the 15 Earth-based constellations when the system is operating in one-way mode without terrain information or clock synchronization (solving with 8-hr dynamic measurements). Table B.1.6.1 tabulates the weighted system availabilities from figures B.1.6.1 to B.1.6.3. Table B.1.6.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

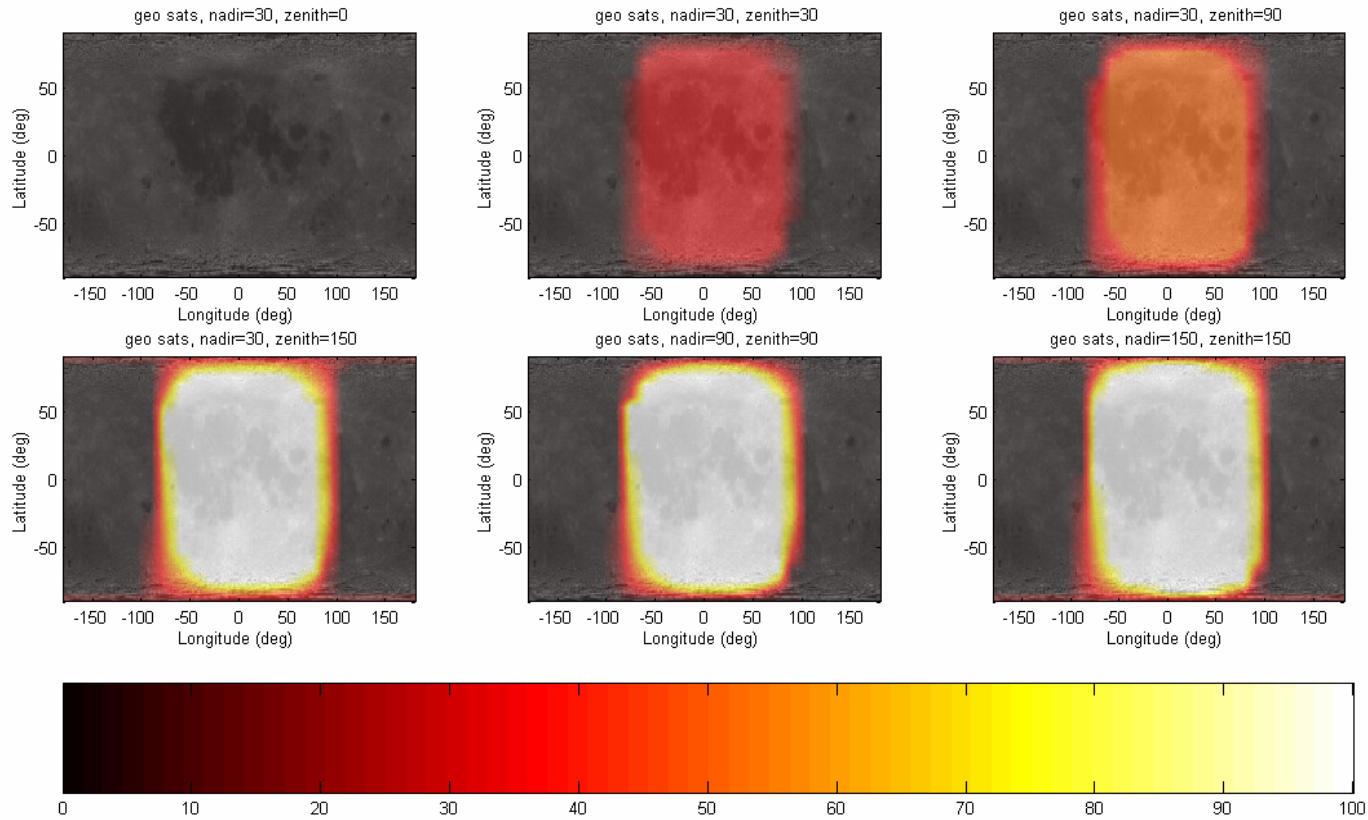

Figure B.1.6.1.—GEO system availability results.

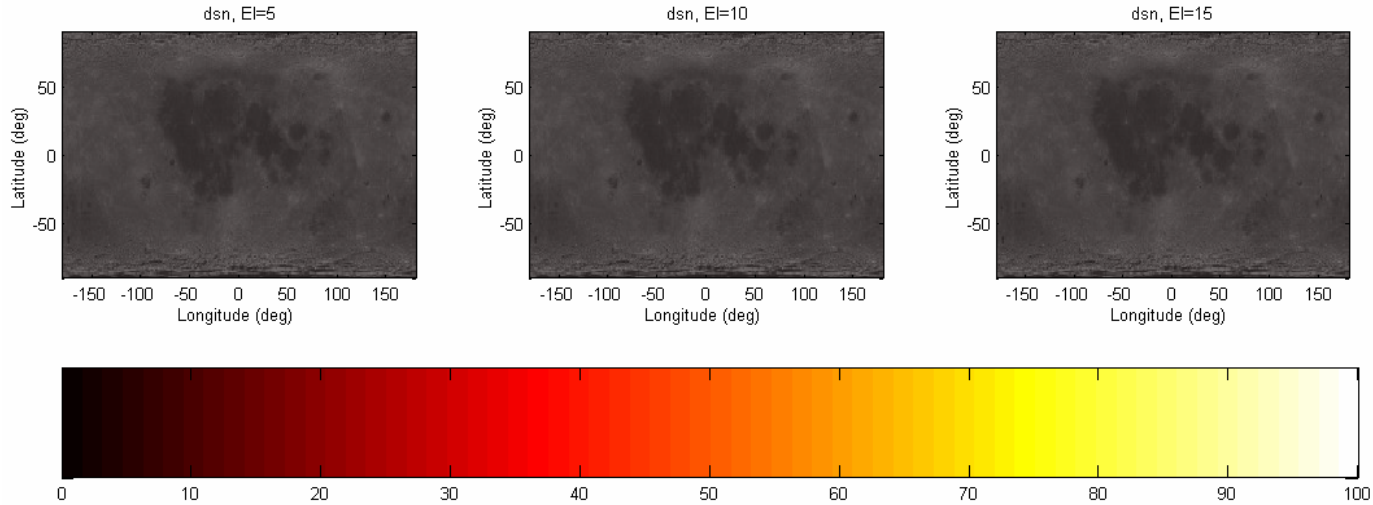

Figure B.1.6.2.—DSN system availability results.

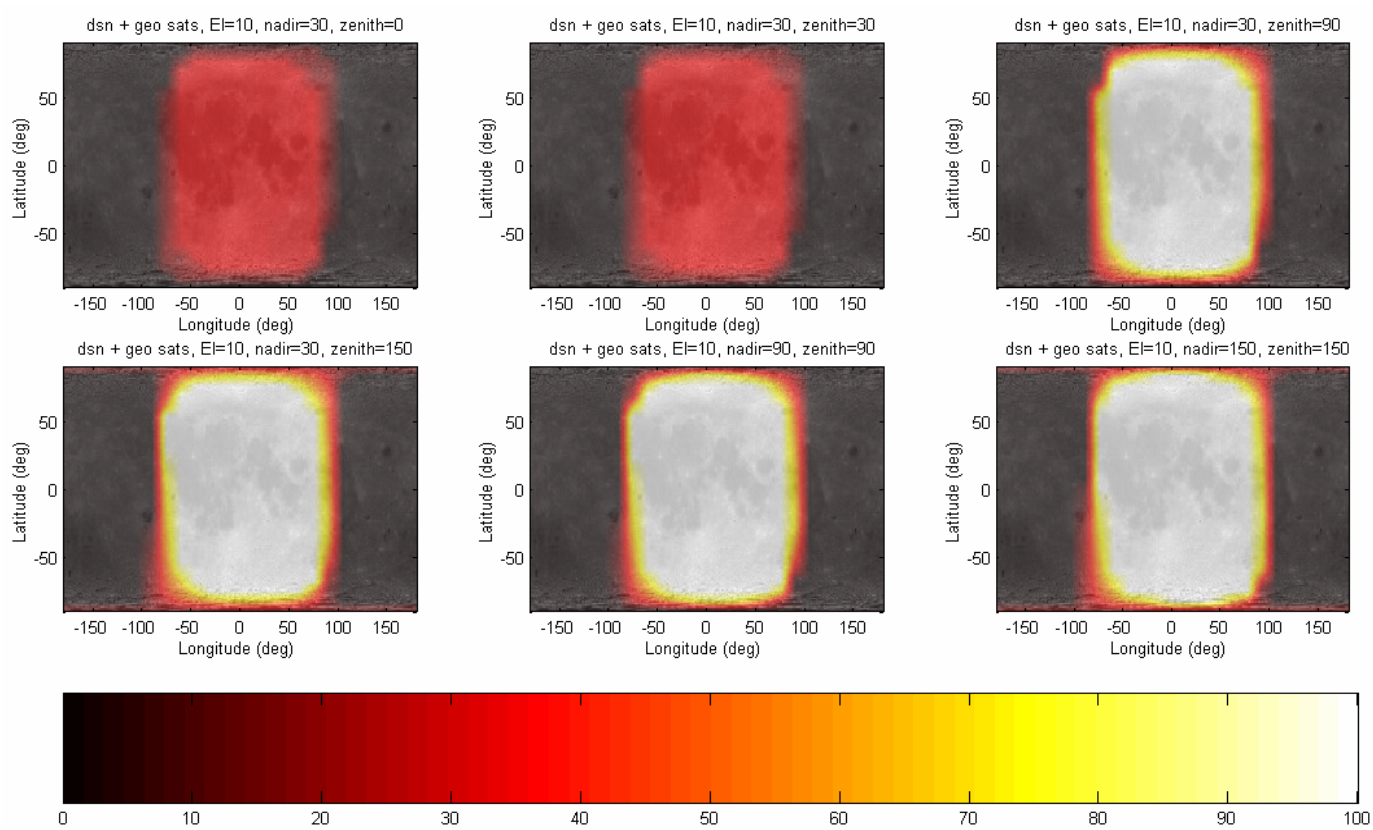

Figure B.1.6.3.—DSNGEO system availability results.

TABLE B.1.6.1—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	13.63	5.86	25.87	0.00	30.59
GEO 90/30	22.88	13.08	43.43	0.00	50.98
GEO 150/30	46.52	25.32	87.76	0.01	100.00
GEO 90/90	46.60	24.00	88.35	0.00	100.00
GEO 150/150	48.20	34.79	90.24	0.01	100.00
DSN 5	0.00	0.00	0.00	0.00	0.00
DSN 10	0.00	0.00	0.00	0.00	0.00
DSN 15	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30	15.62	6.69	29.67	0.00	35.32
DSN+GEO 10/30/30	16.11	7.84	30.51	0.00	36.15
DSN+GEO 10/90/30	45.31	22.36	86.04	0.00	100.00
DSN+GEO 10/150/30	46.66	26.48	87.86	0.01	100.00
DSN+GEO 10/90/90	46.79	26.53	88.36	0.00	100.00
DSN+GEO 10/150/150	48.20	34.79	90.24	0.01	100.00

TABLE B.1.6.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	8.01	3.58	15.20	0.00	17.94
GEO 90/30	8.38	6.24	15.91	0.00	18.56
GEO 150/30	7.56	5.83	14.04	0.00	14.44
GEO 90/90	7.45	6.69	13.81	0.00	13.50
GEO 150/150	1.03	5.17	1.50	0.00	0.00
DSN 5	0.00	0.00	0.00	0.00	0.00
DSN 10	0.00	0.00	0.00	0.00	0.00
DSN 15	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30 -v1	2.49	1.71	4.73	0.00	5.79
DSN+GEO 10/0/30 -v2	5.91	2.58	11.24	0.00	13.37
DSN+GEO 10/30/30 -v1	0.47	0.74	0.84	0.00	1.12
DSN+GEO 10/30/30 -v2	1.67	1.54	3.09	0.00	3.58
DSN+GEO 10/90/30 -v1	4.43	2.06	8.39	0.00	9.42
DSN+GEO 10/90/30 -v2	6.31	4.60	11.85	0.00	13.04
DSN+GEO 10/150/30 -v1	0.06	0.51	0.06	0.00	0.00
DSN+GEO 10/150/30 -v2	3.46	3.93	6.20	0.00	5.66
DSN+GEO 10/90/90 -v1	0.03	1.63	0.00	0.00	0.00
DSN+GEO 10/90/90 -v2	0.91	3.19	1.52	0.00	0.00
DSN+GEO 10/150/150 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/150/150 -v2	0.96	4.54	1.43	0.00	0.00

B.1.7 Dynamic (12 hr).—Figures B.1.7.1 to B.1.7.3 show the system availability results for the 15 Earth-based constellations when the system is operating in one-way mode without terrain information or clock synchronization (solving with 12-hr dynamic measurements). Table B.1.7.1 tabulates the weighted system availabilities from figures B.1.7.1 to B.1.7.3. Table B.1.7.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

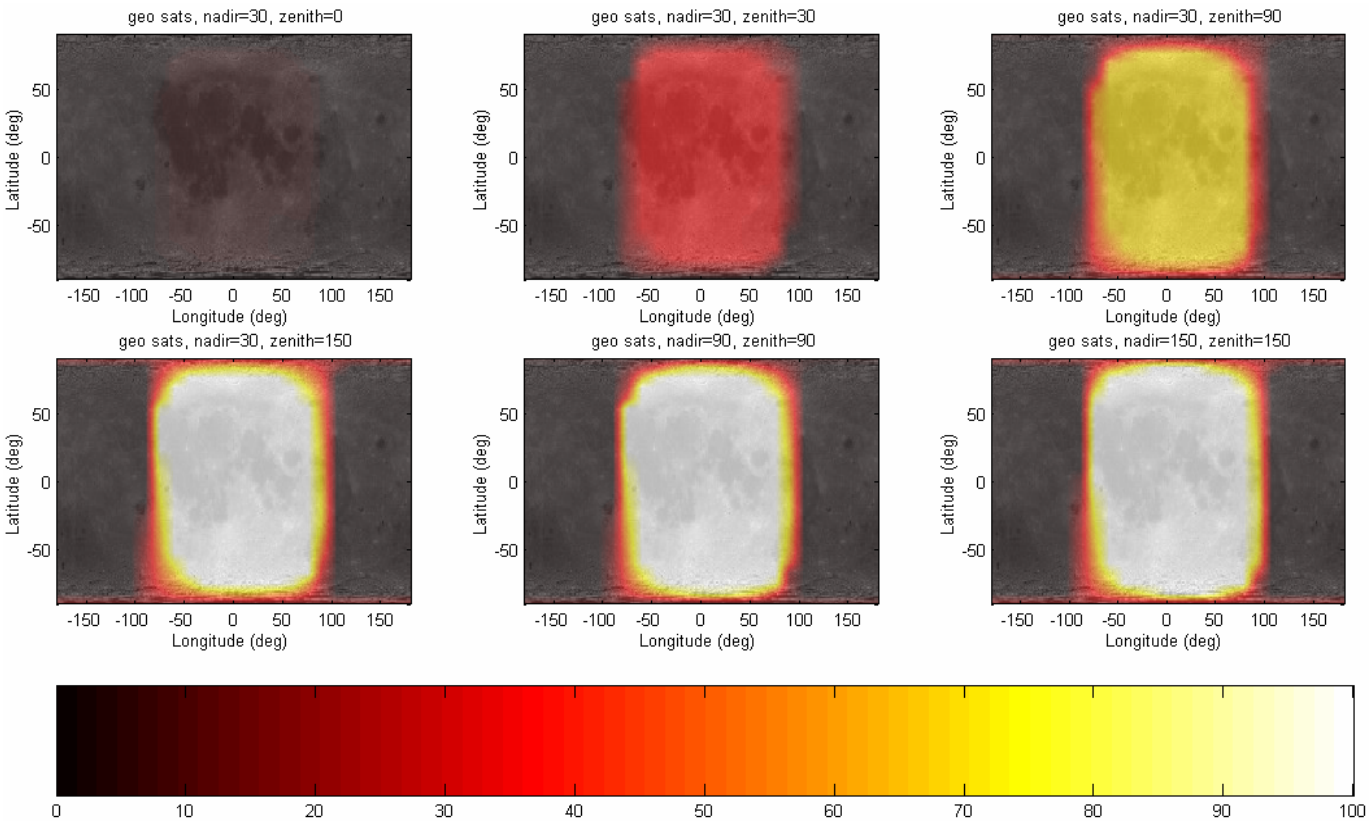

Figure B.1.7.1.—GEO system availability results.

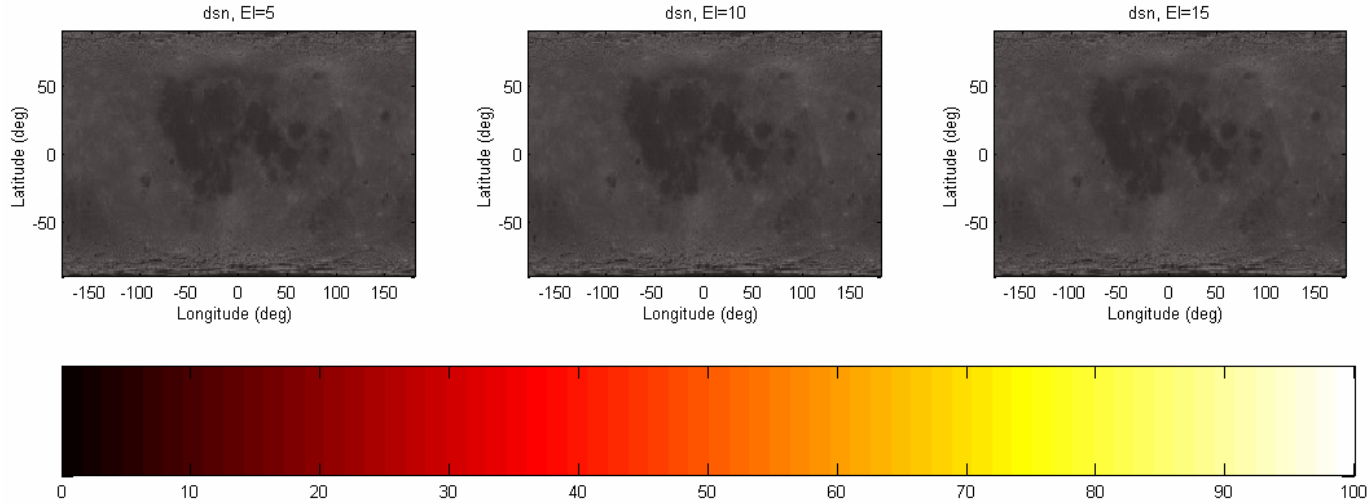

Figure B.1.7.2.—DSN system availability results.

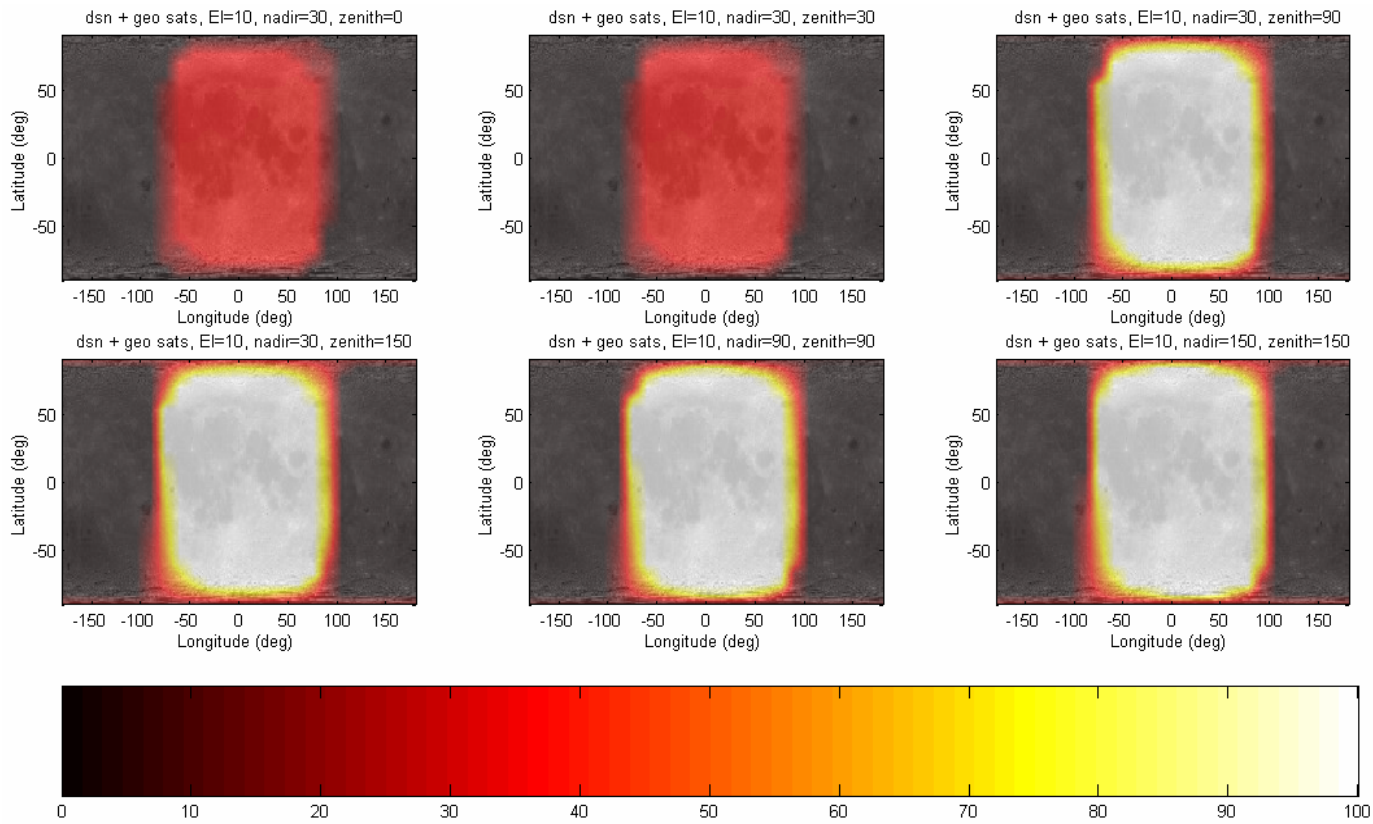

Figure B.1.7.3.—DSNGEO system availability results.

TABLE B.1.7.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	1.69	0.84	3.24	0.00	3.83
GEO 30/30	14.86	7.13	28.17	0.00	33.28
GEO 90/30	31.52	22.20	59.60	0.00	69.46
GEO 150/30	46.89	26.49	88.37	0.01	100.00
GEO 90/90	47.03	31.51	88.66	0.00	100.00
GEO 150/150	48.35	35.71	90.46	0.01	100.00
DSN 5	0.00	0.00	0.00	0.00	0.00
DSN 10	0.00	0.00	0.00	0.00	0.00
DSN 15	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30	16.92	7.27	32.08	0.00	38.08
DSN+GEO 10/30/30	17.02	8.51	32.16	0.00	38.08
DSN+GEO 10/90/30	45.85	25.16	86.69	0.00	100.00
DSN+GEO 10/150/30	47.00	27.53	88.44	0.01	100.00
DSN+GEO 10/90/90	47.16	31.81	88.66	0.00	100.00
DSN+GEO 10/150/150	48.35	35.71	90.46	0.01	100.00

TABLE B.1.7.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	1.08	0.59	2.04	0.00	2.45
GEO 30/30	3.56	2.54	6.67	0.00	7.94
GEO 90/30	9.01	9.73	16.95	0.00	19.61
GEO 150/30	0.99	2.48	1.65	0.00	0.00
GEO 90/90	0.81	7.37	1.04	0.00	0.10
GEO 150/150	0.43	2.51	0.64	0.00	0.00
DSN 5	0.00	0.00	0.00	0.00	0.00
DSN 10	0.00	0.00	0.00	0.00	0.00
DSN 15	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30 -v1	0.96	0.58	1.81	0.00	2.32
DSN+GEO 10/0/30 -v2	4.43	1.94	8.39	0.00	10.02
DSN+GEO 10/30/30 -v1	0.20	0.48	0.31	0.00	0.45
DSN+GEO 10/30/30 -v2	1.29	1.08	2.37	0.00	2.87
DSN+GEO 10/90/30 -v1	1.80	0.68	3.39	0.00	3.58
DSN+GEO 10/90/30 -v2	1.54	3.10	2.60	0.00	2.16
DSN+GEO 10/150/30 -v1	0.04	0.29	0.05	0.00	0.00
DSN+GEO 10/150/30 -v2	0.64	1.95	0.98	0.00	0.00
DSN+GEO 10/90/90 -v1	0.01	0.21	0.00	0.00	0.00
DSN+GEO 10/90/90 -v2	0.60	4.99	0.74	0.00	0.00
DSN+GEO 10/150/150 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/150/150 -v2	0.42	2.51	0.64	0.00	0.00

B.2 Good Terrain, No Clock, One-Way Mode

B.2.1 Kinematic.—Figures B.2.1.1 to B.2.1.3 show the system availability results for the 15 Earth-based constellations when the system is operating in one-way mode with terrain information but without clock synchronization (solving with kinematic measurements). Table B.2.1.1 tabulates the weighted system availabilities from figures B.2.1.1 to B.2.1.3. Table B.2.1.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

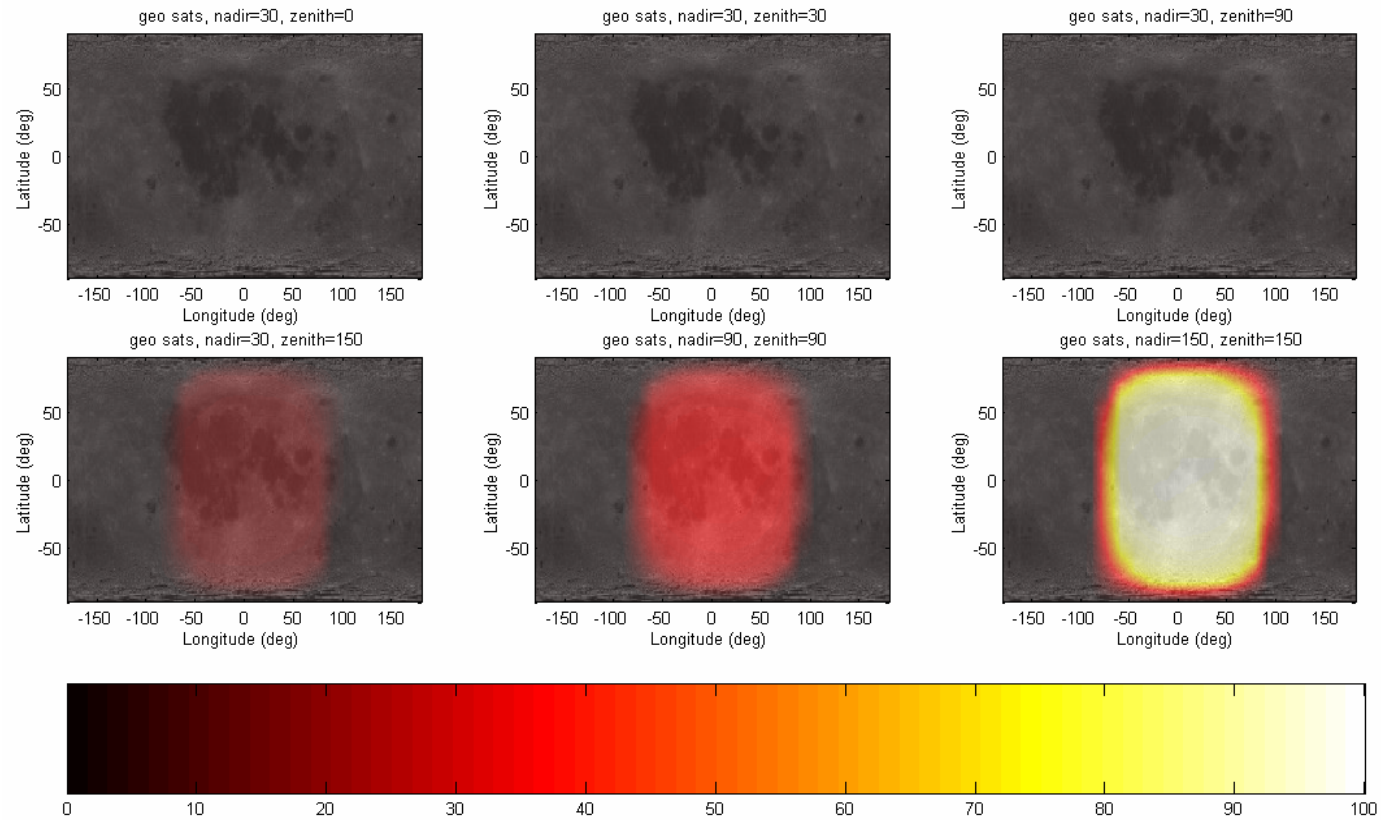

Figure B.2.1.1.—GEO system availability results.

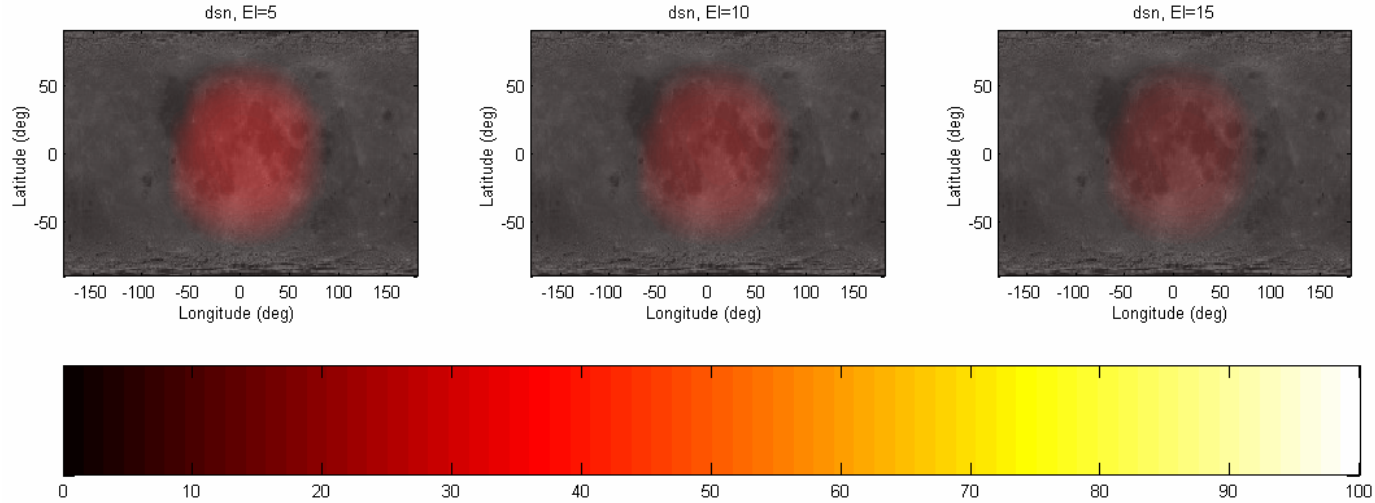

Figure B.2.1.2.—DSN system availability results.

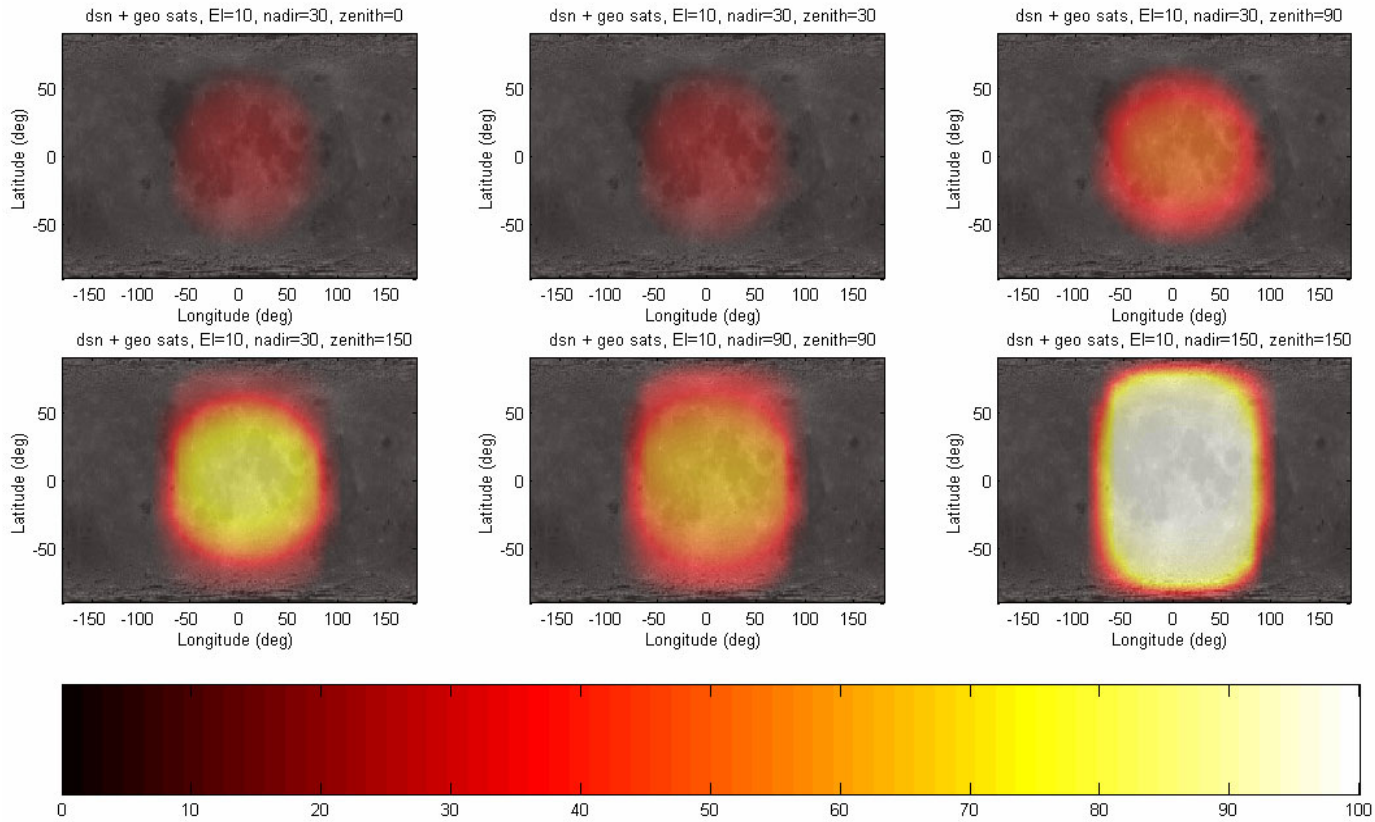

Figure B.2.1.3.—DSNGEO system availability results.

TABLE B.2.1.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	0.00	0.00	0.00	0.00	0.00
GEO 90/30	0.00	0.00	0.00	0.00	0.00
GEO 150/30	6.26	1.64	12.19	0.00	15.20
GEO 90/90	15.02	3.05	29.67	0.00	36.14
GEO 150/150	41.27	11.02	80.44	0.00	96.60
DSN 5	5.90	0.00	13.63	0.00	23.53
DSN 10	4.25	0.00	9.82	0.00	16.97
DSN 15	3.15	0.00	7.27	0.00	12.63
DSN+GEO 10/0/30	4.57	0.00	10.61	0.00	18.35
DSN+GEO 10/30/30	5.00	0.00	11.61	0.00	20.00
DSN+GEO 10/90/30	13.73	0.00	31.88	0.00	48.92
DSN+GEO 10/150/30	24.92	1.72	54.84	0.00	78.10
DSN+GEO 10/90/90	22.97	3.13	48.02	0.00	63.65
DSN+GEO 10/150/150	41.76	11.15	81.44	0.00	97.76

TABLE B.2.1.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	0.00	0.00	0.00	0.00	0.00
GEO 90/30	0.00	0.00	0.00	0.00	0.00
GEO 150/30	3.37	1.01	6.50	0.00	8.00
GEO 90/90	9.96	2.05	19.67	0.00	23.88
GEO 150/150	16.10	4.90	31.20	0.00	36.00
DSN 5	3.89	0.00	9.00	0.00	15.12
DSN 10	2.84	0.00	6.58	0.00	10.93
DSN 15	2.12	0.00	4.92	0.00	8.18
DSN+GEO 10/0/30 -v1	2.94	0.00	6.84	0.00	11.33
DSN+GEO 10/0/30 -v2	4.33	0.00	10.03	0.00	17.28
DSN+GEO 10/30/30 -v1	3.16	0.00	7.33	0.00	12.17
DSN+GEO 10/30/30 -v2	4.60	0.00	10.64	0.00	18.22
DSN+GEO 10/90/30 -v1	5.34	0.00	12.17	0.00	17.49
DSN+GEO 10/90/30 -v2	6.96	0.00	15.85	0.00	22.44
DSN+GEO 10/150/30 -v1	6.65	0.02	14.94	0.00	20.80
DSN+GEO 10/150/30 -v2	8.15	1.02	17.56	0.00	23.68
DSN+GEO 10/90/90 -v1	2.46	0.03	5.65	0.00	8.11
DSN+GEO 10/90/90 -v2	10.75	2.11	21.19	0.00	23.54
DSN+GEO 10/150/150 -v1	0.19	0.04	0.38	0.00	0.43
DSN+GEO 10/150/150 -v2	10.60	4.92	18.66	0.00	17.38

B.2.2 Dynamic (15 min).—Figures B.2.2.1 to B.2.2.3 show the system availability results for the 15 Earth-based constellations when the system is operating in one-way mode with terrain information but without clock synchronization (solving with 15-min dynamic measurements). Table B.2.2.1 tabulates the weighted system availabilities from figures B.2.2.1 to B.2.2.3. Table B.2.2.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

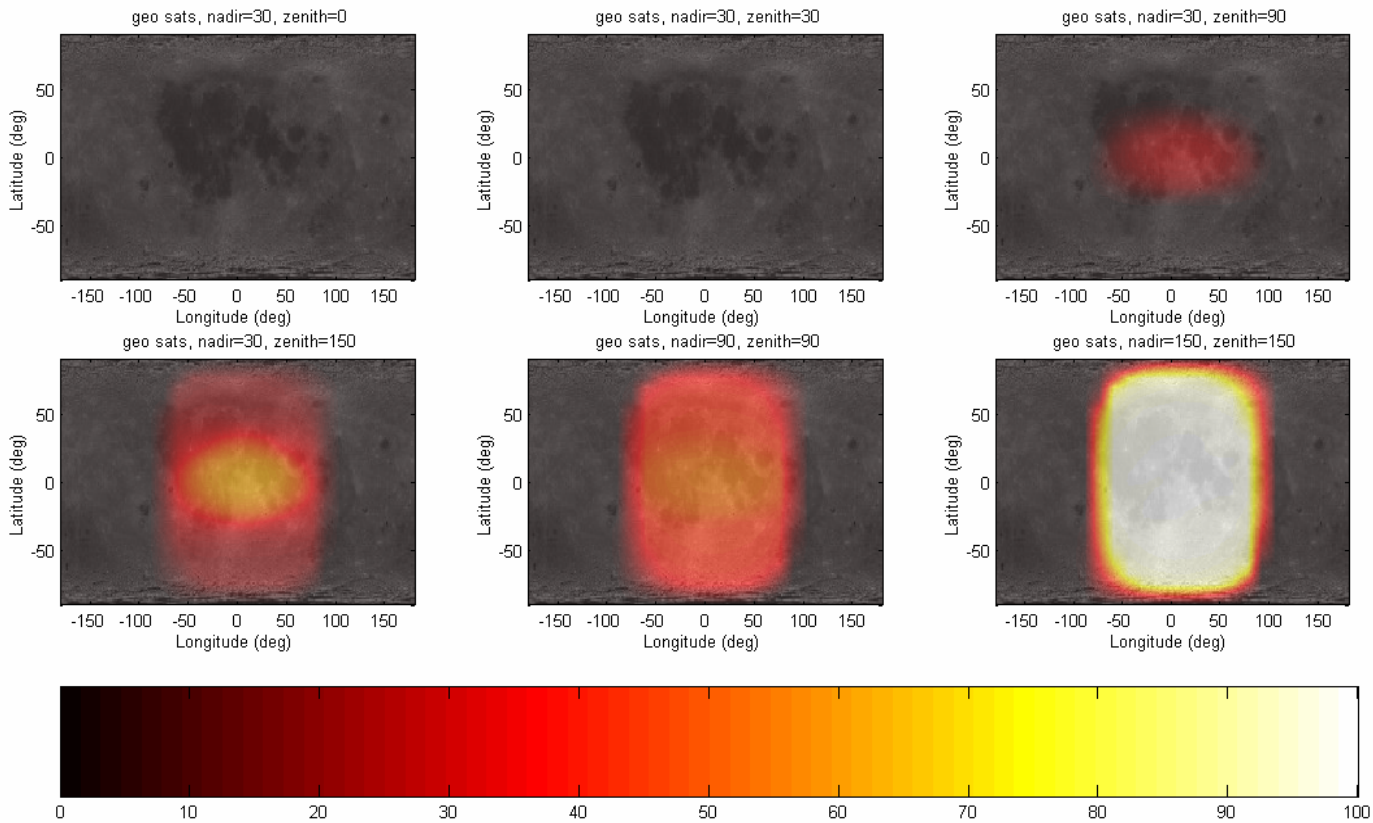

Figure B.2.2.1.—GEO system availability results.

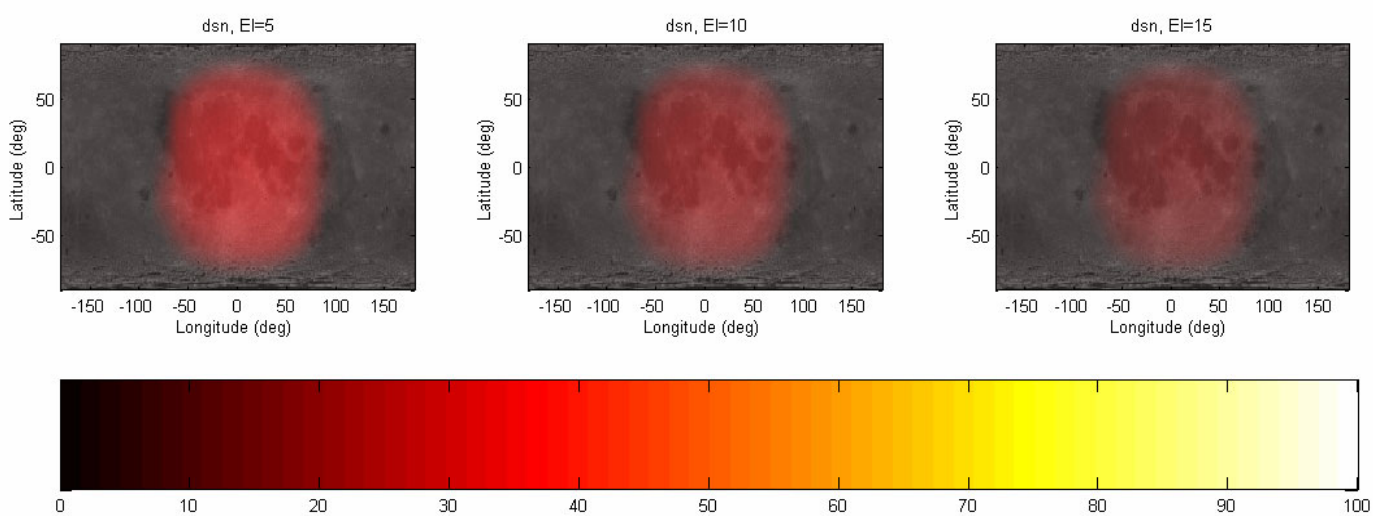

Figure B.2.2.2.—DSN system availability results.

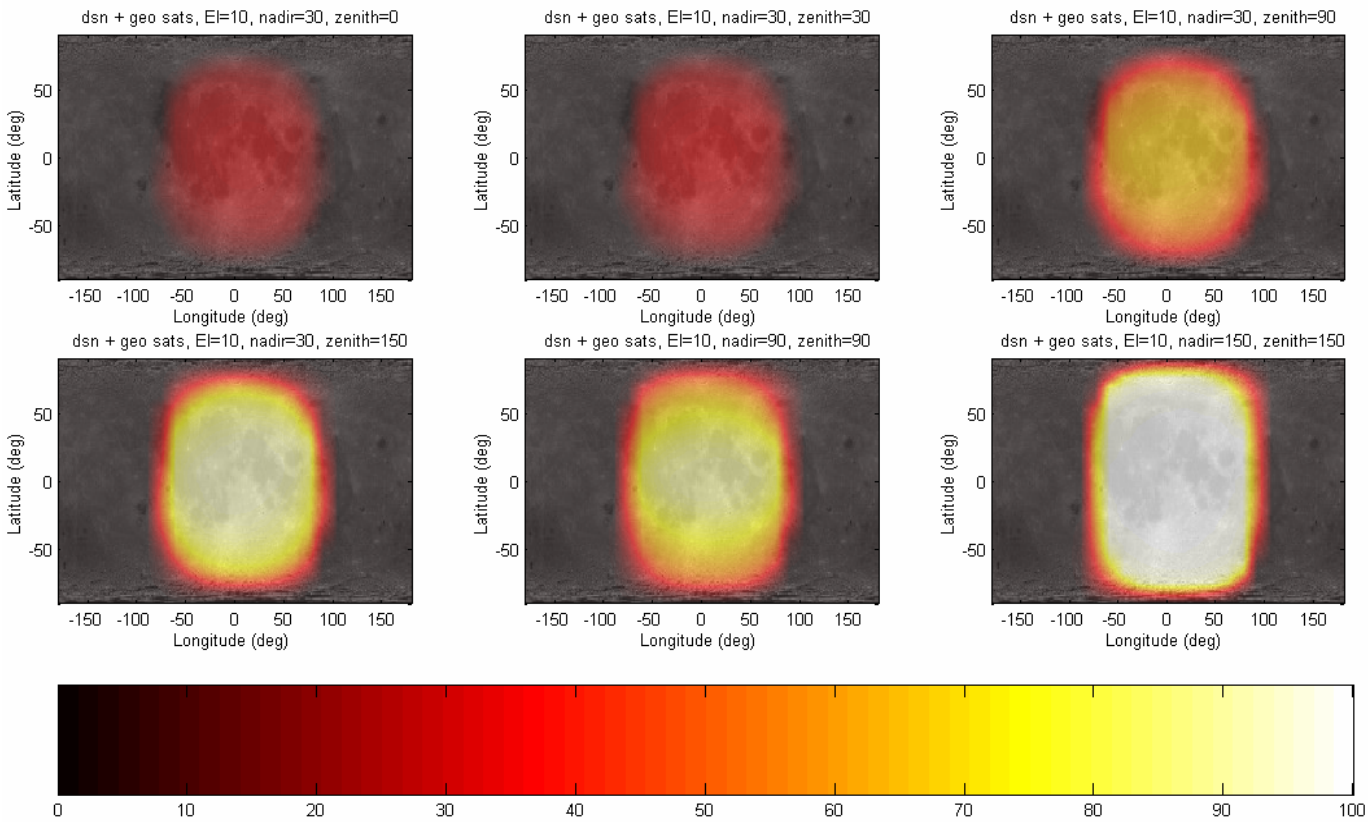

Figure B.2.2.3.—DSNGEO system availability results.

TABLE B.2.2.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	0.00	0.00	0.00	0.00	0.00
GEO 90/30	3.55	0.01	8.69	0.00	18.15
GEO 150/30	14.87	2.66	32.17	0.00	52.59
GEO 90/90	20.06	5.44	39.66	0.00	50.51
GEO 150/150	43.38	14.82	83.42	0.00	98.58
DSN 5	10.77	0.00	22.80	0.00	32.04
DSN 10	7.71	0.00	16.32	0.00	22.94
DSN 15	5.73	0.00	12.11	0.00	17.04
DSN+GEO 10/0/30	8.80	0.00	18.81	0.00	26.55
DSN+GEO 10/30/30	9.76	0.00	20.90	0.00	29.35
DSN+GEO 10/90/30	33.55	0.08	49.84	0.00	65.76
DSN+GEO 10/150/30	35.33	3.43	72.47	0.00	92.45
DSN+GEO 10/90/90	33.08	5.62	67.68	0.00	87.49
DSN+GEO 10/150/150	43.89	15.15	84.32	0.00	99.07

TABLE B.2.2.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	0.00	0.00	0.00	0.00	0.00
GEO 90/30	1.19	0.00	2.91	0.00	6.08
GEO 150/30	5.21	1.54	10.76	0.00	15.99
GEO 90/90	12.12	3.65	23.38	0.00	27.31
GEO 150/150	13.59	6.48	25.10	0.00	25.05
DSN 5	6.89	0.00	14.58	0.00	20.05
DSN 10	4.92	0.00	10.43	0.00	14.17
DSN 15	3.72	0.00	7.89	0.00	10.73
DSN+GEO 10/0/30 -v1	5.11	0.00	10.84	0.00	14.71
DSN+GEO 10/0/30 -v2	7.95	0.00	16.87	0.00	23.65
DSN+GEO 10/30/30 -v1	5.49	0.00	11.64	0.00	15.61
DSN+GEO 10/30/30 -v2	8.19	0.00	17.33	0.00	23.88
DSN+GEO 10/90/30 -v1	16.58	0.05	13.07	0.00	14.30
DSN+GEO 10/90/30 -v2	19.76	0.04	19.94	0.00	24.62
DSN+GEO 10/150/30 -v1	6.55	0.35	12.51	0.00	11.77
DSN+GEO 10/150/30 -v2	10.23	1.61	20.80	0.00	25.84
DSN+GEO 10/90/90 -v1	3.60	0.08	7.62	0.00	9.61
DSN+GEO 10/90/90 -v2	10.29	3.76	18.98	0.00	20.46
DSN+GEO 10/150/150 -v1	0.18	0.15	0.31	0.00	0.12
DSN+GEO 10/150/150 -v2	6.17	6.16	9.72	0.00	6.76

B.2.3 Dynamic (1 hr).—Figures B.2.3.1 to B.2.3.3 show the system availability results for the 15 Earth-based constellations when the system is operating in one-way mode with terrain information but without clock synchronization (solving with 1-hr dynamic measurements). Table B.2.3.1 tabulates the weighted system availabilities from figures B.2.3.1 to B.2.3.3. Table B.2.3.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

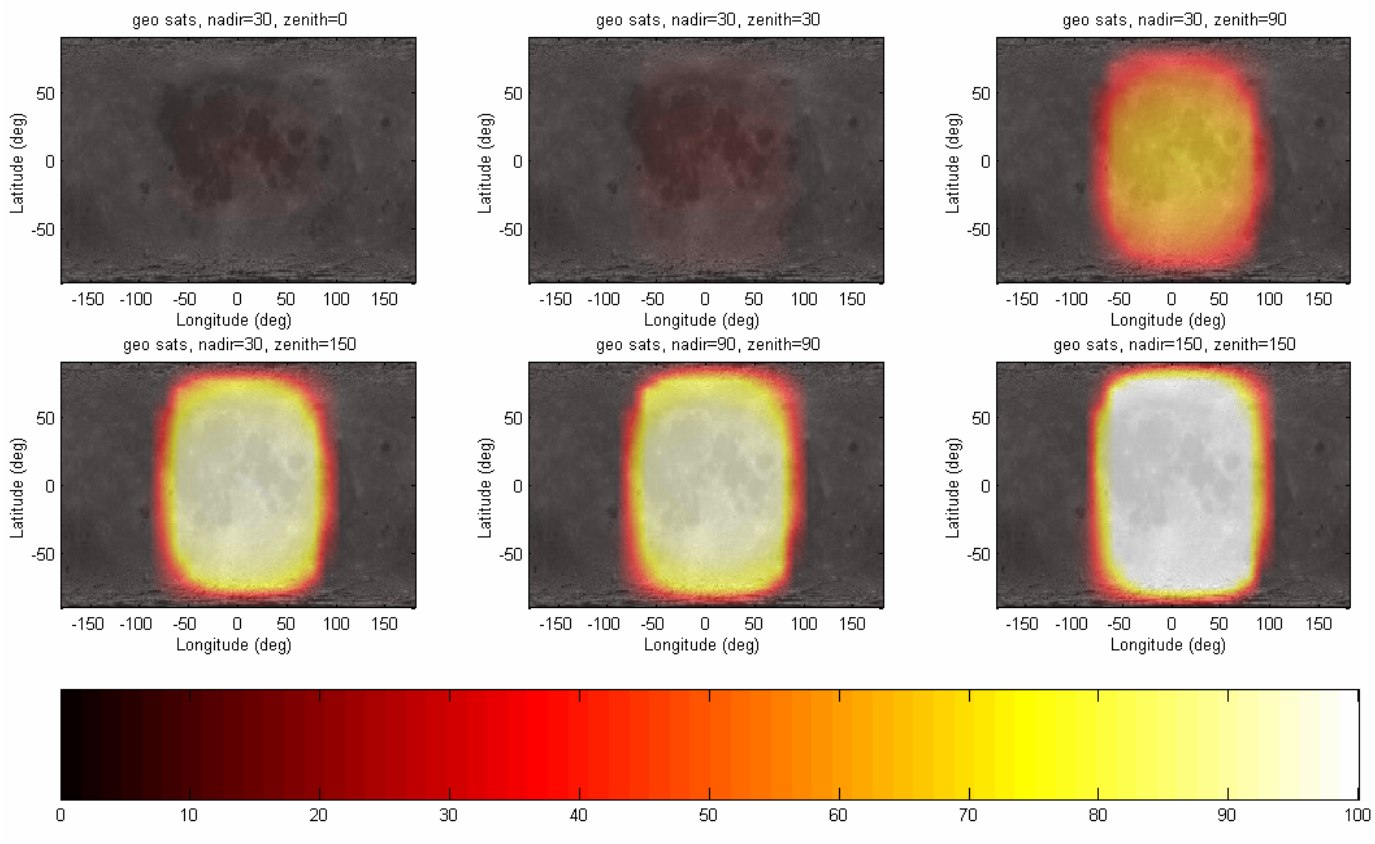

Figure B.2.3.1.—GEO system availability results.

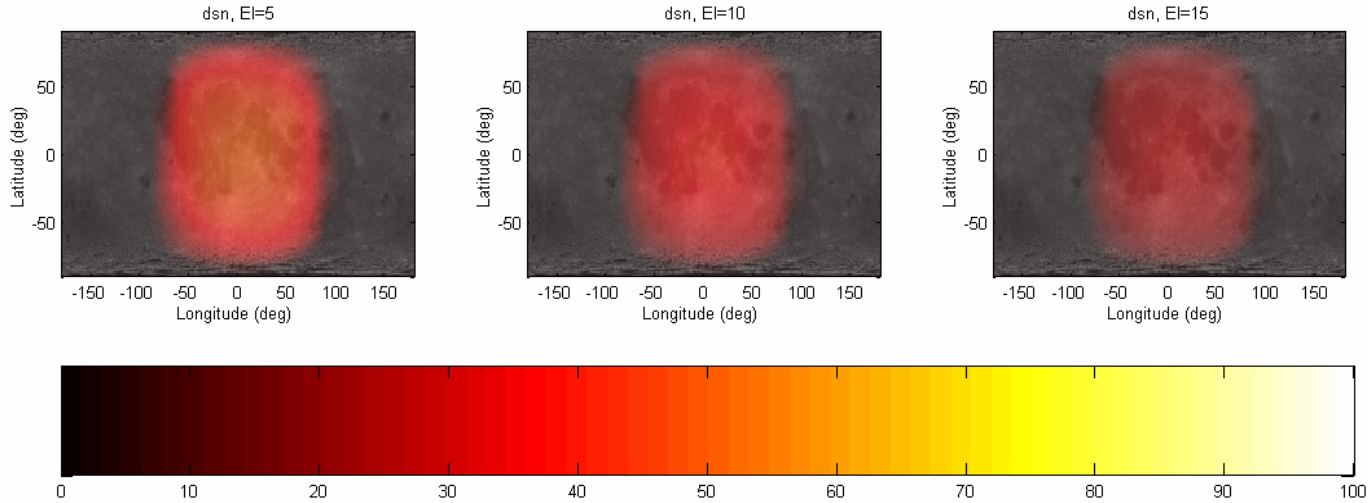

Figure B.2.3.2.—DSN system availability results.

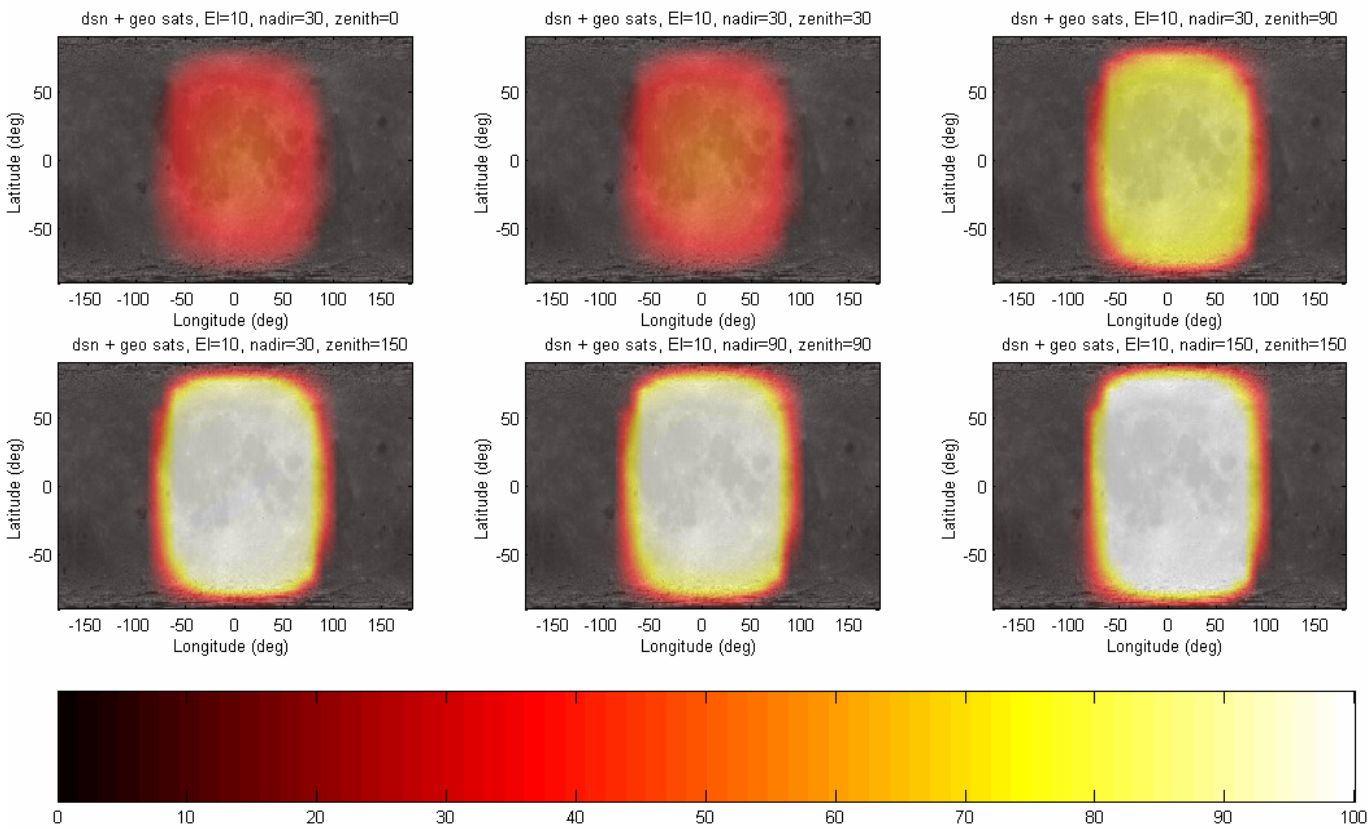

Figure B.2.3.3.—DSNGEO system availability results.

TABLE B.2.3.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.89	0.08	1.93	0.00	2.97
GEO 30/30	2.16	0.59	4.44	0.00	6.28
GEO 90/30	24.97	3.64	51.13	0.00	65.63
GEO 150/30	39.37	8.25	77.88	0.00	94.51
GEO 90/90	40.23	12.91	78.66	0.00	94.20
GEO 150/150	45.52	19.67	86.64	0.00	99.60
DSN 5	17.21	1.33	35.07	0.00	47.46
DSN 10	12.99	1.03	26.62	0.00	37.13
DSN 15	9.46	0.80	19.38	0.00	27.11
DSN+GEO 10/0/30	16.01	1.13	32.98	0.00	45.54
DSN+GEO 10/30/30	18.19	1.71	37.27	0.00	50.41
DSN+GEO 10/90/30	34.57	6.66	68.26	0.00	82.98
DSN+GEO 10/150/30	42.73	11.10	83.04	0.00	98.26
DSN+GEO 10/90/90	42.67	13.85	82.69	0.00	97.43
DSN+GEO 10/150/150	45.77	20.52	87.04	0.00	99.72

TABLE B.2.3.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.29	0.02	0.61	0.00	0.95
GEO 30/30	0.72	0.19	1.47	0.00	2.09
GEO 90/30	8.91	1.46	18.18	0.00	23.19
GEO 150/30	10.67	2.84	20.98	0.00	24.61
GEO 90/90	11.26	6.10	20.20	0.00	20.98
GEO 150/150	2.92	5.55	4.33	0.00	2.19
DSN 5	9.70	0.74	19.71	0.00	24.28
DSN 10	7.23	0.52	14.82	0.00	18.81
DSN 15	5.13	0.38	10.53	0.00	12.99
DSN+GEO 10/0/30 -v1	7.52	0.53	15.42	0.00	39.62
DSN+GEO 10/0/30 -v2	11.21	1.02	22.75	0.00	27.66
DSN+GEO 10/30/30 -v1	7.46	0.57	15.16	0.00	18.62
DSN+GEO 10/30/30 -v2	11.21	1.25	22.57	0.00	26.63
DSN+GEO 10/90/30 -v1	2.83	1.07	4.93	0.00	4.37
DSN+GEO 10/90/30 -v2	10.72	3.19	20.36	0.00	21.12
DSN+GEO 10/150/30 -v1	1.10	0.92	1.65	0.00	1.15
DSN+GEO 10/150/30 -v2	9.17	3.10	17.34	0.00	17.21
DSN+GEO 10/90/90 -v1	0.65	0.33	1.08	0.00	0.84
DSN+GEO 10/90/90 -v2	6.45	5.40	11.12	0.00	10.35
DSN+GEO 10/150/150 -v1	0.08	0.44	0.14	0.00	0.01
DSN+GEO 10/150/150 -v2	1.63	4.34	2.25	0.00	0.87

B.2.4 Dynamic (2 hr).—Figures B.2.4.1 to B.2.4.3 show the system availability results for the 15 Earth-based constellations when the system is operating in one-way mode with terrain information but without clock synchronization (solving with 2-hr dynamic measurements). Table B.2.4.1 tabulates the weighted system availabilities from figures B.2.4.1 to B.2.4.3. Table B.2.4.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

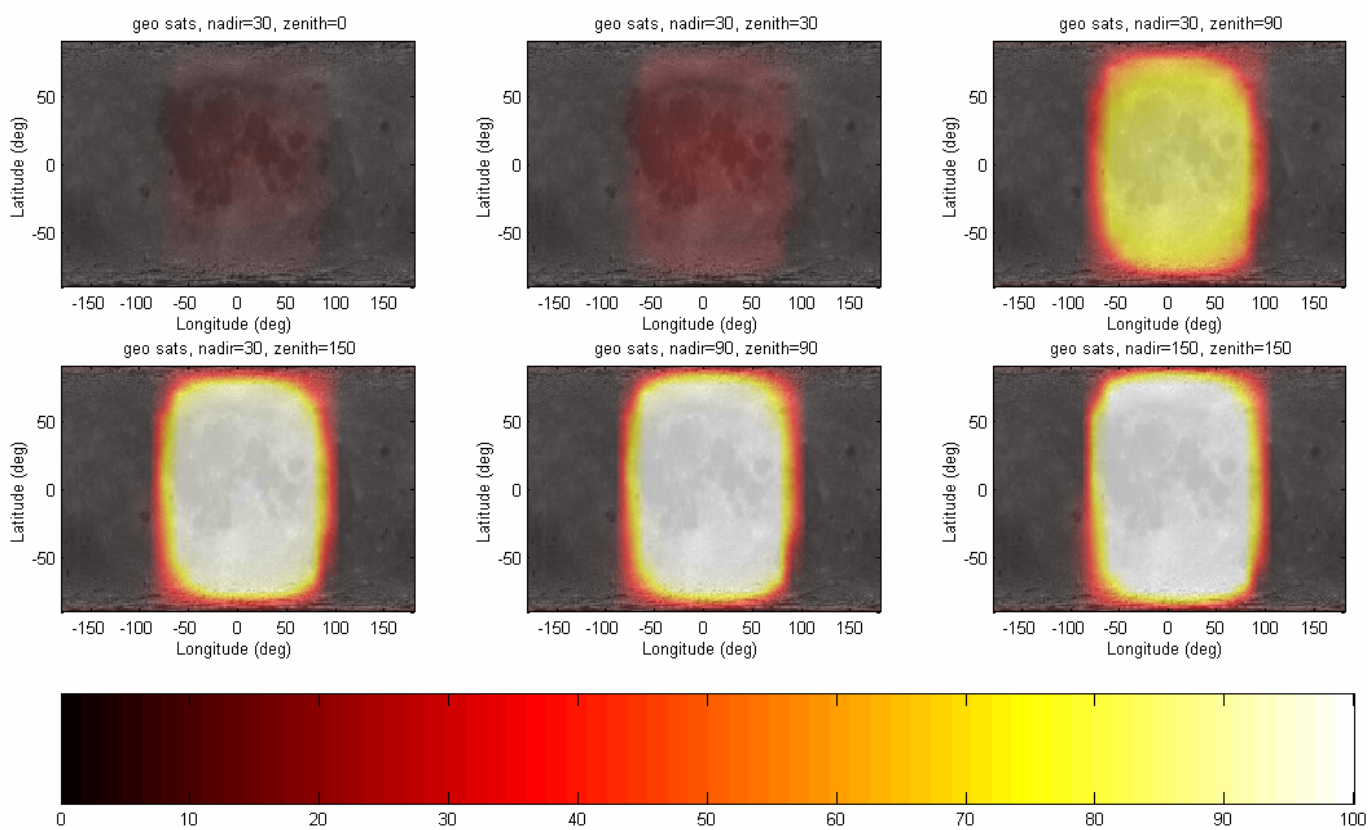

Figure B.2.4.1.—GEO system availability results.

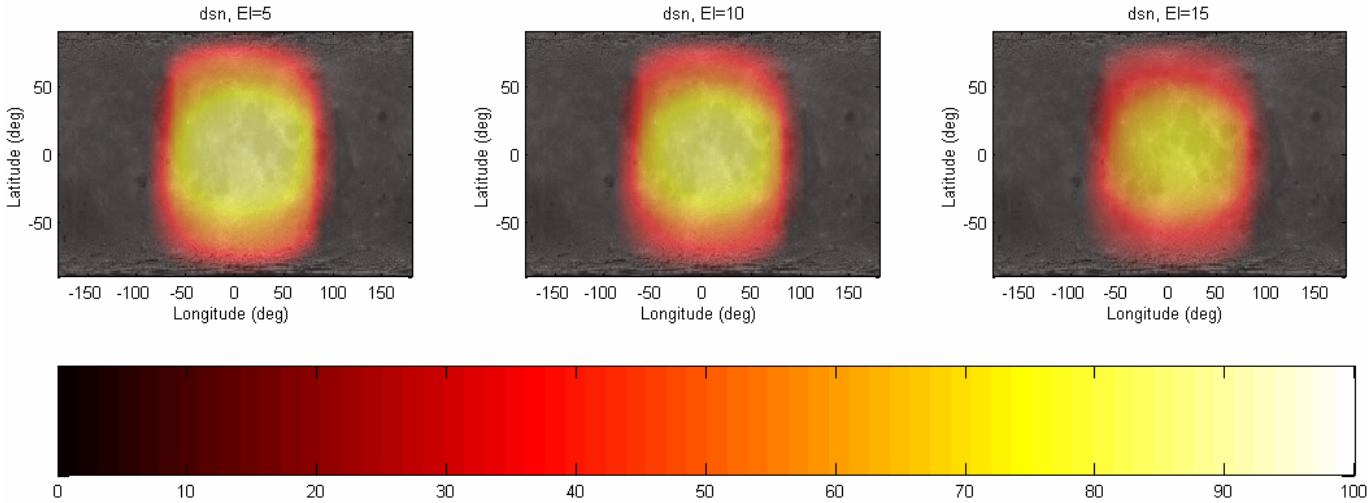

Figure B.2.4.2.—DSN system availability results.

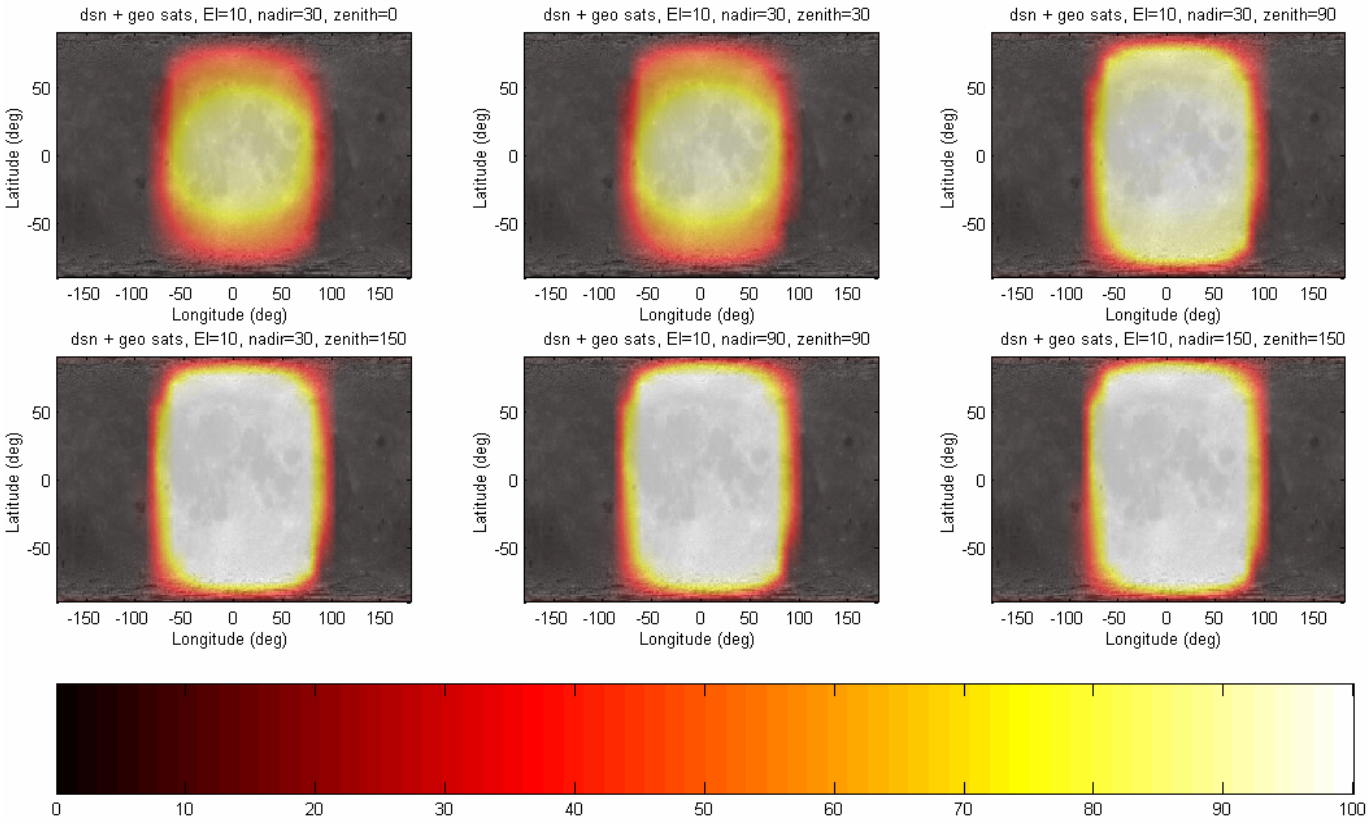

Figure B.2.4.3.—DSNGEO system availability results.

TABLE B.2.4.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	2.50	0.70	5.14	0.00	7.18
GEO 30/30	5.24	2.02	10.46	0.00	14.02
GEO 90/30	34.45	10.91	67.75	0.01	82.62
GEO 150/30	43.70	16.94	84.11	0.01	98.23
GEO 90/90	44.50	19.13	84.97	0.01	98.91
GEO 150/150	46.79	25.15	88.46	0.01	99.93
DSN 5	29.63	3.33	61.62	0.00	83.64
DSN 10	26.87	2.53	56.88	0.00	80.15
DSN 15	22.47	2.01	48.34	0.00	70.80
DSN+GEO 10/0/30	31.00	3.32	64.90	0.00	88.93
DSN+GEO 10/30/30	33.57	4.80	69.47	0.00	92.76
DSN+GEO 10/90/30	42.29	15.72	82.08	0.01	98.31
DSN+GEO 10/150/30	45.36	20.43	86.46	0.01	99.45
DSN+GEO 10/90/90	45.30	20.99	86.14	0.01	99.48
DSN+GEO 10/150/150	46.89	25.72	88.60	0.01	99.97

TABLE B.2.4.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.80	0.22	1.64	0.00	2.27
GEO 30/30	1.73	0.67	3.47	0.00	4.63
GEO 90/30	12.23	4.21	23.82	0.01	28.41
GEO 150/30	10.13	4.70	19.37	0.01	21.57
GEO 90/90	8.21	6.48	13.89	0.01	12.89
GEO 150/150	1.22	4.21	1.78	0.01	0.27
DSN 5	11.54	1.52	22.78	0.00	26.58
DSN 10	11.87	0.98	22.15	0.00	27.94
DSN 15	9.08	0.72	19.02	0.00	25.57
DSN+GEO 10/0/30 -v1	10.76	0.99	21.78	0.00	27.15
DSN+GEO 10/0/30 -v2	11.04	2.47	21.08	0.00	22.41
DSN+GEO 10/30/30 -v1	9.81	1.12	19.53	0.00	23.09
DSN+GEO 10/30/30 -v2	10.28	2.91	19.11	0.00	18.77
DSN+GEO 10/90/30 -v1	2.21	1.23	4.00	0.00	3.96
DSN+GEO 10/90/30 -v2	6.76	6.48	10.87	0.01	7.61
DSN+GEO 10/150/30 -v1	0.57	0.96	0.79	0.00	0.39
DSN+GEO 10/150/30 -v2	4.18	5.45	6.54	0.01	3.05
DSN+GEO 10/90/90 -v1	0.20	0.93	0.30	0.00	0.12
DSN+GEO 10/90/90 -v2	3.43	4.67	5.58	0.01	4.74
DSN+GEO 10/150/150 -v1	0.04	0.39	0.05	0.00	0.00
DSN+GEO 10/150/150 -v2	0.85	3.30	1.25	0.01	0.18

B.2.5 Dynamic (4 hr).—Figures B.2.5.1 to B.2.5.3 show the system availability results for the 15 Earth-based constellations when the system is operating in one-way mode with terrain information but without clock synchronization (solving with 4-hr dynamic measurements). Table B.2.5.1 tabulates the weighted system availabilities from figures B.2.5.1 to B.2.5.3. Table B.2.5.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

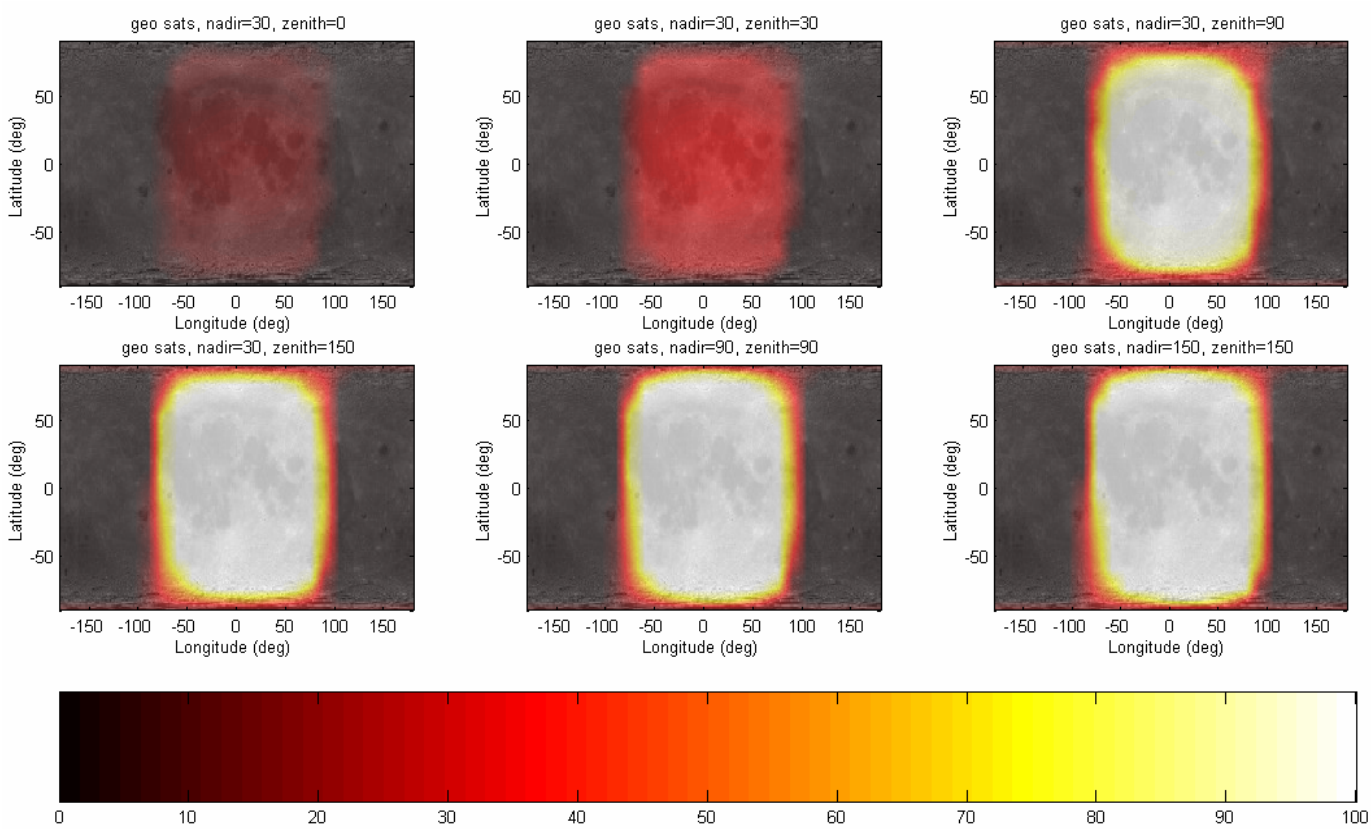

Figure B.2.5.1.—GEO system availability results.

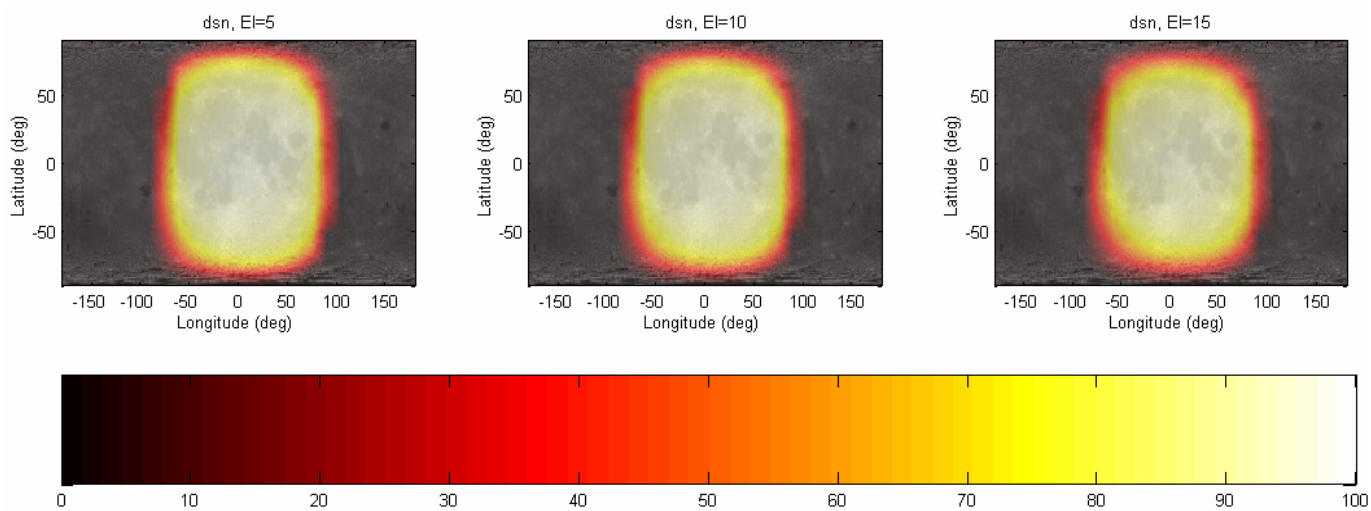

Figure B.2.5.2.—DSN system availability results.

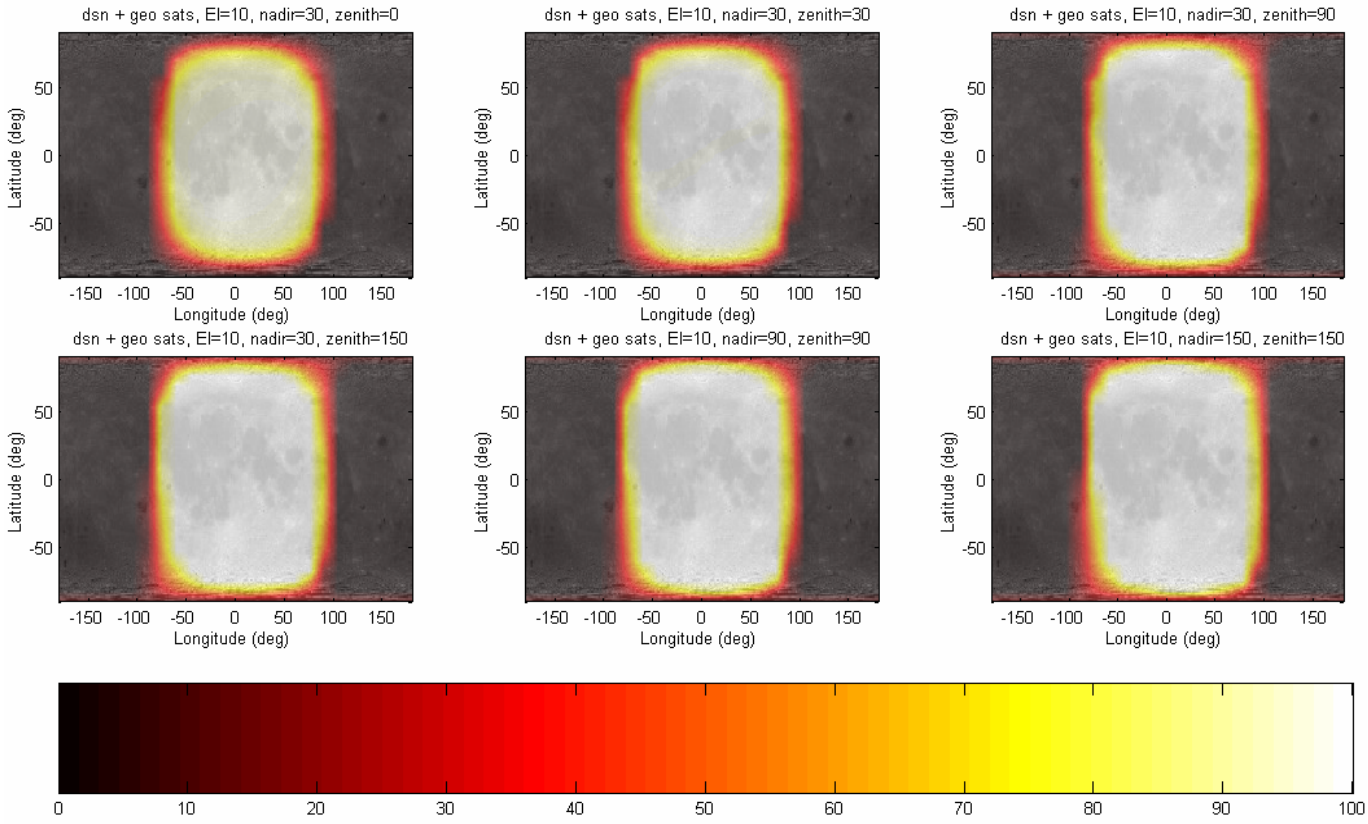

Figure B.2.5.3.—DSNGEO system availability results.

TABLE B.2.5.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	6.16	2.26	12.29	0.00	16.36
GEO 30/30	13.71	5.49	26.88	0.00	34.05
GEO 90/30	43.55	16.25	83.97	0.01	98.92
GEO 150/30	46.51	24.89	88.07	0.01	99.68
GEO 90/90	46.40	27.49	87.50	0.01	99.92
GEO 150/150	48.15	32.94	90.45	0.01	100.00
DSN 5	38.99	7.16	77.40	0.00	95.28
DSN 10	37.83	5.47	75.80	0.00	94.43
DSN 15	36.08	4.34	73.34	0.00	93.21
DSN+GEO 10/0/30	41.02	8.22	80.70	0.00	97.53
DSN+GEO 10/30/30	42.76	11.76	83.13	0.00	98.80
DSN+GEO 10/90/30	45.46	21.74	86.36	0.01	99.90
DSN+GEO 10/150/30	46.91	26.24	88.59	0.01	99.99
DSN+GEO 10/90/90	46.61	28.79	87.79	0.01	99.98
DSN+GEO 10/150/150	48.15	32.98	90.45	0.01	100.00

TABLE B.2.5.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	1.99	0.76	3.96	0.00	5.20
GEO 30/30	5.24	1.97	10.29	0.00	12.72
GEO 90/30	12.82	5.01	24.41	0.00	27.78
GEO 150/30	7.44	5.97	13.81	0.00	13.94
GEO 90/90	2.28	6.32	3.11	0.00	1.36
GEO 150/150	0.92	4.20	1.40	0.00	0.00
DSN 5	10.59	2.89	19.63	0.00	20.65
DSN 10	11.75	1.98	22.39	0.00	24.72
DSN 15	12.28	1.34	24.10	0.00	27.93
DSN+GEO 10/0/30 -v1	9.95	2.20	18.49	0.00	19.75
DSN+GEO 10/0/30 -v2	8.62	4.82	15.03	0.00	13.31
DSN+GEO 10/30/30 -v1	7.95	2.34	14.45	0.00	14.78
DSN+GEO 10/30/30 -v2	6.74	5.91	11.06	0.00	9.18
DSN+GEO 10/90/30 -v1	0.45	0.89	0.58	0.00	0.17
DSN+GEO 10/90/30 -v2	2.13	6.20	2.84	0.00	1.33
DSN+GEO 10/150/30 -v1	0.10	0.32	0.13	0.00	0.07
DSN+GEO 10/150/30 -v2	1.64	5.16	2.37	0.00	0.49
DSN+GEO 10/90/90 -v1	0.07	0.62	0.08	0.00	0.00
DSN+GEO 10/90/90 -v2	0.92	4.29	1.20	0.00	0.27
DSN+GEO 10/150/150 -v1	0.00	0.04	0.00	0.00	0.00
DSN+GEO 10/150/150 -v2	0.81	3.80	1.25	0.00	0.00

B.2.6 Dynamic (8 hr).—Figures B.2.6.1 to B.2.6.3 show the system availability results for the 15 Earth-based constellations when the system is operating in one-way mode with terrain information but without clock synchronization (solving with 8-hr dynamic measurements). Table B.2.6.1 tabulates the weighted system availabilities from figures B.2.6.1 to B.2.6.3. Table B.2.6.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

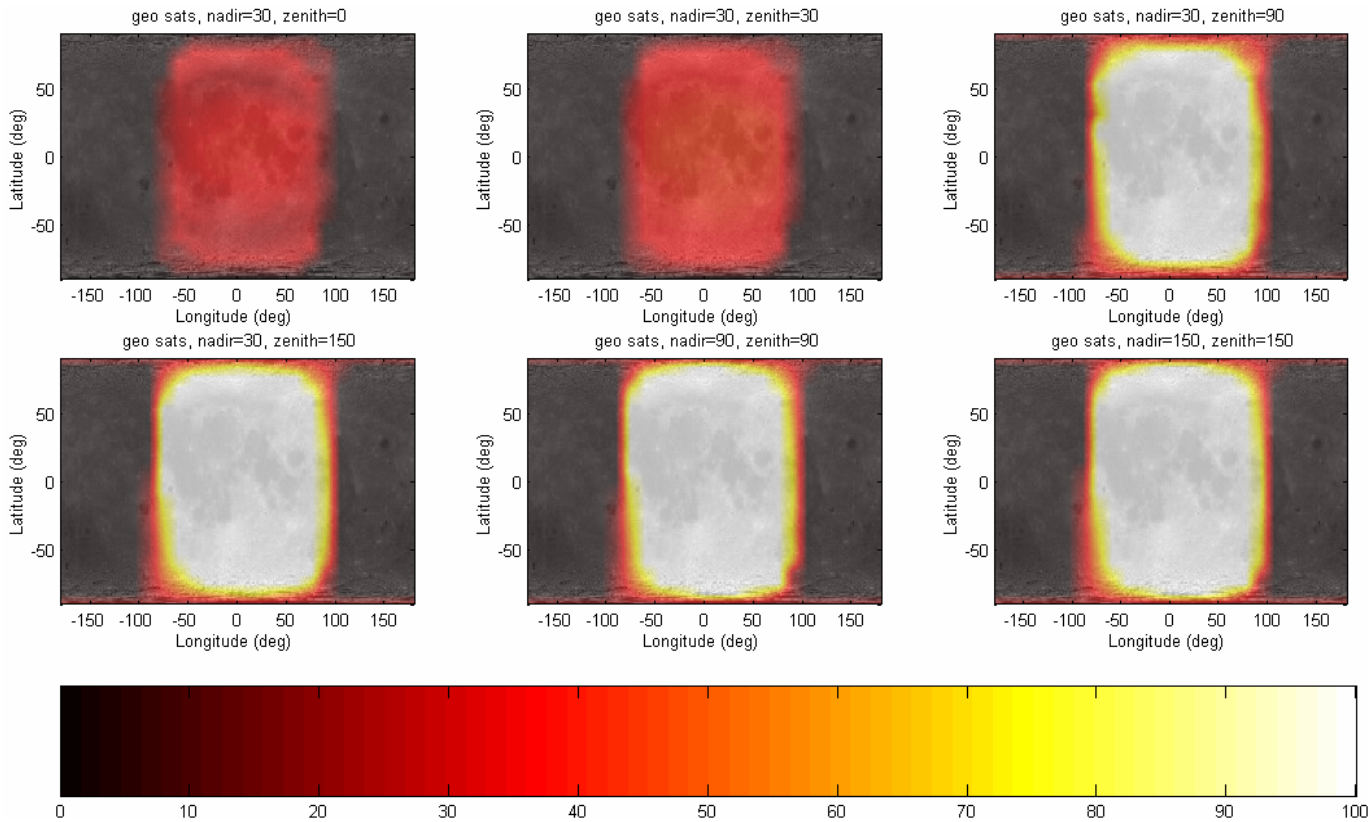

Figure B.2.6.1.—GEO system availability results.

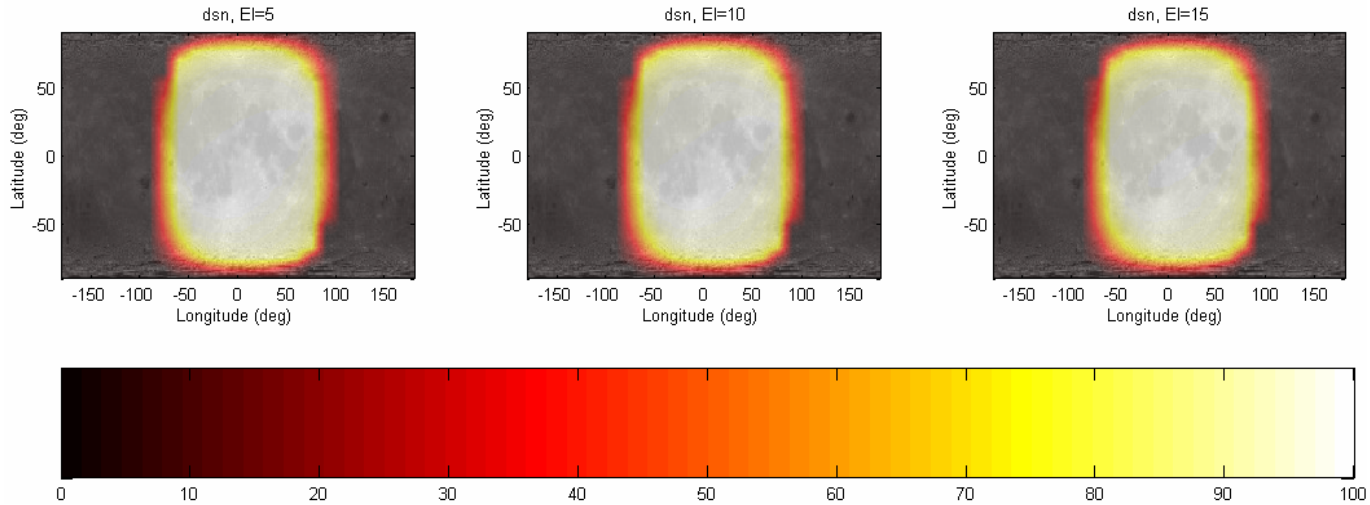

Figure B.2.6.2.—DSN system availability results.

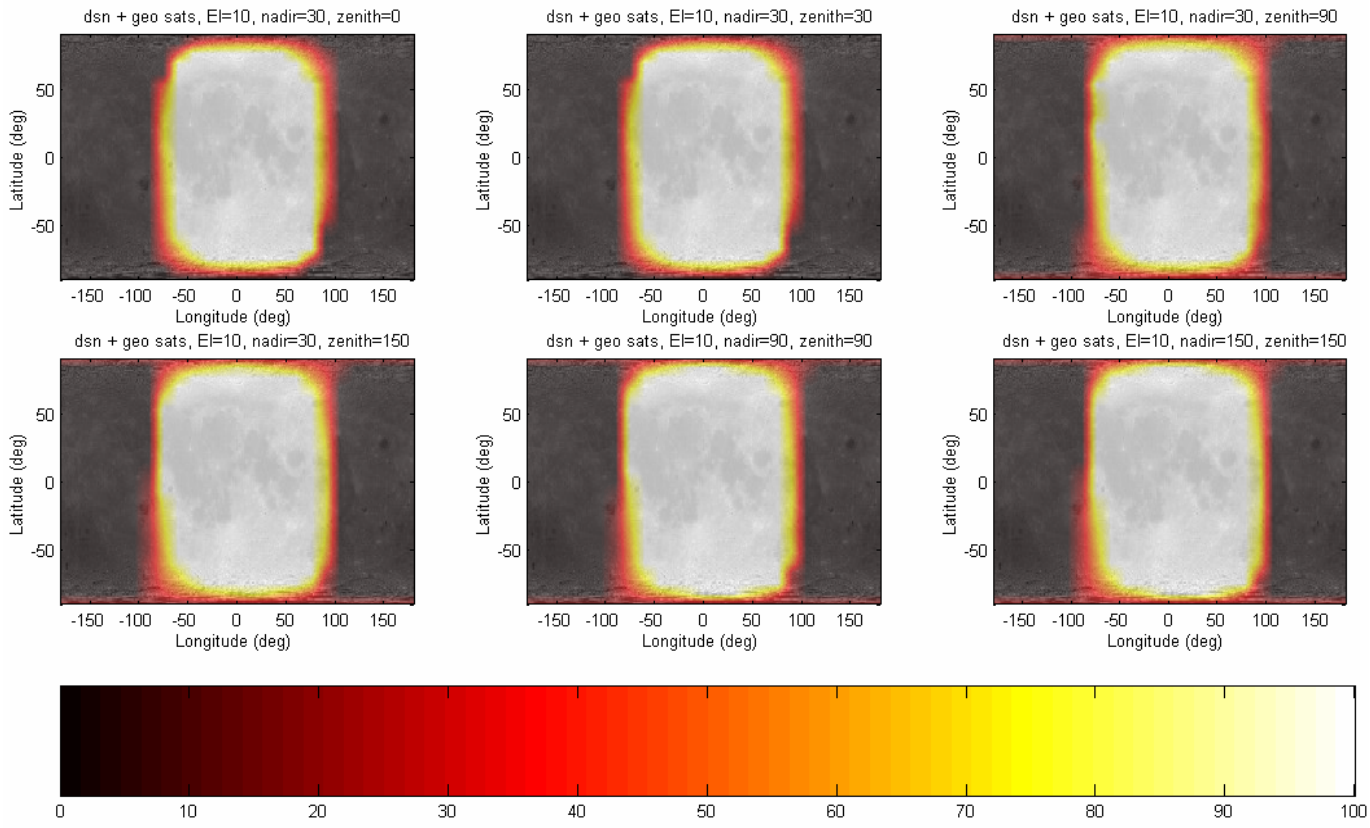

Figure B.2.6.3.—DSNGEO system availability results.

TABLE B.2.6.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	14.78	6.24	28.78	0.00	36.90
GEO 30/30	17.93	7.88	34.68	0.00	42.26
GEO 90/30	46.19	24.08	87.33	0.02	100.00
GEO 150/30	48.00	28.62	90.43	0.02	100.00
GEO 90/90	47.74	34.83	89.31	0.02	100.00
GEO 150/150	48.70	36.06	91.25	0.02	100.00
DSN 5	43.02	13.45	83.20	0.00	93.71
DSN 10	42.52	12.35	82.54	0.00	98.49
DSN 15	41.80	10.62	81.62	0.00	98.15
DSN+GEO 10/0/30	44.88	18.41	85.56	0.00	99.89
DSN+GEO 10/30/30	45.00	19.57	85.70	0.00	100.00
DSN+GEO 10/90/30	46.62	27.29	87.65	0.02	100.00
DSN+GEO 10/150/30	48.03	29.27	90.43	0.02	100.00
DSN+GEO 10/90/90	47.74	34.83	89.31	0.02	100.00
DSN+GEO 10/150/150	48.70	36.06	91.25	0.02	100.00

TABLE B.2.6.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	5.41	2.59	10.41	0.00	12.99
GEO 30/30	3.05	1.31	5.94	0.00	6.48
GEO 90/30	6.26	5.97	11.09	0.00	11.10
GEO 150/30	1.22	3.48	2.01	0.00	0.02
GEO 90/90	0.85	5.28	1.09	0.00	0.05
GEO 150/150	0.54	2.94	0.85	0.00	0.00
DSN 5	6.17	4.18	10.36	0.00	3.99
DSN 10	7.61	4.18	13.24	0.00	12.52
DSN 15	8.94	3.76	15.98	0.00	15.85
DSN+GEO 10/0/30 -v1	4.23	3.47	7.03	0.00	6.53
DSN+GEO 10/0/30 -v2	2.05	5.18	2.64	0.00	1.25
DSN+GEO 10/30/30 -v1	3.93	3.20	6.42	0.00	5.64
DSN+GEO 10/30/30 -v2	0.73	3.56	0.72	0.00	0.19
DSN+GEO 10/90/30 -v1	0.08	0.89	0.08	0.00	0.00
DSN+GEO 10/90/30 -v2	0.57	2.68	0.69	0.00	0.00
DSN+GEO 10/150/30 -v1	0.01	0.41	50.00	0.00	0.00
DSN+GEO 10/150/30 -v2	0.86	2.59	1.37	0.00	0.00
DSN+GEO 10/90/90 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/90/90 -v2	0.66	4.49	0.87	0.00	0.00
DSN+GEO 10/150/150 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/150/150 -v2	0.53	2.85	0.84	0.00	0.00

B.2.7 Dynamic (12 hr).—Figures B.2.7.1 to B.2.7.3 show the system availability results for the 15 Earth-based constellations when the system is operating in one-way mode with terrain information but without clock synchronization (solving with 12-hr dynamic measurements). Table B.2.7.1 tabulates the weighted system availabilities from figures B.2.7.1 to B.2.7.3. Table B.2.7.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

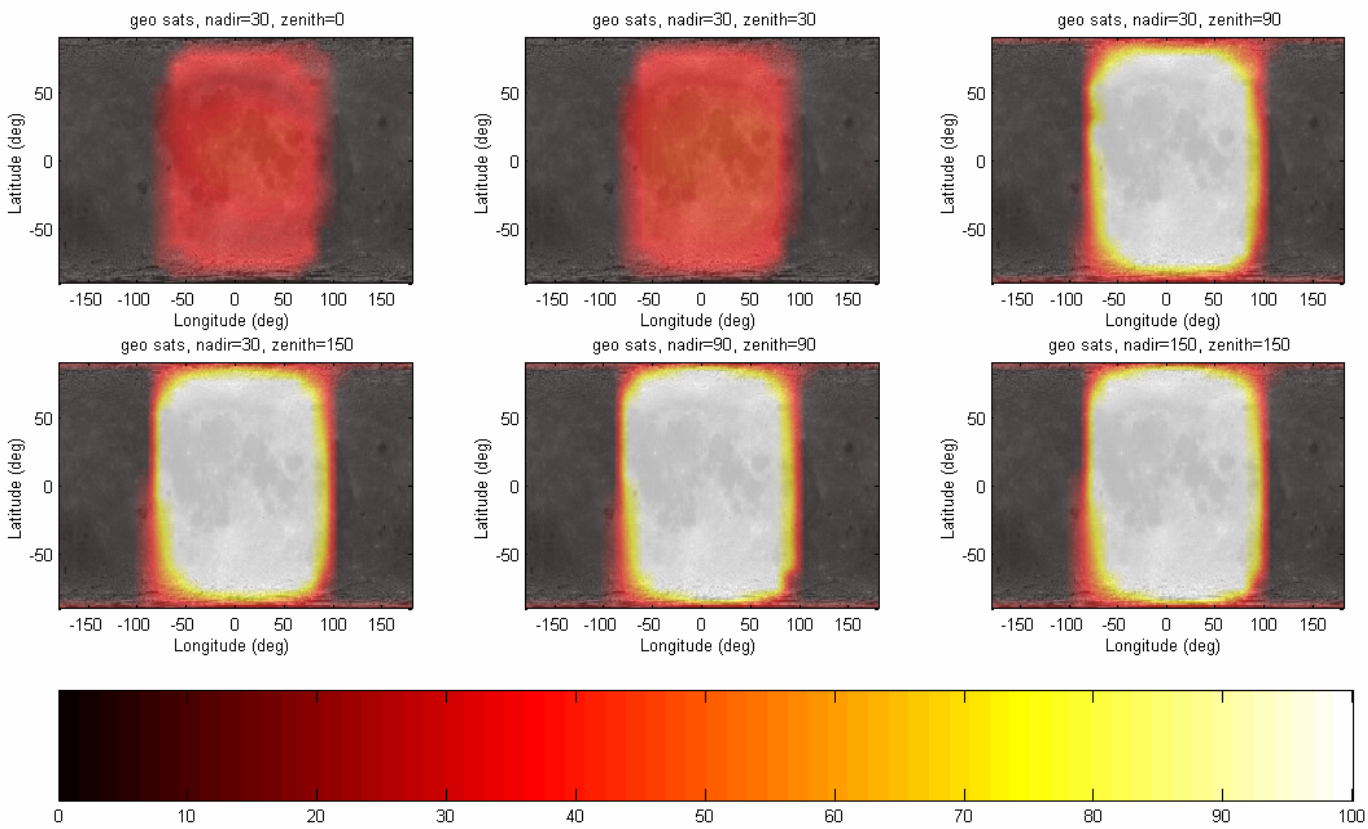

Figure B.2.7.1.—GEO system availability results.

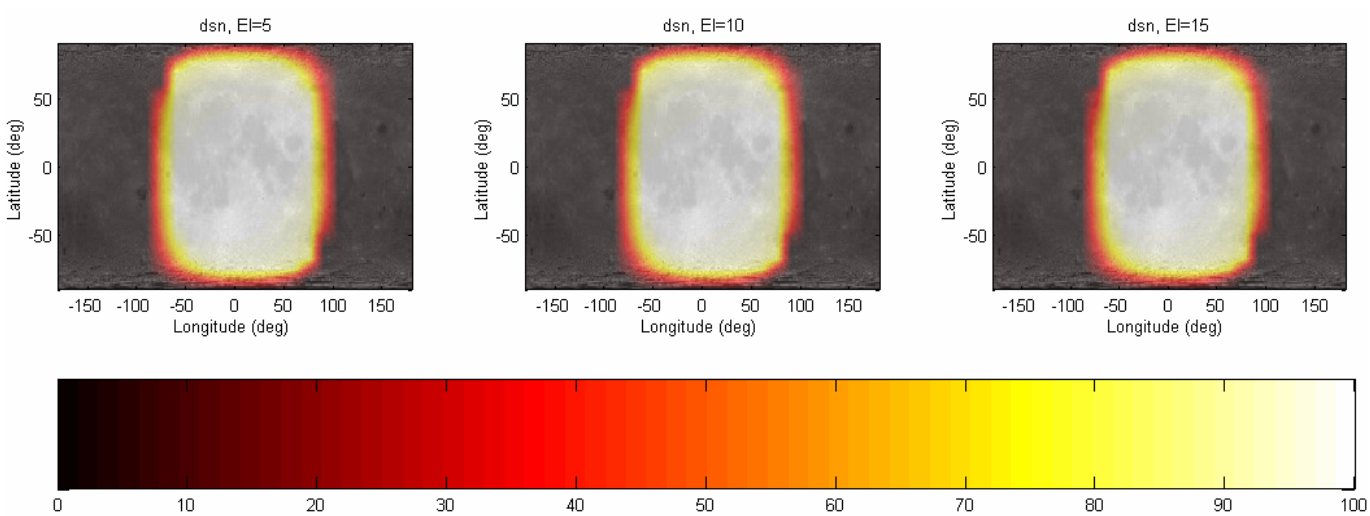

Figure B.2.7.2.—DSN system availability results.

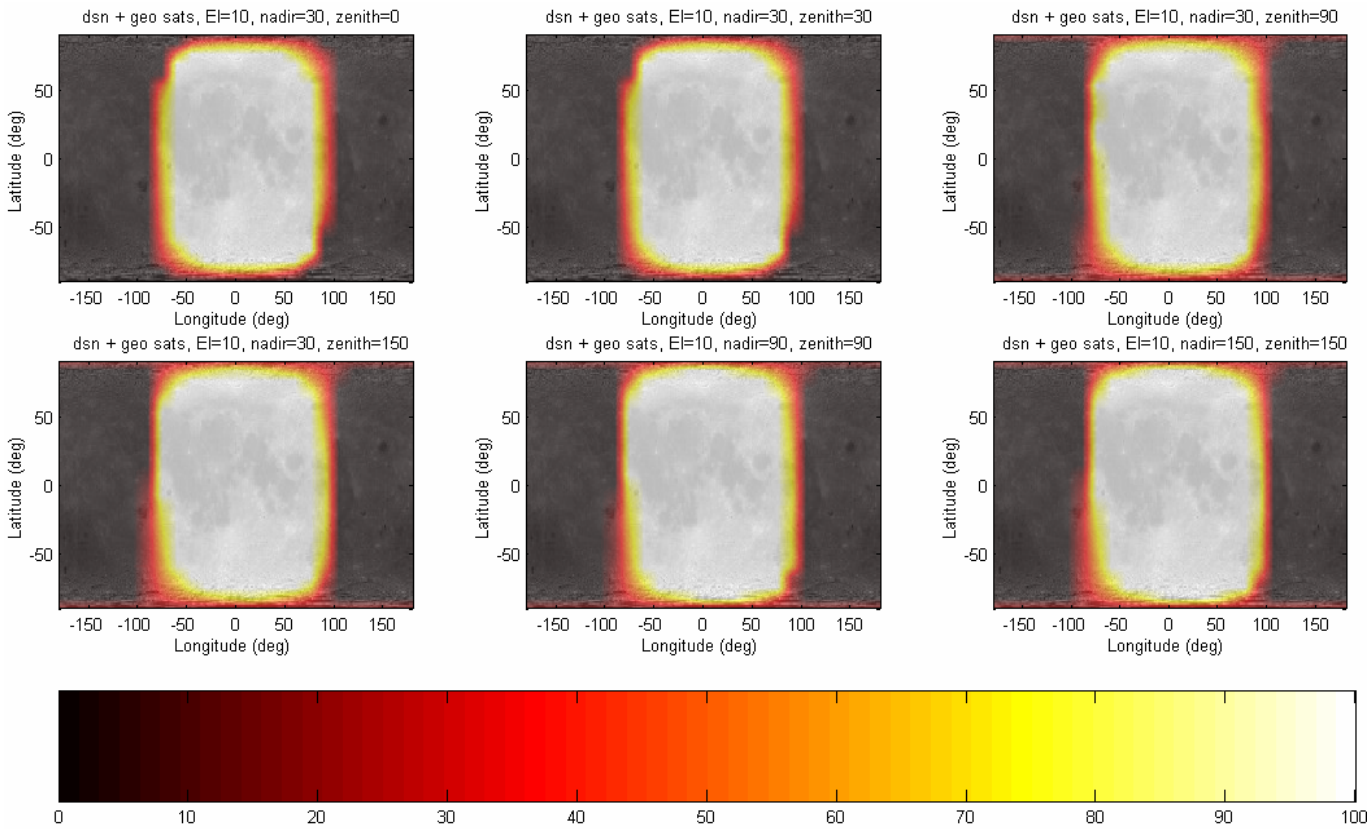

Figure B.2.7.3.—DSNGEO system availability results.

TABLE B.2.7.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	16.26	6.88	31.58	0.00	39.81
GEO 30/30	18.57	8.54	35.83	0.00	43.54
GEO 90/30	46.61	26.01	87.96	0.02	100.00
GEO 150/30	48.17	29.06	90.70	0.03	100.00
GEO 90/90	47.87	35.18	89.48	0.02	100.00
GEO 150/150	48.82	36.36	91.45	0.03	100.00
DSN 5	43.87	15.19	84.44	0.00	99.44
DSN 10	43.54	14.50	84.01	0.00	99.26
DSN 15	43.07	13.54	83.39	0.00	99.07
DSN+GEO 10/0/30	45.16	19.67	85.92	0.00	100.00
DSN+GEO 10/30/30	45.27	21.10	86.02	0.00	100.00
DSN+GEO 10/90/30	46.90	27.91	88.17	0.02	100.00
DSN+GEO 10/150/30	48.20	29.86	90.70	0.03	100.00
DSN+GEO 10/90/90	47.87	35.18	89.48	0.02	100.00
DSN+GEO 10/150/150	48.82	36.36	91.45	0.03	100.00

TABLE B.2.7.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	4.05	2.27	7.67	0.00	8.86
GEO 30/30	1.49	1.39	2.78	0.00	2.91
GEO 90/30	1.40	4.44	1.95	0.00	0.83
GEO 150/30	0.53	1.47	0.83	0.01	0.00
GEO 90/90	0.40	2.61	0.51	0.00	0.00
GEO 150/150	0.26	1.15	0.43	0.01	0.00
DSN 5	2.02	3.85	2.98	0.00	2.14
DSN 10	2.65	3.78	3.82	0.00	2.56
DSN 15	3.94	3.89	5.91	0.00	4.23
DSN+GEO 10/0/30 -v1	0.97	2.61	1.03	0.00	0.17
DSN+GEO 10/0/30 -v2	0.54	1.91	0.62	0.00	0.15
DSN+GEO 10/30/30 -v1	0.92	2.59	0.92	0.00	0.00
DSN+GEO 10/30/30 -v2	0.22	1.15	0.24	0.00	0.00
DSN+GEO 10/90/30 -v1	0.05	1.06	0.04	0.00	0.00
DSN+GEO 10/90/30 -v2	0.42	1.27	0.61	0.00	0.00
DSN+GEO 10/150/30 -v1	0.01	0.57	0.00	0.00	0.00
DSN+GEO 10/150/30 -v2	0.46	1.26	0.74	0.01	0.00
DSN+GEO 10/90/90 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/90/90 -v2	0.37	2.13	0.48	0.00	0.00
DSN+GEO 10/150/150 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/150/150 -v2	0.26	1.15	0.43	0.01	0.00

B.3 No Terrain, 3-hr Clock Synchronization, One-Way Mode

B.3.1 Kinematic.—Figures B.3.1.1 to B.3.1.3 show the system availability results for the 15 Earth-based constellations when the system is operating in one-way mode without terrain information but with clock synchronization (solving with kinematic measurements). Table B.3.1.1 tabulates the weighted system availabilities from figures B.3.1.1 to B.3.1.3. Table B.3.1.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

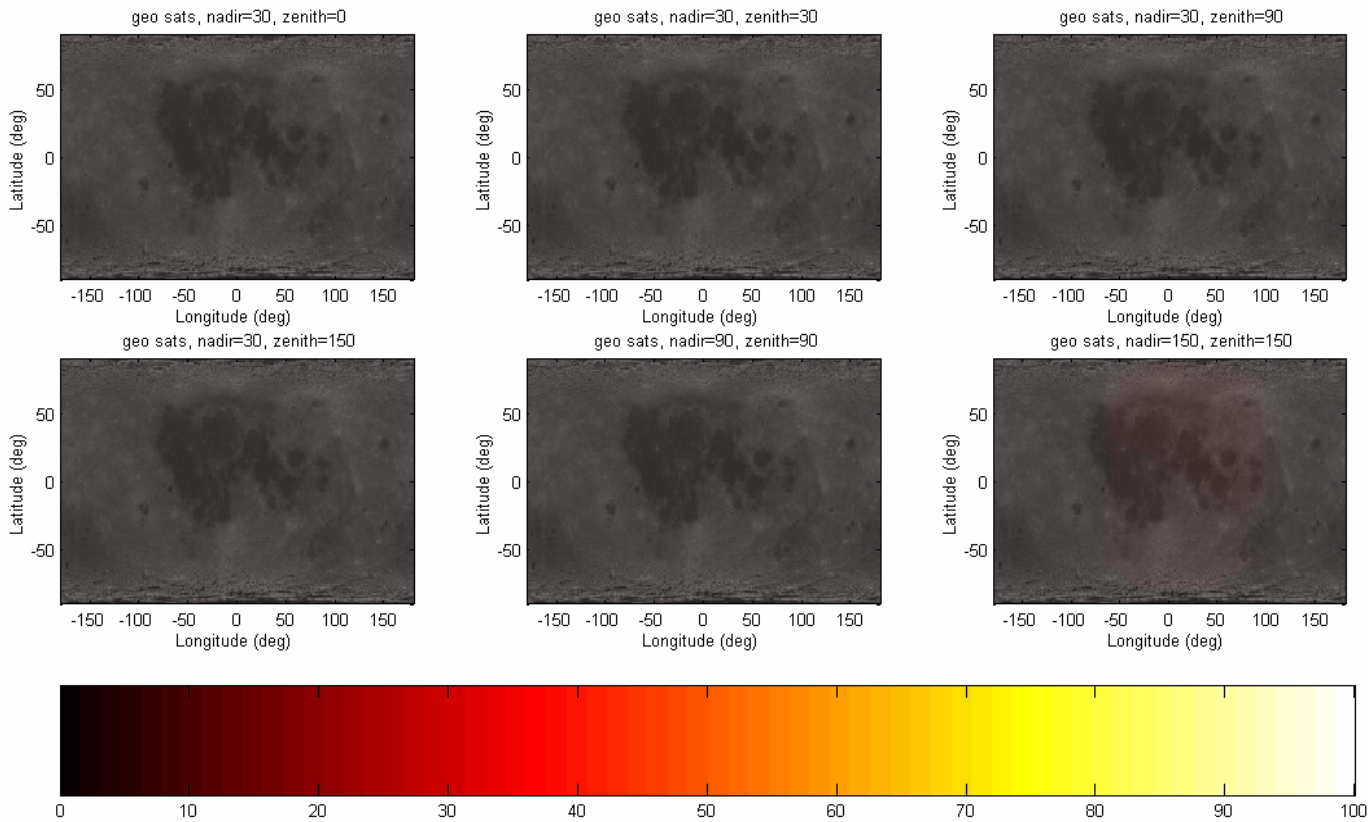

Figure B.3.1.1.—GEO system availability results.

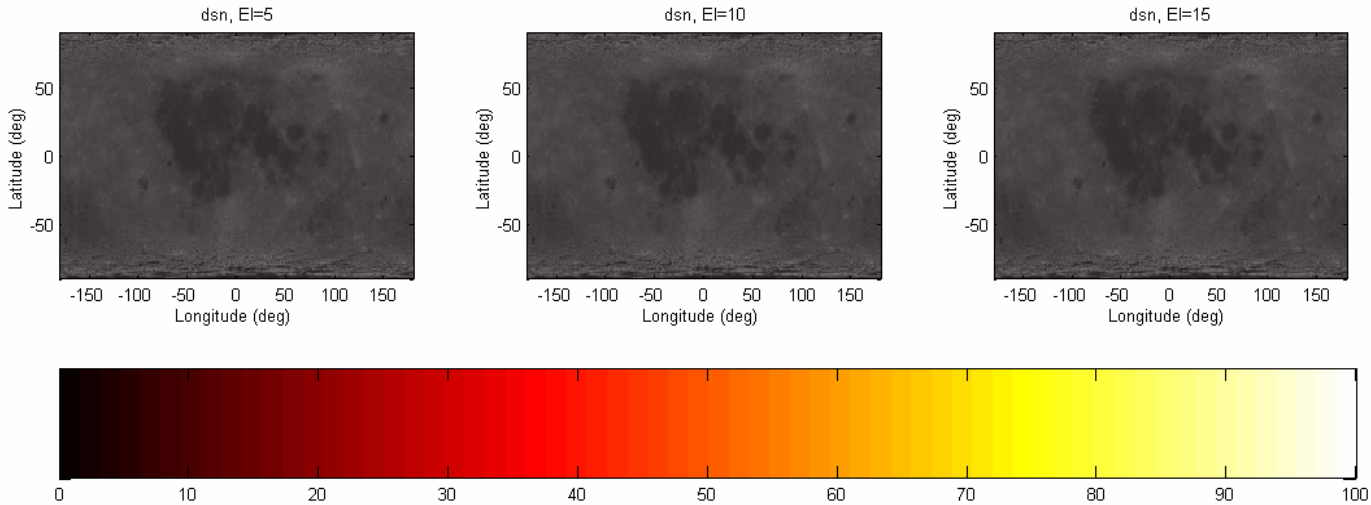

Figure B.3.1.2.—DSN system availability results.

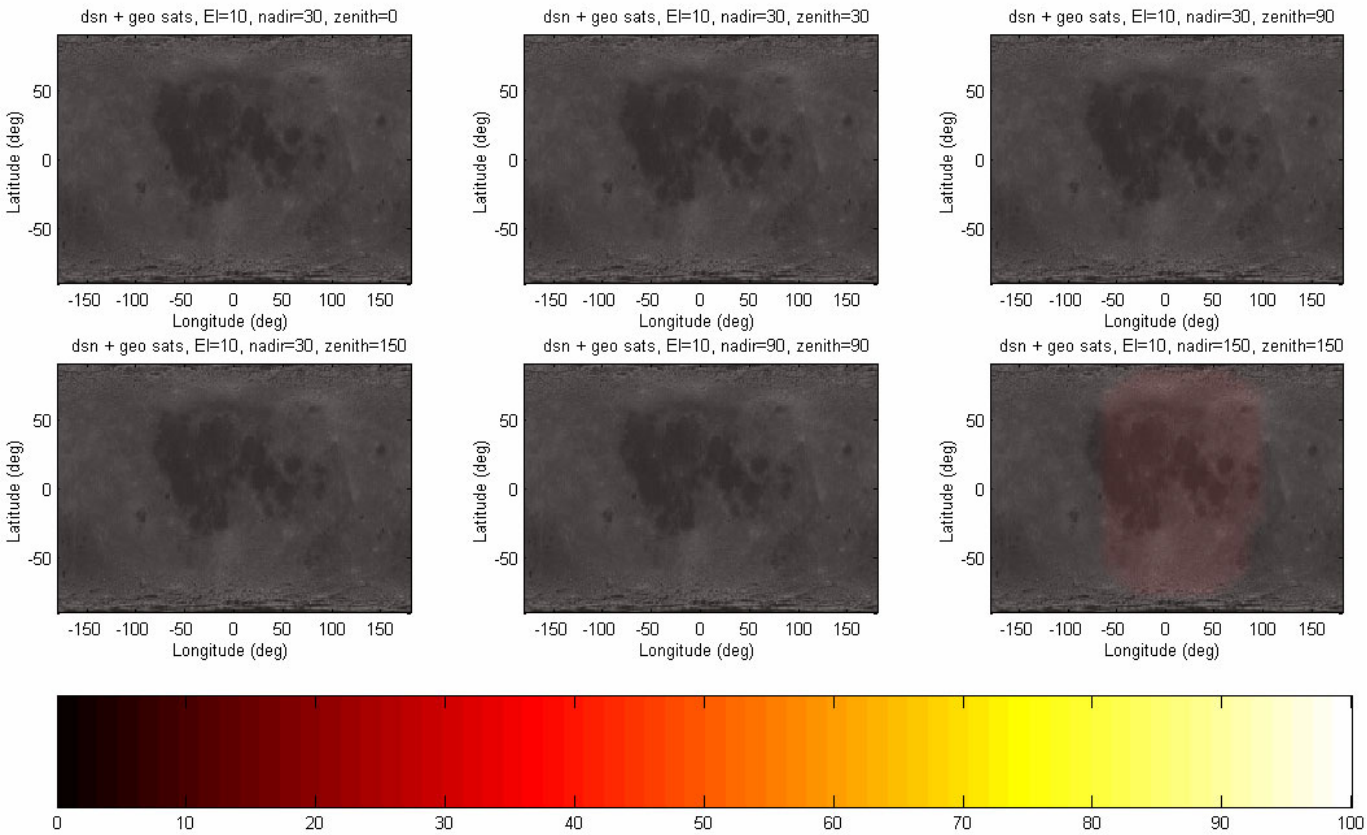

Figure B.3.1.3.—DSNGEO system availability results.

TABLE B.3.1.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	0.00	0.00	0.00	0.00	0.00
GEO 90/30	0.00	0.00	0.00	0.00	0.00
GEO 150/30	0.00	0.00	0.00	0.00	0.00
GEO 90/90	0.00	0.00	0.00	0.00	0.00
GEO 150/150	1.28	0.00	2.41	0.00	2.85
DSN 5	0.00	0.00	0.00	0.00	0.00
DSN 10	0.00	0.00	0.00	0.00	0.00
DSN 15	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/30/30	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/90/30	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/150/30	0.07	0.00	0.13	0.00	0.15
DSN+GEO 10/90/90	0.01	0.00	0.02	0.00	0.03
DSN+GEO 10/150/150	2.19	0.01	4.18	0.00	5.05

TABLE B.3.1.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	0.00	0.00	0.00	0.00	0.00
GEO 90/30	0.00	0.00	0.00	0.00	0.00
GEO 150/30	0.00	0.00	0.00	0.00	0.00
GEO 90/90	0.00	0.00	0.00	0.00	0.00
GEO 150/150	1.28	0.00	2.41	0.00	2.85
DSN 5	0.00	0.00	0.00	0.00	0.00
DSN 10	0.00	0.00	0.00	0.00	0.00
DSN 15	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30 -v2	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/30/30 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/30/30 -v2	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/90/30 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/90/30 -v2	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/150/30 -v1	0.04	0.00	0.07	0.00	0.07
DSN+GEO 10/150/30 -v2	0.07	0.00	0.13	0.00	0.15
DSN+GEO 10/90/90 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/90/90 -v2	0.01	0.00	0.02	0.00	0.03
DSN+GEO 10/150/150 -v1	0.35	0.01	0.68	0.00	0.77
DSN+GEO 10/150/150 -v2	1.76	0.01	3.37	0.00	4.07

B.3.2 Dynamic (15 min).—Figures B.3.2.1 to B.3.2.3 show the system availability results for the 15 Earth-based constellations when the system is operating in one-way mode without terrain information but with clock synchronization (solving with 15-min dynamic measurements). Table B.3.2.1 tabulates the weighted system availabilities from figures B.3.2.1 to B.3.2.3. Table B.3.2.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

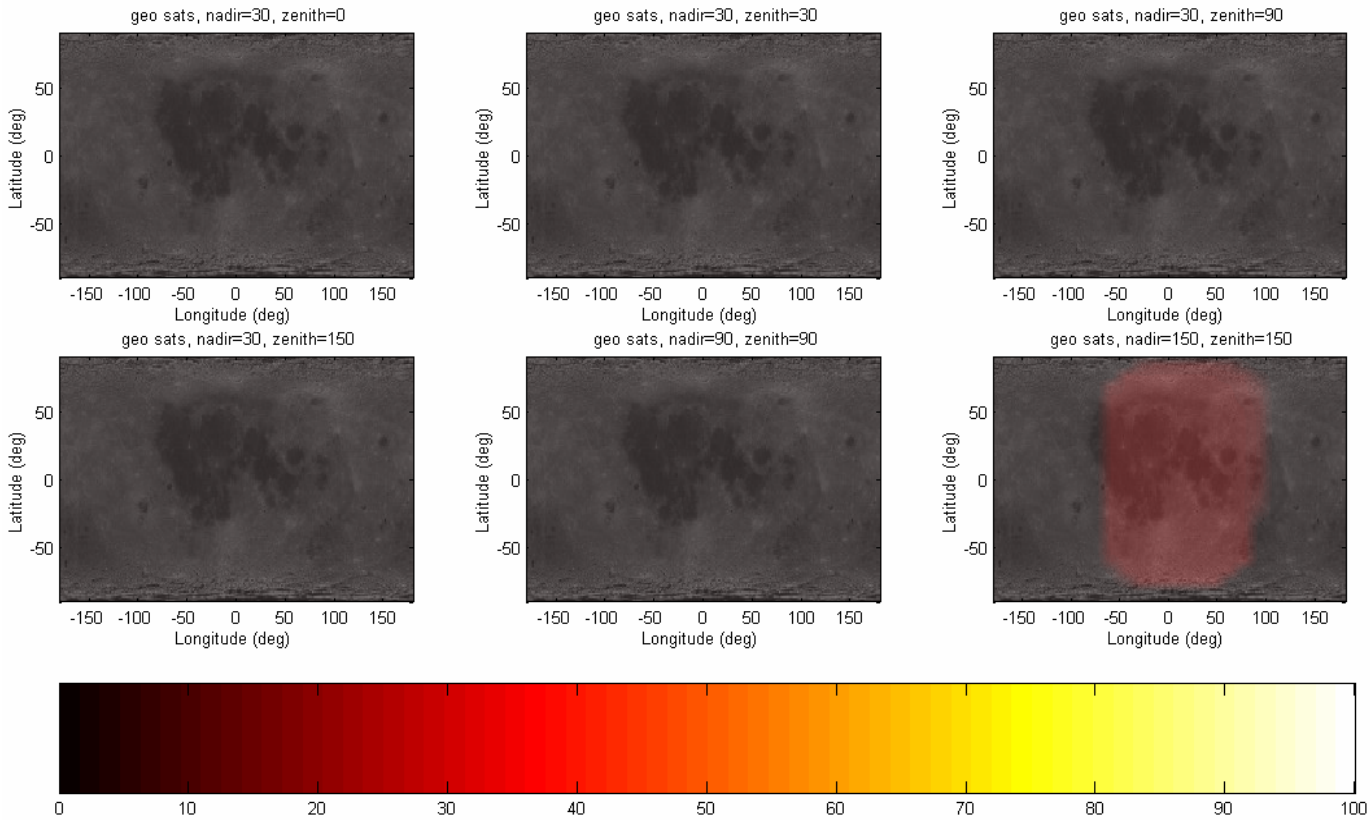

Figure B.3.2.1.—GEO system availability results.

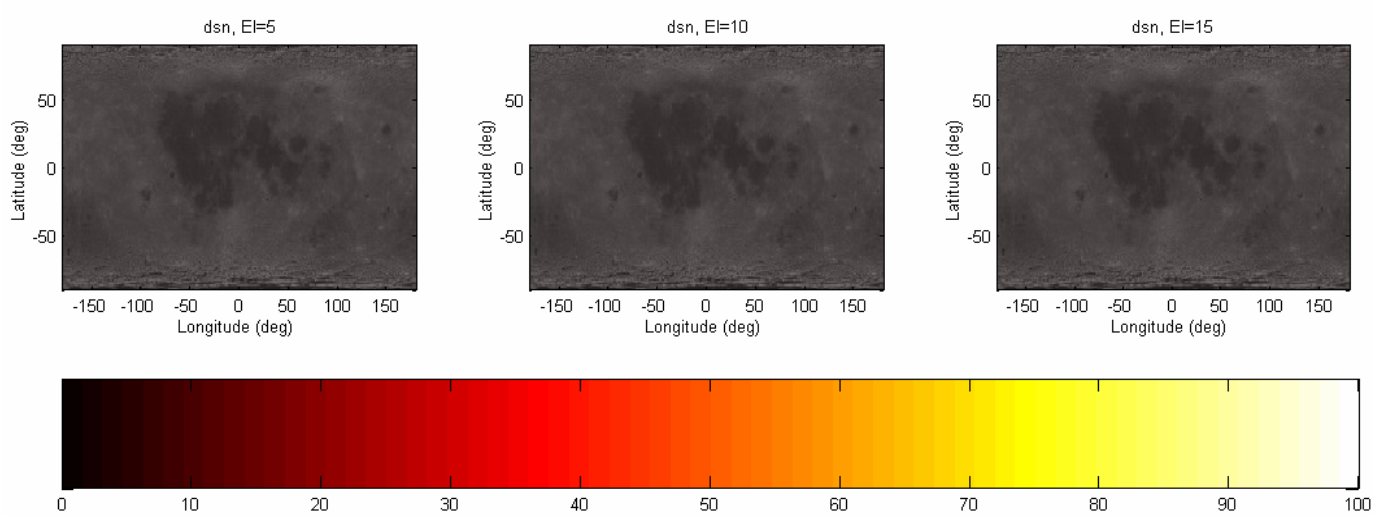

Figure B.3.2.2.—DSN system availability results.

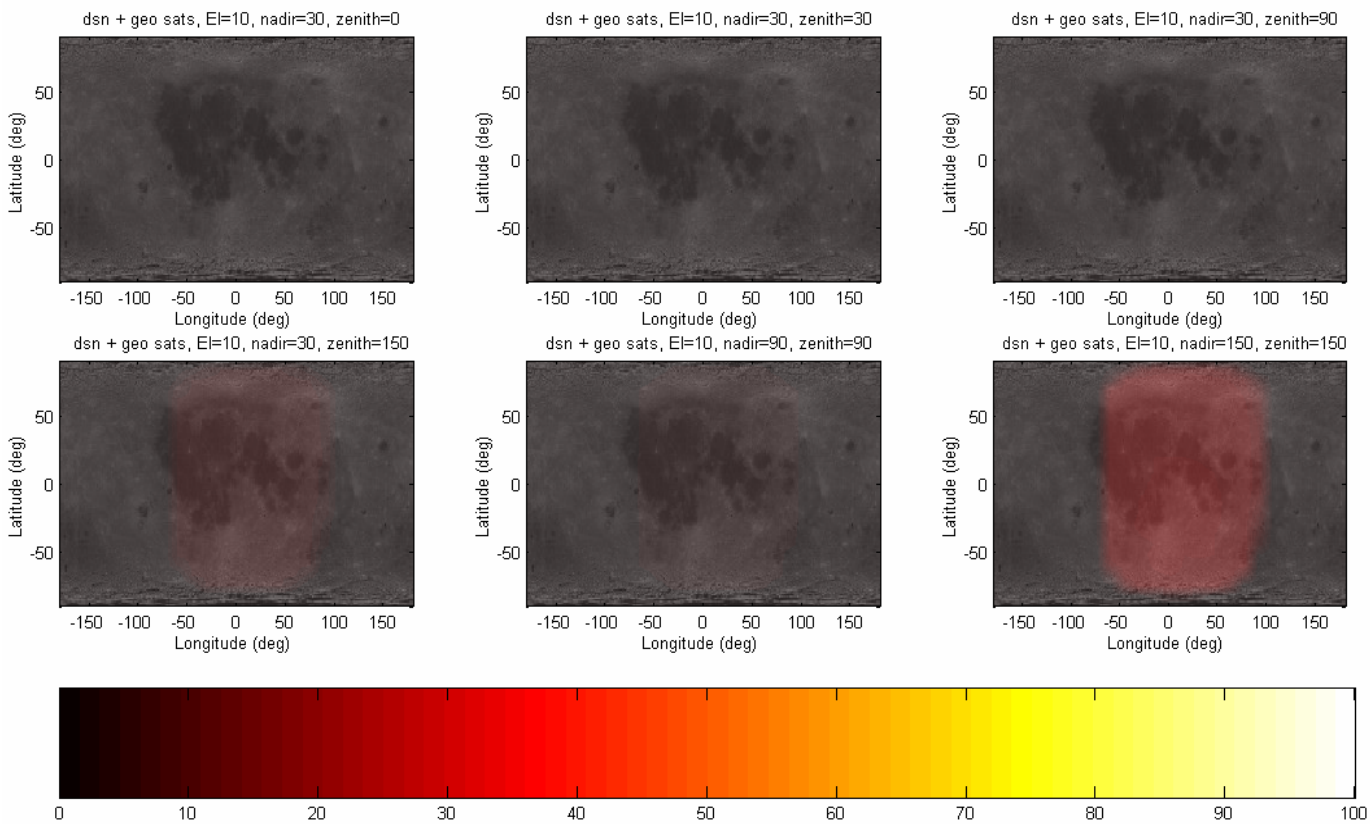

Figure B.3.2.3.—DSNGEO system availability results.

TABLE B.3.2.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	0.00	0.00	0.00	0.00	0.00
GEO 90/30	0.00	0.00	0.00	0.00	0.00
GEO 150/30	0.57	0.00	1.07	0.00	1.30
GEO 90/90	0.00	0.00	0.00	0.00	0.00
GEO 150/150	5.65	0.20	10.79	0.00	13.43
DSN 5	0.00	0.00	0.00	0.00	0.00
DSN 10	0.00	0.00	0.00	0.00	0.00
DSN 15	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/30/30	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/90/30	0.01	0.00	0.01	0.00	0.01
DSN+GEO 10/150/30	2.16	0.00	4.11	0.00	4.95
DSN+GEO 10/90/90	1.21	2.00	2.32	0.00	2.75
DSN+GEO 10/150/150	6.78	0.66	12.90	0.00	15.64

TABLE B.3.2.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	0.00	0.00	0.00	0.00	0.00
GEO 90/30	0.00	0.00	0.00	0.00	0.00
GEO 150/30	0.57	0.00	1.07	0.00	1.30
GEO 90/90	0.00	0.00	0.00	0.00	0.00
GEO 150/150	5.65	0.20	10.79	0.00	13.43
DSN 5	0.00	0.00	0.00	0.00	0.00
DSN 10	0.00	0.00	0.00	0.00	0.00
DSN 15	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30 -v2	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/30/30 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/30/30 -v2	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/90/30 -v1	0.01	0.00	0.01	0.00	0.01
DSN+GEO 10/90/30 -v2	0.01	0.00	0.01	0.00	0.01
DSN+GEO 10/150/30 -v1	0.46	0.00	0.87	0.00	1.01
DSN+GEO 10/150/30 -v2	1.92	0.00	3.65	0.00	4.40
DSN+GEO 10/90/90 -v1	0.25	2.00	0.47	0.00	0.54
DSN+GEO 10/90/90 -v2	1.07	2.00	2.05	0.00	2.43
DSN+GEO 10/150/150 -v1	0.36	0.22	0.66	0.00	0.75
DSN+GEO 10/150/150 -v2	2.86	0.61	5.43	0.00	6.66

B.3.3 Dynamic (1 hr).—Figures B.3.3.1 to B.3.3.3 show the system availability results for the 15 Earth-based constellations when the system is operating in one-way mode without terrain information but with clock synchronization (solving with 1-hr dynamic measurements). Table B.3.3.1 tabulates the weighted system availabilities from figures B.3.3.1 to B.3.3.3. Table B.3.3.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

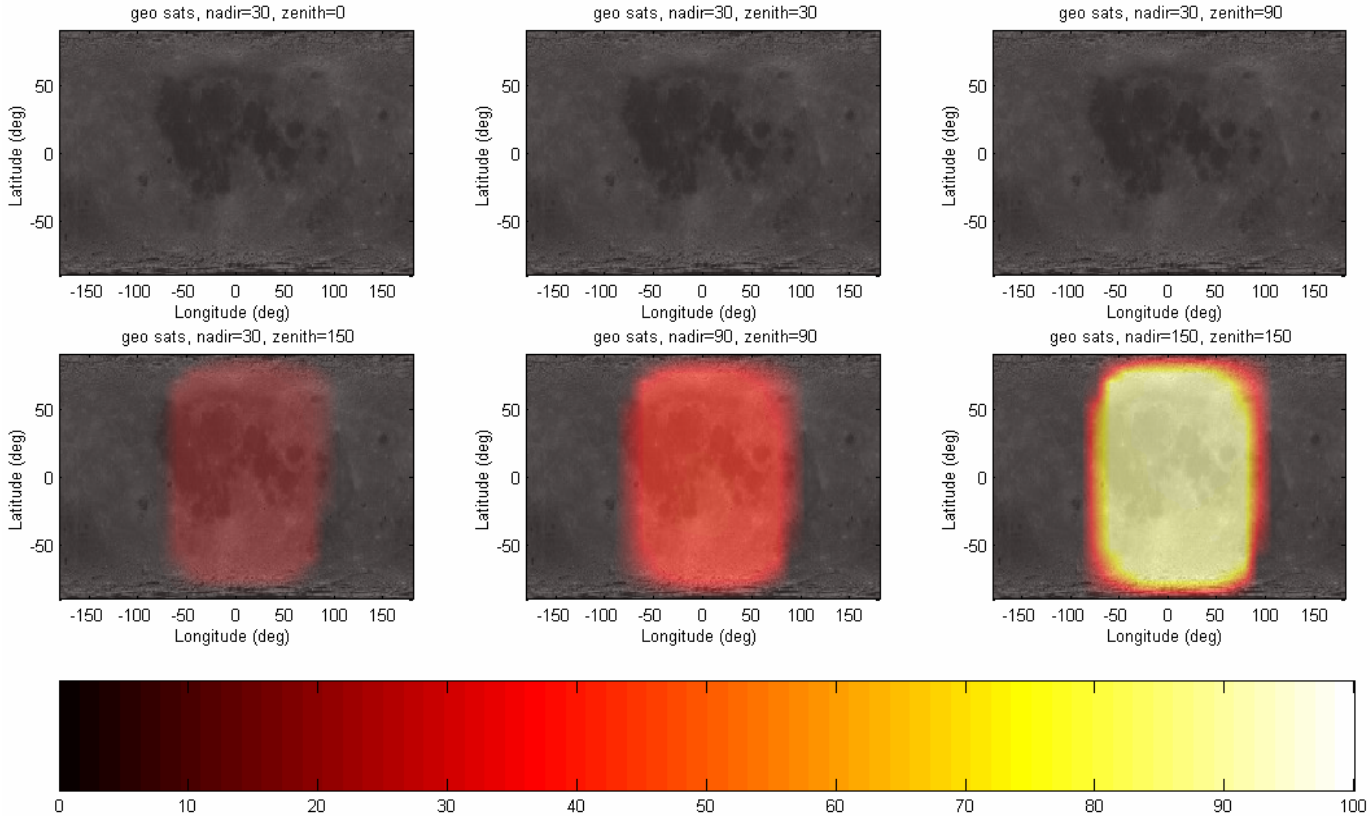

Figure B.3.3.1.—GEO system availability results.

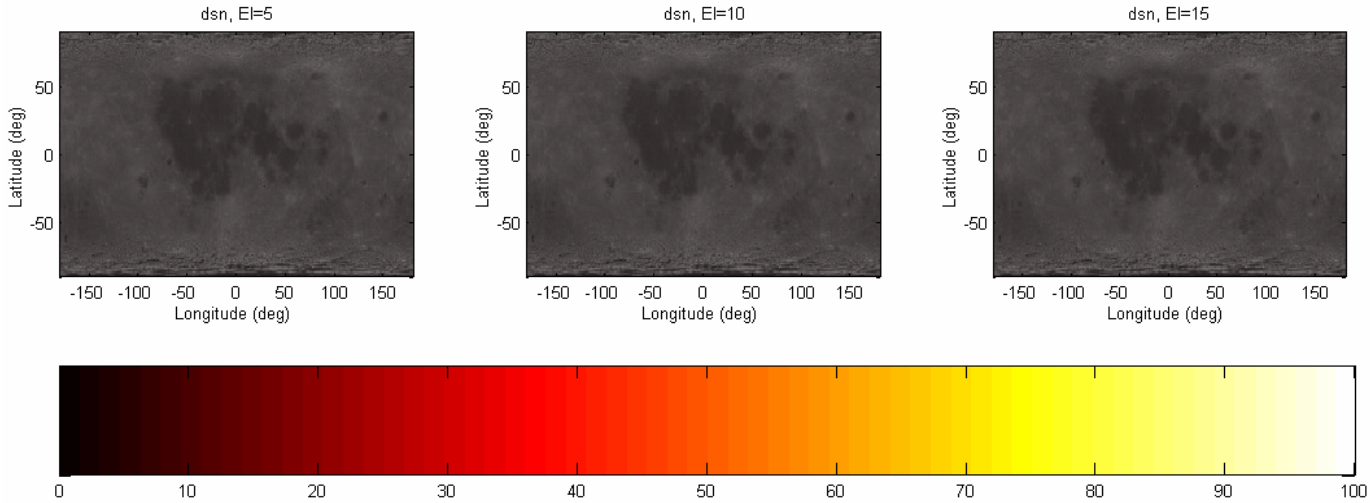

Figure B.3.3.2.—DSN system availability results.

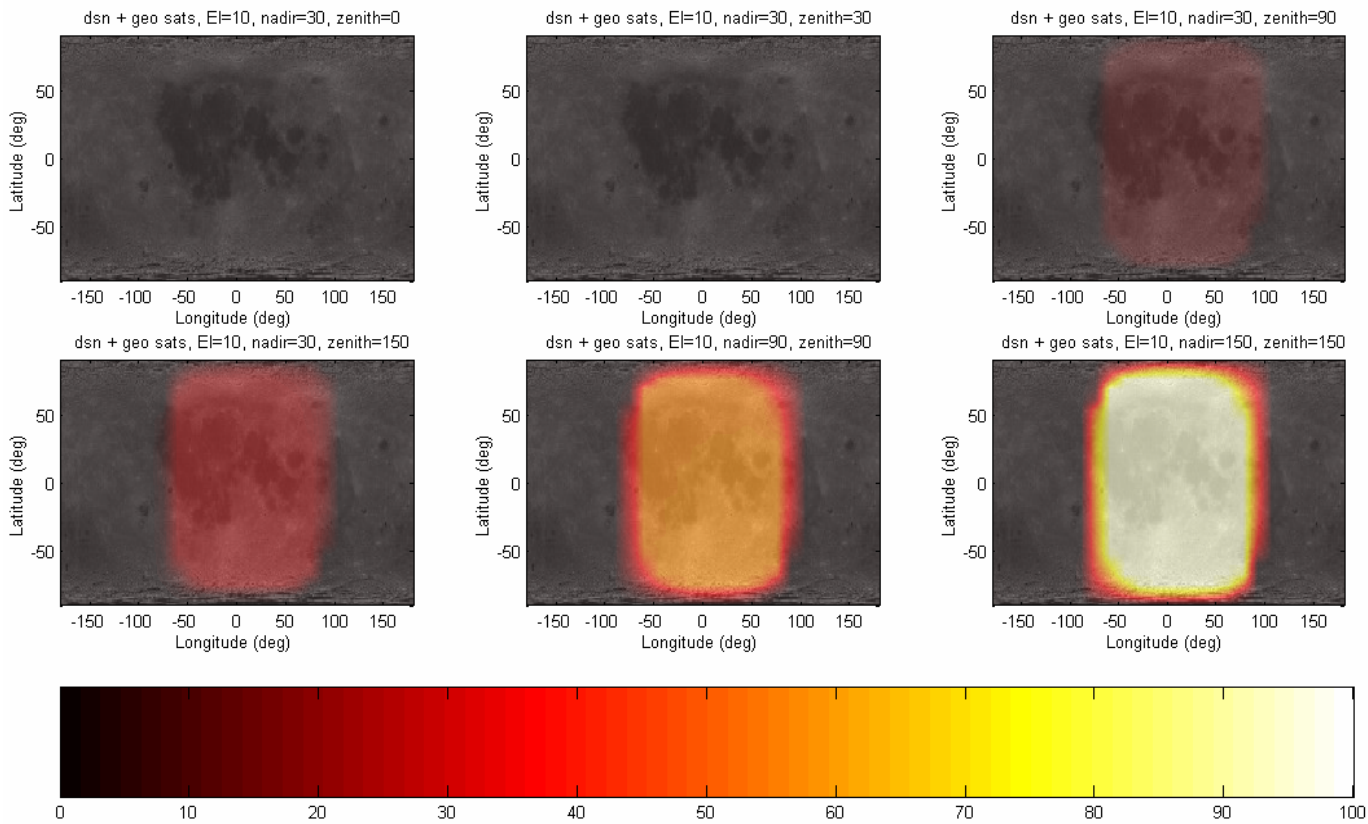

Figure B.3.3.3.—DSNGEO system availability results.

TABLE B.3.3.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	0.00	0.00	0.00	0.00	0.00
GEO 90/30	0.00	0.00	0.00	0.00	0.00
GEO 150/30	7.04	1.04	13.41	0.00	16.47
GEO 90/90	17.85	6.50	34.12	0.00	40.58
GEO 150/150	39.78	18.74	75.71	0.00	89.11
DSN 5	0.00	0.00	0.00	0.00	0.00
DSN 10	0.00	0.00	0.00	0.00	0.00
DSN 15	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/30/30	0.47	0.01	0.89	0.00	1.05
DSN+GEO 10/90/30	4.01	0.23	7.64	0.00	9.06
DSN+GEO 10/150/30	9.41	1.70	17.93	0.00	21.51
DSN+GEO 10/90/90	25.04	9.25	47.82	0.00	56.61
DSN+GEO 10/150/150	42.51	21.05	80.75	0.00	94.65

TABLE B.3.3.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	0.00	0.00	0.00	0.00	0.00
GEO 90/30	0.00	0.00	0.00	0.00	0.00
GEO 150/30	5.77	0.63	10.99	0.00	13.55
GEO 90/90	11.16	4.24	21.34	0.00	25.38
GEO 150/150	11.63	6.58	21.83	0.00	24.29
DSN 5	0.00	0.00	0.00	0.00	0.00
DSN 10	0.00	0.00	0.00	0.00	0.00
DSN 15	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30 -v2	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/30/30 -v1	0.16	0.01	0.31	0.00	0.36
DSN+GEO 10/30/30 -v2	0.17	0.01	0.31	0.00	0.37
DSN+GEO 10/90/30 -v1	1.11	0.18	2.09	0.00	2.48
DSN+GEO 10/90/30 -v2	2.08	0.19	3.92	0.00	4.63
DSN+GEO 10/150/30 -v1	0.50	0.24	0.96	0.00	1.07
DSN+GEO 10/150/30 -v2	3.79	0.97	7.22	0.00	8.67
DSN+GEO 10/90/90 -v1	2.35	0.83	4.43	0.00	5.10
DSN+GEO 10/90/90 -v2	12.61	5.65	24.10	0.00	28.34
DSN+GEO 10/150/150 -v1	1.36	0.95	2.56	0.00	2.86
DSN+GEO 10/150/150 -v2	5.94	4.92	10.89	0.00	11.01

B.3.4 Dynamic (2 hr).—Figures B.3.4.1 to B.3.4.3 show the system availability results for the 15 Earth-based constellations when the system is operating in one-way mode without terrain information but with clock synchronization (solving with 2-hr dynamic measurements). Table B.3.4.1 tabulates the weighted system availabilities from figures B.3.4.1 to B.3.4.3. Table B.3.4.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

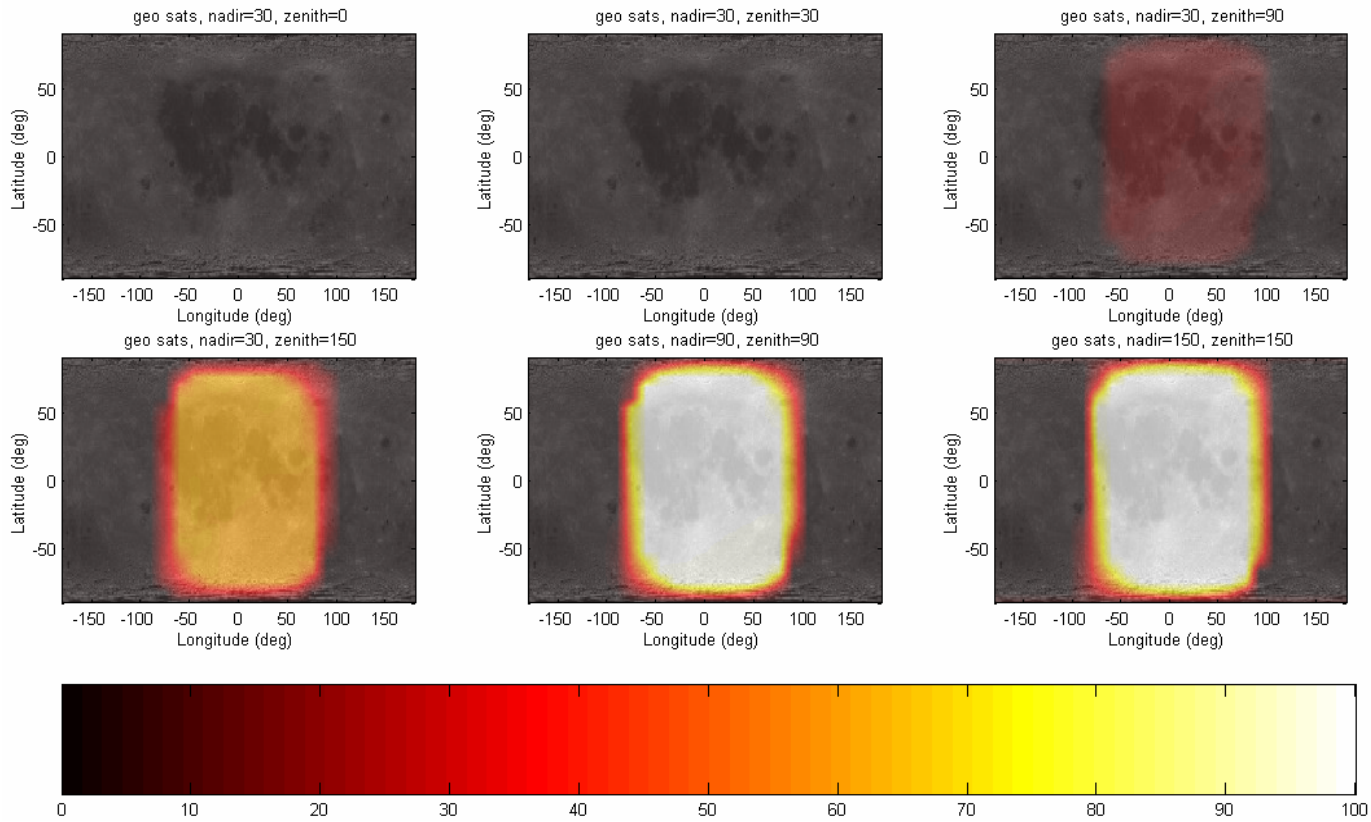

Figure B.3.4.1.—GEO system availability results.

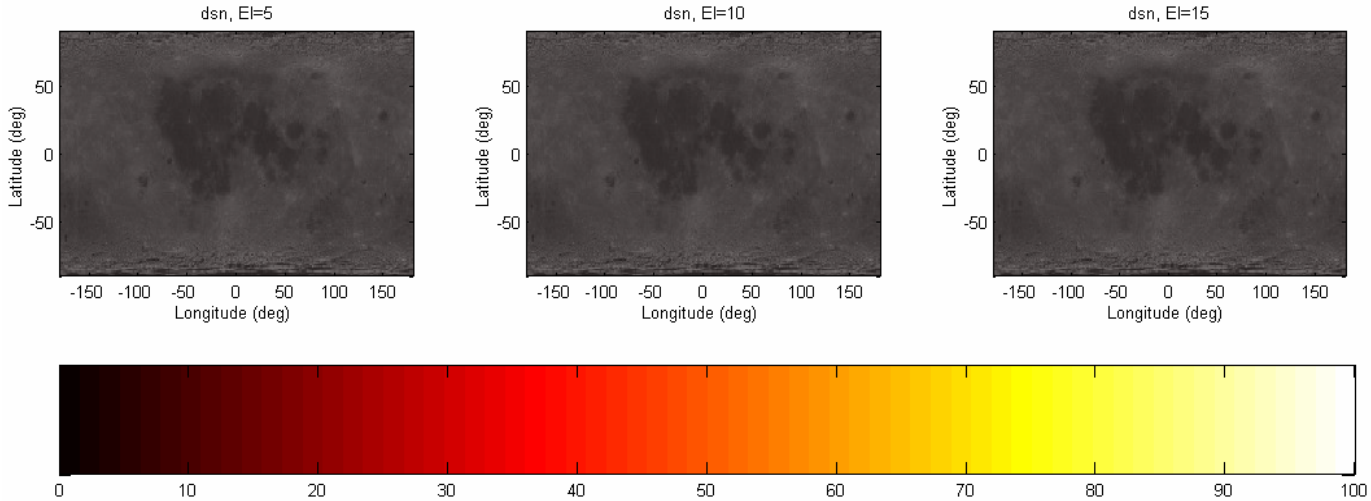

Figure B.3.4.2.—DSN system availability results.

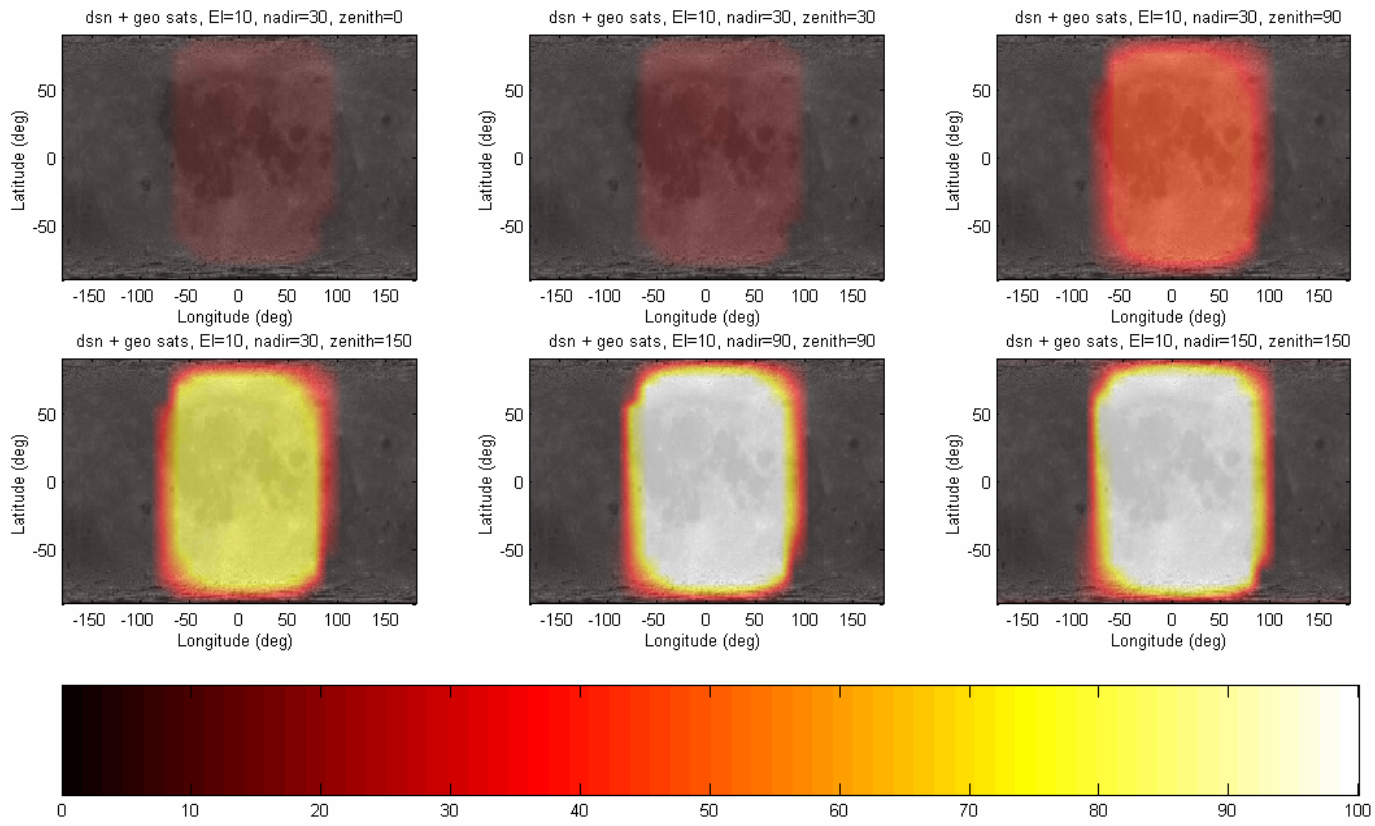

Figure B.3.4.3.—DSNGEO system availability results.

TABLE B.3.4.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	0.00	0.00	0.00	0.00	0.00
GEO 90/30	5.33	0.41	10.21	0.00	12.70
GEO 150/30	26.81	11.92	50.90	0.00	61.30
GEO 90/90	44.84	18.90	85.29	0.00	98.64
GEO 150/150	46.70	25.83	87.88	0.00	99.80
DSN 5	0.00	0.00	0.00	0.00	0.00
DSN 10	0.00	0.00	0.00	0.00	0.00
DSN 15	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30	3.89	0.04	7.36	0.00	8.78
DSN+GEO 10/30/30	5.46	0.71	10.35	0.00	12.29
DSN+GEO 10/90/30	19.64	6.68	37.49	0.00	44.07
DSN+GEO 10/150/30	35.28	16.71	67.19	0.00	79.98
DSN+GEO 10/90/90	45.35	20.24	86.05	0.00	99.12
DSN+GEO 10/150/150	46.80	26.60	88.02	0.00	99.88

TABLE B.3.4.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	0.00	0.00	0.00	0.00	0.00
GEO 90/30	2.77	0.27	5.21	0.00	6.32
GEO 150/30	10.13	5.38	19.00	0.00	23.22
GEO 90/90	6.56	4.30	12.28	0.00	13.00
GEO 150/150	1.59	4.48	2.48	0.00	0.88
DSN 5	0.00	0.00	0.00	0.00	0.00
DSN 10	0.00	0.00	0.00	0.00	0.00
DSN 15	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30 -v1	1.56	0.00	2.93	0.00	3.52
DSN+GEO 10/0/30 -v2	1.52	0.04	2.84	0.00	3.27
DSN+GEO 10/30/30 -v1	1.58	0.50	2.99	0.00	3.57
DSN+GEO 10/30/30 -v2	1.54	0.51	2.86	0.00	3.30
DSN+GEO 10/90/30 -v1	4.56	2.44	8.70	0.00	10.16
DSN+GEO 10/90/30 -v2	8.45	4.20	16.15	0.00	18.92
DSN+GEO 10/150/30 -v1	2.89	1.64	5.48	0.00	6.35
DSN+GEO 10/150/30 -v2	8.00	4.11	15.18	0.00	18.66
DSN+GEO 10/90/90 -v1	0.11	0.64	0.16	0.00	0.06
DSN+GEO 10/90/90 -v2	2.94	2.76	5.29	0.00	4.93
DSN+GEO 10/150/150 -v1	0.03	0.68	0.02	0.00	0.00
DSN+GEO 10/150/150 -v2	1.18	3.37	1.76	0.00	0.36

B.3.5 Dynamic (4 hr).—Figures B.3.5.1 to B.3.5.3 show the system availability results for the 15 Earth-based constellations when the system is operating in one-way mode without terrain information but with clock synchronization (solving with 4-hr dynamic measurements). Table B.3.5.1 tabulates the weighted system availabilities from figures B.3.5.1 to B.3.5.3. Table B.3.5.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

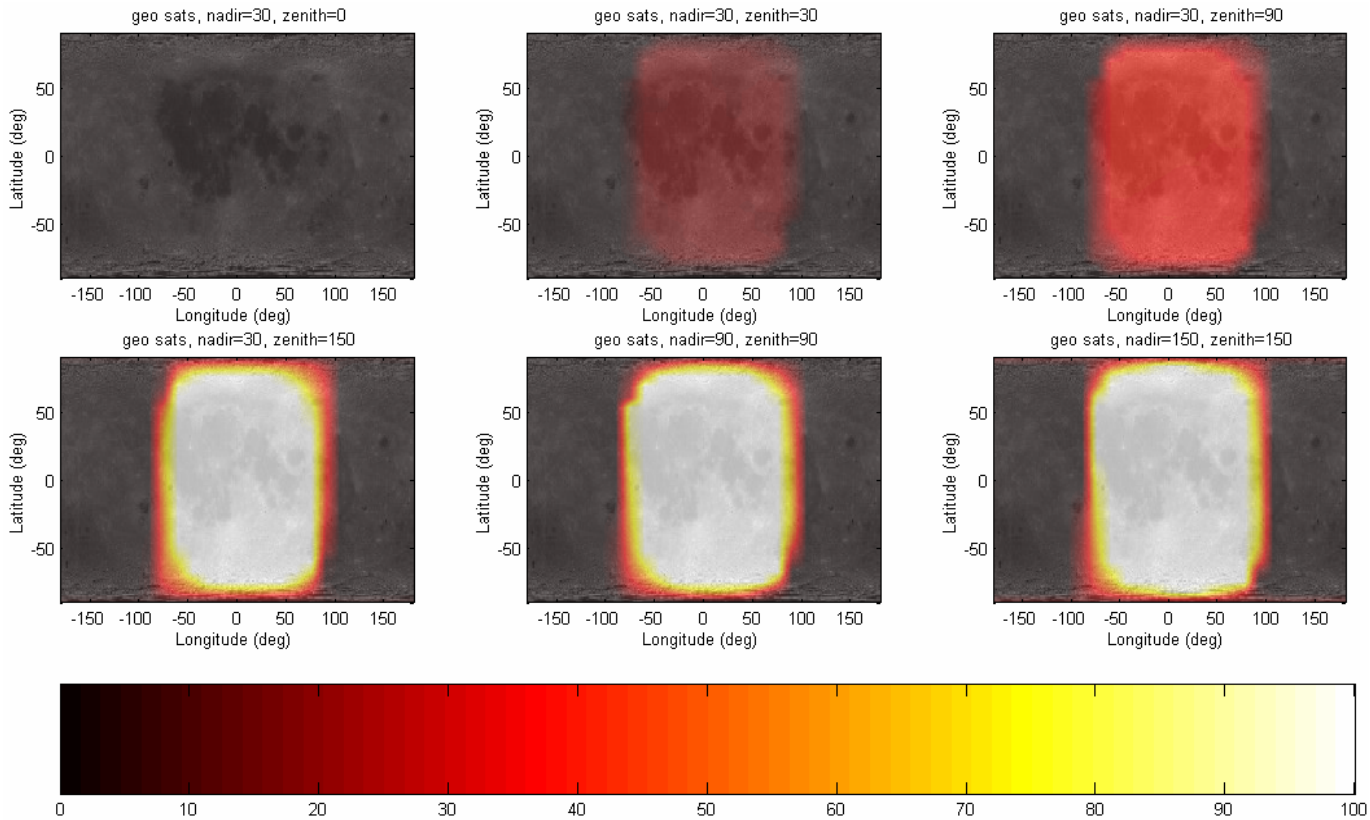

Figure B.3.5.1.—GEO system availability results.

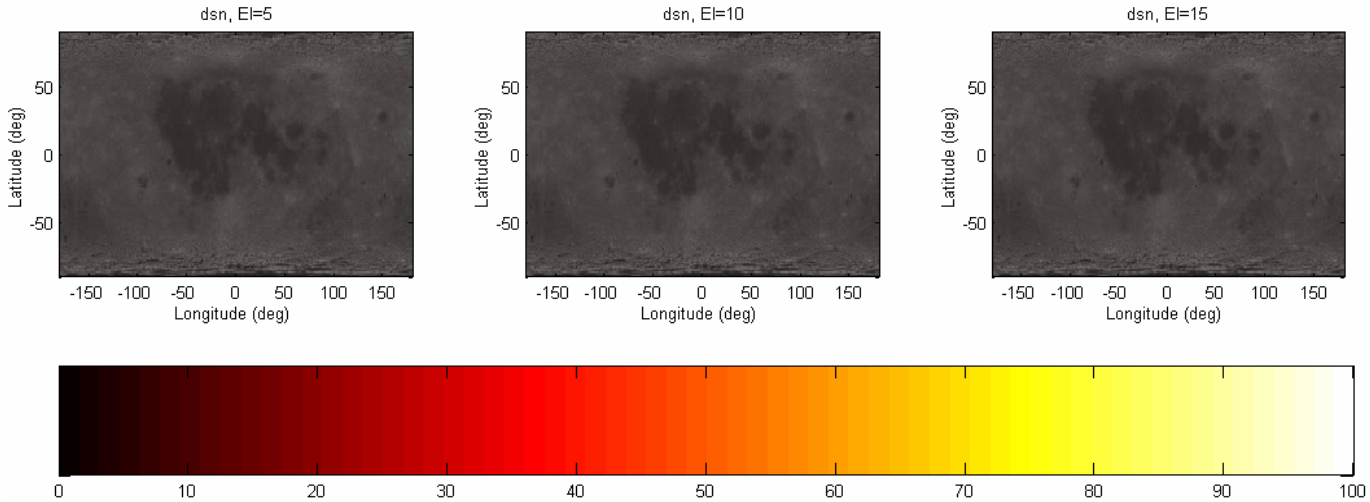

Figure B.3.5.2.—DSN system availability results.

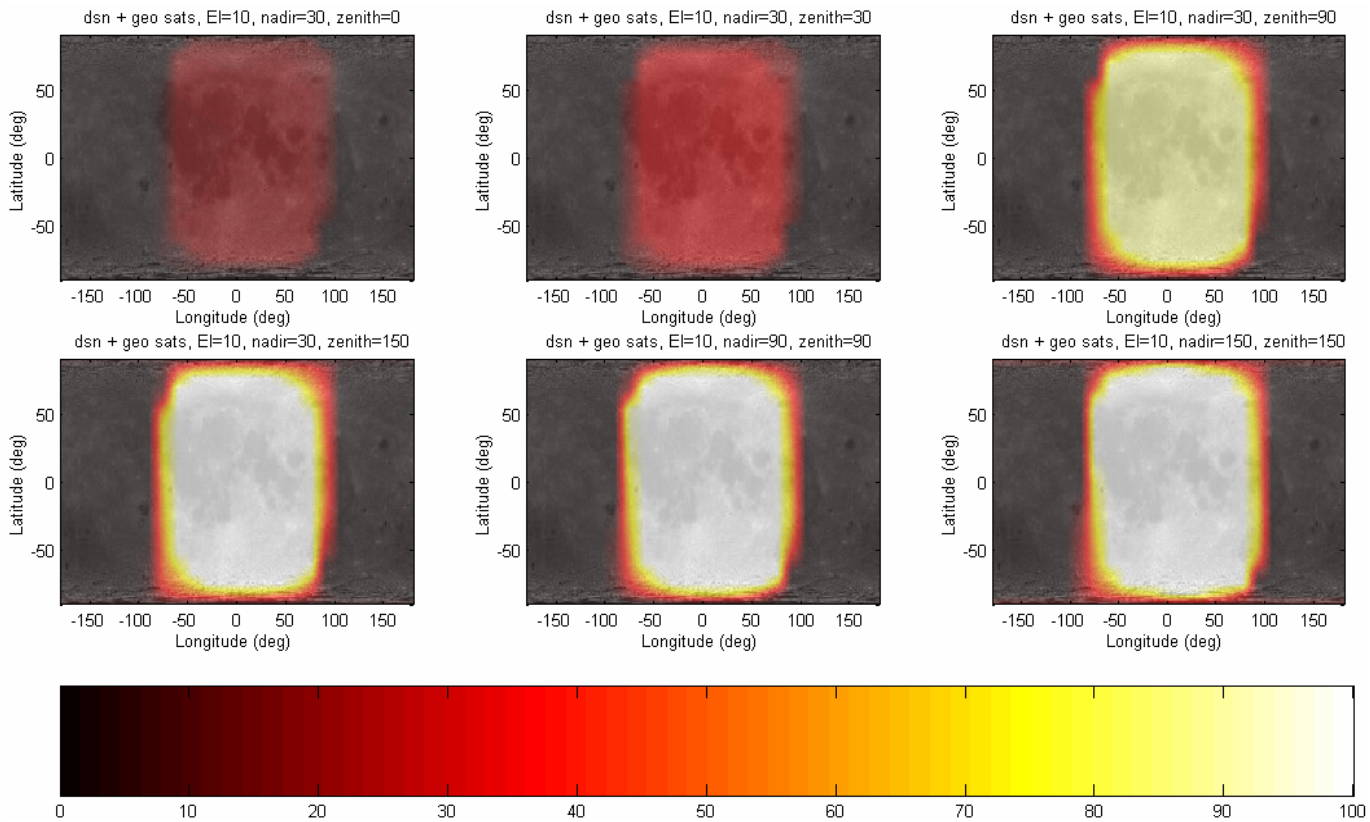

Figure B.3.5.3.—DSNGEO system availability results.

TABLE B.3.5.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	7.10	1.60	13.59	0.00	16.23
GEO 90/30	17.51	7.10	33.27	0.00	39.16
GEO 150/30	44.51	22.37	84.34	0.00	99.69
GEO 90/90	45.93	20.92	87.17	0.00	99.57
GEO 150/150	47.60	31.86	89.29	0.00	100.00
DSN 5	0.00	0.00	0.00	0.00	0.00
DSN 10	0.00	0.00	0.00	0.00	0.00
DSN 15	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30	7.68	1.49	14.59	0.00	17.29
DSN+GEO 10/30/30	12.43	4.93	23.65	0.00	27.90
DSN+GEO 10/90/30	40.46	17.67	77.06	0.00	90.48
DSN+GEO 10/150/30	45.24	23.81	85.76	0.00	99.86
DSN+GEO 10/90/90	46.30	24.07	87.53	0.00	99.94
DSN+GEO 10/150/150	47.67	31.87	89.29	0.00	100.00

TABLE B.3.5.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	4.31	1.23	8.23	0.00	9.56
GEO 90/30	4.72	2.39	8.90	0.00	10.33
GEO 150/30	10.38	6.49	19.52	0.00	22.46
GEO 90/90	1.39	2.49	2.43	0.00	1.54
GEO 150/150	0.93	4.34	1.39	0.00	0.00
DSN 5	0.00	0.00	0.00	0.00	0.00
DSN 10	0.00	0.00	0.00	0.00	0.00
DSN 15	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30 -v1	1.26	0.40	2.39	0.00	2.83
DSN+GEO 10/0/30 -v2	1.79	0.79	3.39	0.00	4.00
DSN+GEO 10/30/30 -v1	1.21	1.26	2.30	0.00	2.55
DSN+GEO 10/30/30 -v2	4.23	2.76	8.11	0.00	9.18
DSN+GEO 10/90/30 -v1	8.82	2.62	16.80	0.00	19.80
DSN+GEO 10/90/30 -v2	14.40	5.49	27.54	0.00	32.38
DSN+GEO 10/150/30 -v1	0.21	0.84	0.41	0.00	0.00
DSN+GEO 10/150/30 -v2	1.25	2.61	2.22	0.00	1.53
DSN+GEO 10/90/90 -v1	0.08	2.26	0.02	0.00	0.00
DSN+GEO 10/90/90 -v2	0.81	2.26	1.23	0.00	0.40
DSN+GEO 10/150/150 -v1	0.07	0.00	0.00	0.00	0.00
DSN+GEO 10/150/150 -v2	0.92	3.82	1.29	0.00	0.00

B.3.6 Dynamic (8 hr).—Figures B.3.6.1 to B.3.6.3 show the system availability results for the 15 Earth-based constellations when the system is operating in one-way mode without terrain information but with clock synchronization (solving with 8-hr dynamic measurements). Table B.3.6.1 tabulates the weighted system availabilities from figures B.3.6.1 to B.3.6.3. Table B.3.6.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

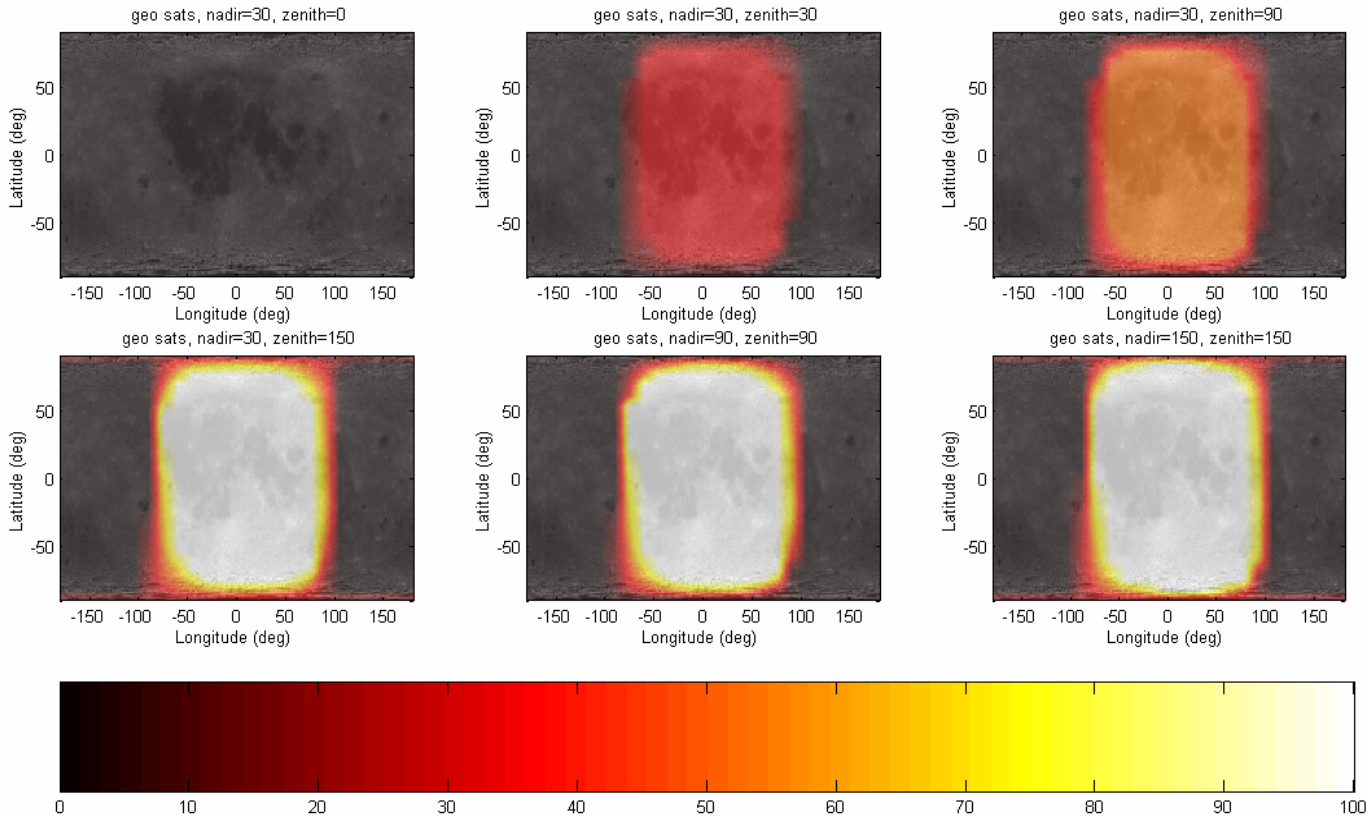

Figure B.3.6.1.—GEO system availability results.

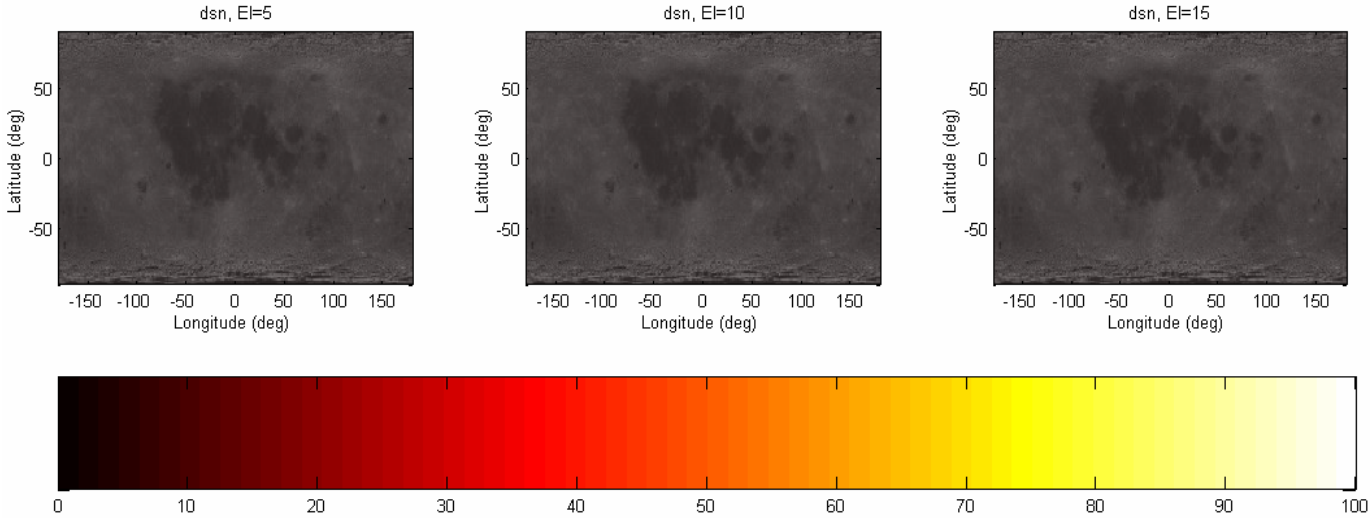

Figure B.3.6.2.—DSN system availability results.

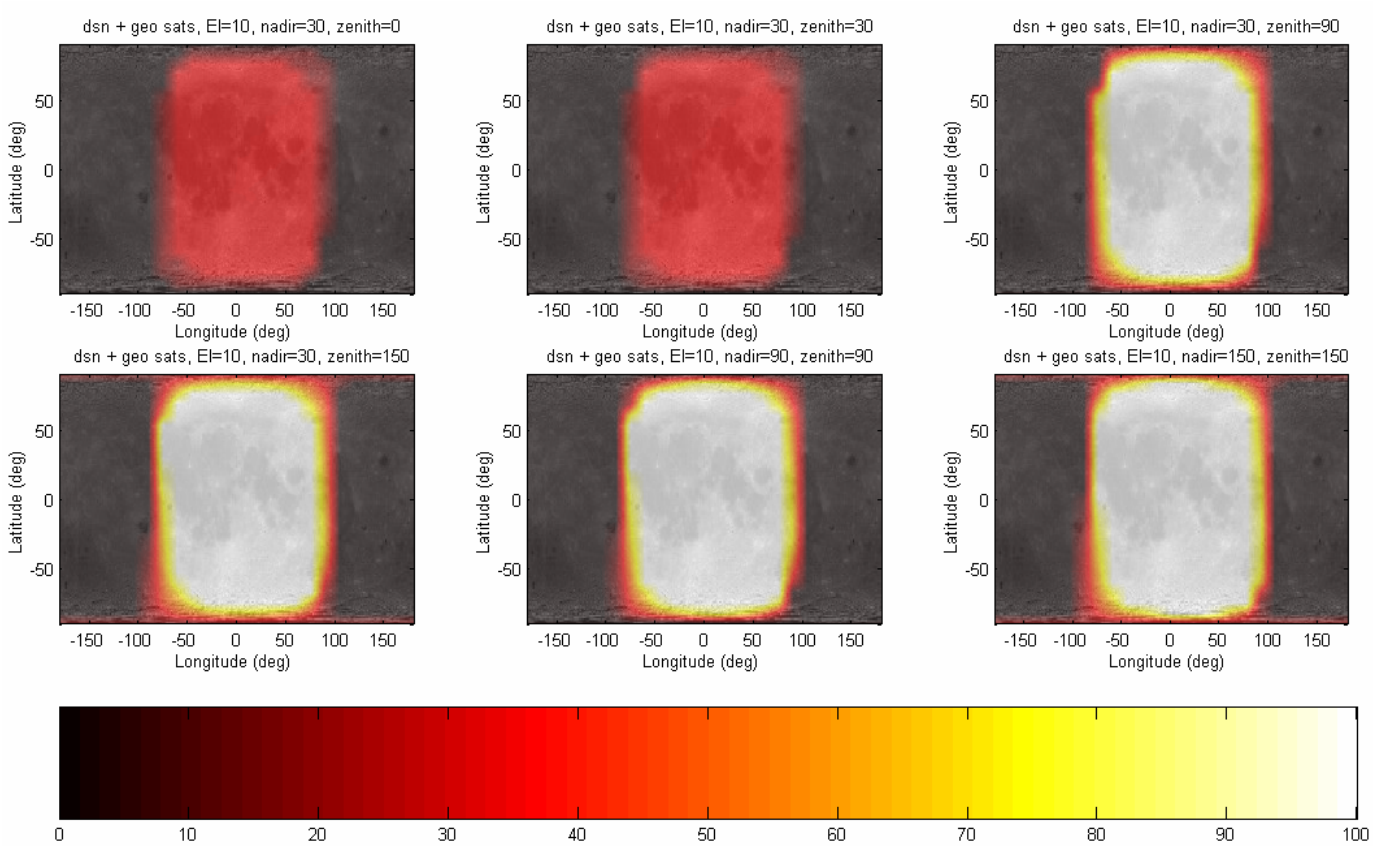

Figure B.3.6.3.—DSNGEO system availability results.

TABLE B.3.6.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	14.28	5.88	27.11	0.00	31.92
GEO 90/30	23.89	14.29	45.34	0.00	53.33
GEO 150/30	46.59	26.32	87.83	0.01	100.00
GEO 90/90	46.72	24.91	88.45	0.00	100.00
GEO 150/150	48.24	35.28	90.29	0.01	100.00
DSN 5	0.00	0.00	0.00	0.00	0.00
DSN 10	0.00	0.00	0.00	0.00	0.00
DSN 15	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30	15.69	6.75	29.80	0.00	35.48
DSN+GEO 10/30/30	16.25	8.13	30.78	0.00	36.51
DSN+GEO 10/90/30	45.39	23.30	86.16	0.00	100.00
DSN+GEO 10/150/30	46.73	27.39	87.93	0.01	100.00
DSN+GEO 10/90/90	46.91	27.57	88.45	0.00	100.00
DSN+GEO 10/150/150	48.24	35.28	90.29	0.01	100.00

TABLE B.3.6.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	2.88	1.96	5.38	0.00	6.16
GEO 90/30	4.80	5.04	9.08	0.00	10.68
GEO 150/30	0.82	2.22	1.34	0.00	0.10
GEO 90/90	0.43	2.87	0.68	0.00	0.00
GEO 150/150	0.33	1.98	0.52	0.00	0.00
DSN 5	0.00	0.00	0.00	0.00	0.00
DSN 10	0.00	0.00	0.00	0.00	0.00
DSN 15	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30 -v1	2.23	1.77	4.25	0.00	5.19
DSN+GEO 10/0/30 -v2	3.77	2.64	7.11	0.00	8.06
DSN+GEO 10/30/30 -v1	0.40	1.02	0.72	0.00	0.89
DSN+GEO 10/30/30 -v2	1.51	1.75	2.81	0.00	3.29
DSN+GEO 10/90/30 -v1	4.09	2.08	7.77	0.00	8.73
DSN+GEO 10/90/30 -v2	3.22	2.56	5.92	0.00	6.26
DSN+GEO 10/150/30 -v1	0.06	0.41	0.06	0.00	0.00
DSN+GEO 10/150/30 -v2	0.55	1.75	0.82	0.00	0.00
DSN+GEO 10/90/90 -v1	0.06	1.81	0.00	0.00	0.00
DSN+GEO 10/90/90 -v2	0.43	2.42	0.64	0.00	0.00
DSN+GEO 10/150/150 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/150/150 -v2	0.33	1.94	0.52	0.00	0.00

B.3.7 Dynamic (12 hr).—Figures B.3.7.1 to B.3.7.3 show the system availability results for the 15 Earth-based constellations when the system is operating in one-way mode without terrain information but with clock synchronization (solving with 12-hr dynamic measurements). Table B.3.7.1 tabulates the weighted system availabilities from figures B.3.7.1 to B.3.7.3. Table B.3.7.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

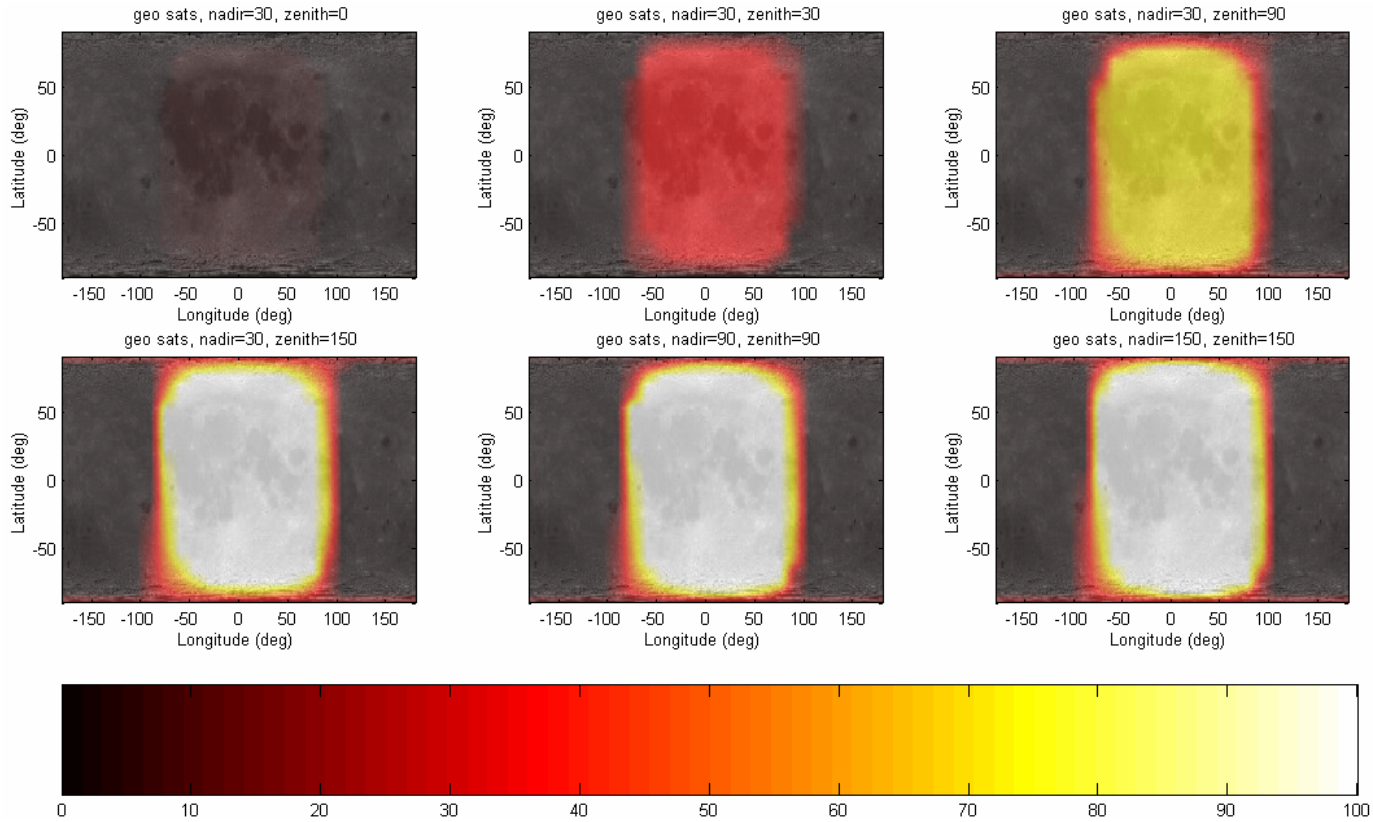

Figure B.3.7.1.—GEO system availability results.

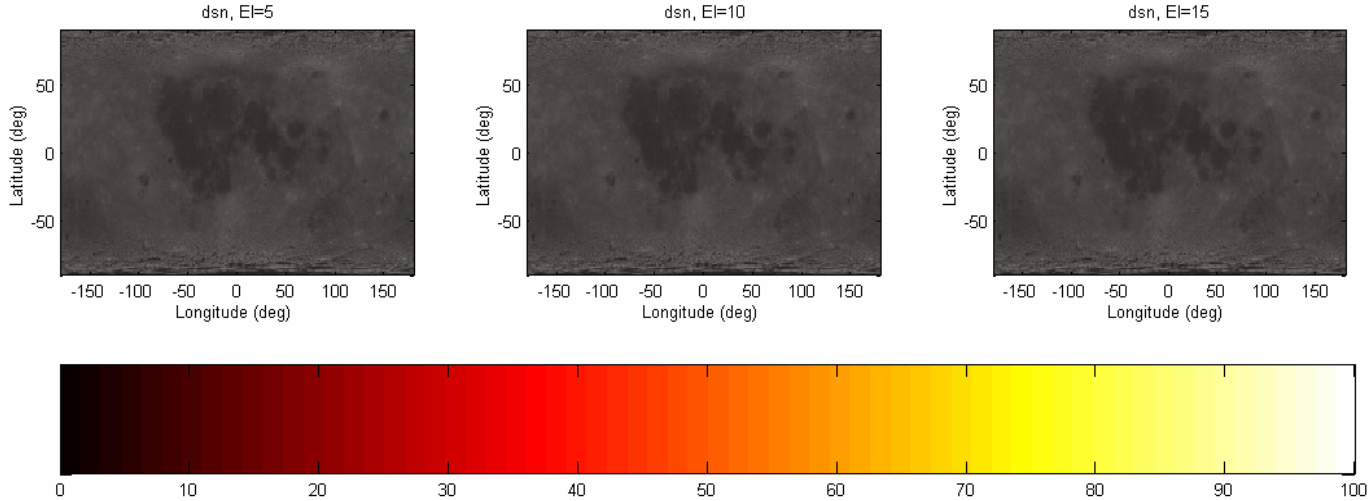

Figure B.3.7.2.—DSN system availability results.

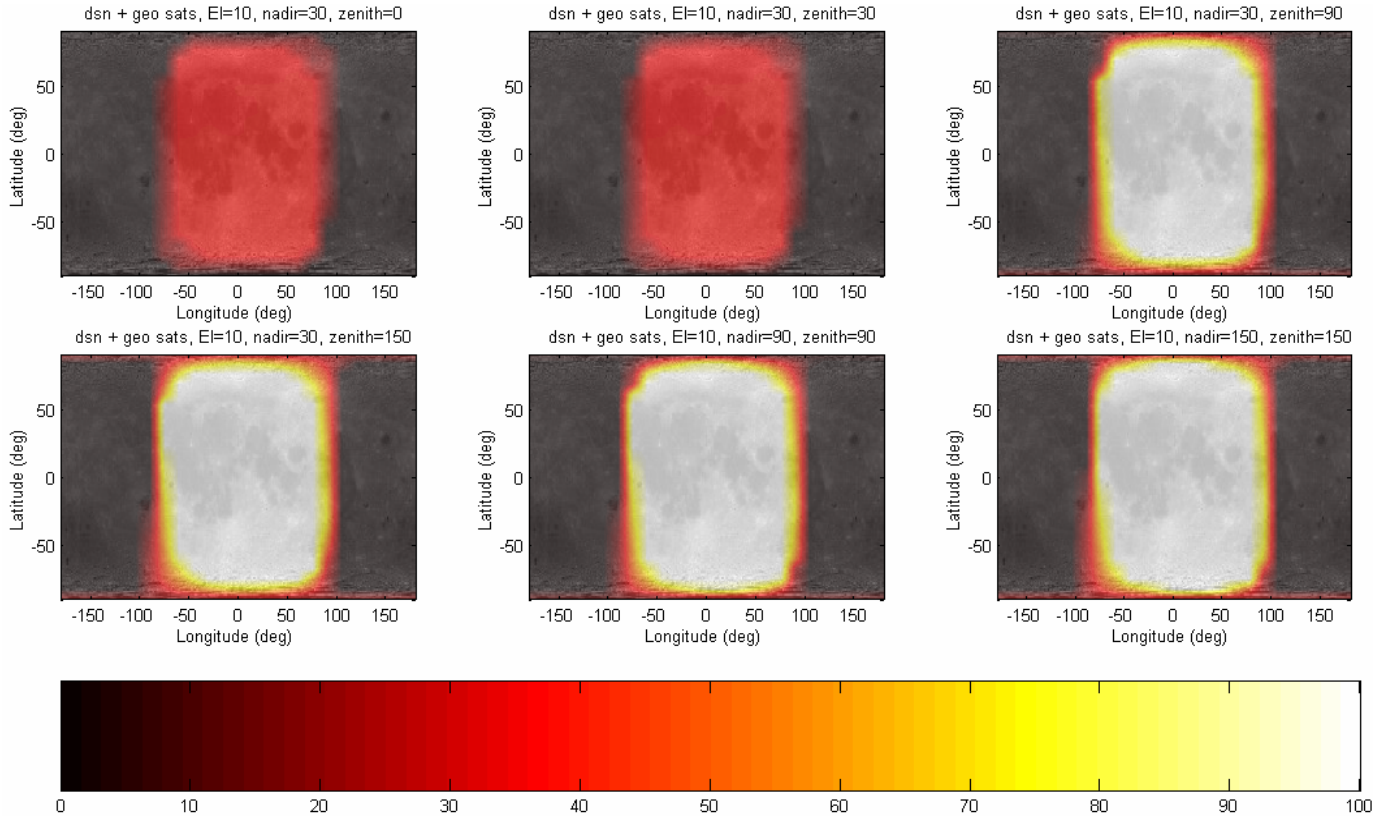

Figure B.3.7.3.—DSNGEO system availability results.

TABLE B.3.7.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	1.69	0.84	3.24	0.00	3.83
GEO 30/30	15.53	7.13	29.49	0.00	34.78
GEO 90/30	32.83	24.31	62.02	0.00	71.95
GEO 150/30	46.95	27.27	88.46	0.01	100.00
GEO 90/90	47.17	32.97	88.78	0.00	100.00
GEO 150/150	48.39	36.14	90.52	0.01	100.00
DSN 5	0.00	0.00	0.00	0.00	0.00
DSN 10	0.00	0.00	0.00	0.00	0.00
DSN 15	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30	16.93	7.27	32.09	0.00	38.08
DSN+GEO 10/30/30	17.03	8.74	32.17	0.00	38.08
DSN+GEO 10/90/30	46.01	26.27	86.89	0.00	100.00
DSN+GEO 10/150/30	47.06	28.27	88.53	0.01	100.00
DSN+GEO 10/90/90	47.29	33.08	88.79	0.00	100.00
DSN+GEO 10/150/150	48.39	36.14	90.52	0.01	100.00

TABLE B.3.7.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	1.08	0.59	2.04	0.00	2.45
GEO 30/30	1.63	1.74	3.09	0.00	3.60
GEO 90/30	5.14	5.37	9.64	0.00	10.96
GEO 150/30	0.42	1.40	0.70	0.00	0.00
GEO 90/90	0.38	5.47	0.37	0.00	0.00
GEO 150/150	0.20	1.21	0.33	0.00	0.00
DSN 5	0.00	0.00	0.00	0.00	0.00
DSN 10	0.00	0.00	0.00	0.00	0.00
DSN 15	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30 -v1	0.83	0.42	1.57	0.00	2.04
DSN+GEO 10/0/30 -v2	1.78	0.98	3.29	0.00	3.88
DSN+GEO 10/30/30 -v1	0.15	0.66	0.25	0.00	0.43
DSN+GEO 10/30/30 -v2	0.98	1.17	1.77	0.00	2.12
DSN+GEO 10/90/30 -v1	0.59	0.47	1.10	0.00	0.68
DSN+GEO 10/90/30 -v2	0.49	1.87	0.63	0.00	0.00
DSN+GEO 10/150/30 -v1	0.04	0.24	0.05	0.00	0.00
DSN+GEO 10/150/30 -v2	0.35	1.11	0.62	0.00	0.00
DSN+GEO 10/90/90 -v1	0.01	0.11	0.01	0.00	0.00
DSN+GEO 10/90/90 -v2	0.34	3.97	0.38	0.00	0.00
DSN+GEO 10/150/150 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/150/150 -v2	0.20	1.21	0.33	0.00	0.00

B.4 Good Terrain, 3-hr Clock Synchronization, One-Way Mode

B.4.1 Kinematic.—Figures B.4.1.1 to B.4.1.3 show the system availability results for the 15 Earth-based constellations when the system is operating in one-way mode with terrain information and clock synchronization (solving with kinematic measurements). Table B.4.1.1 tabulates the weighted system availabilities from figures B.4.1.1 to B.4.1.3. Table B.4.1.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

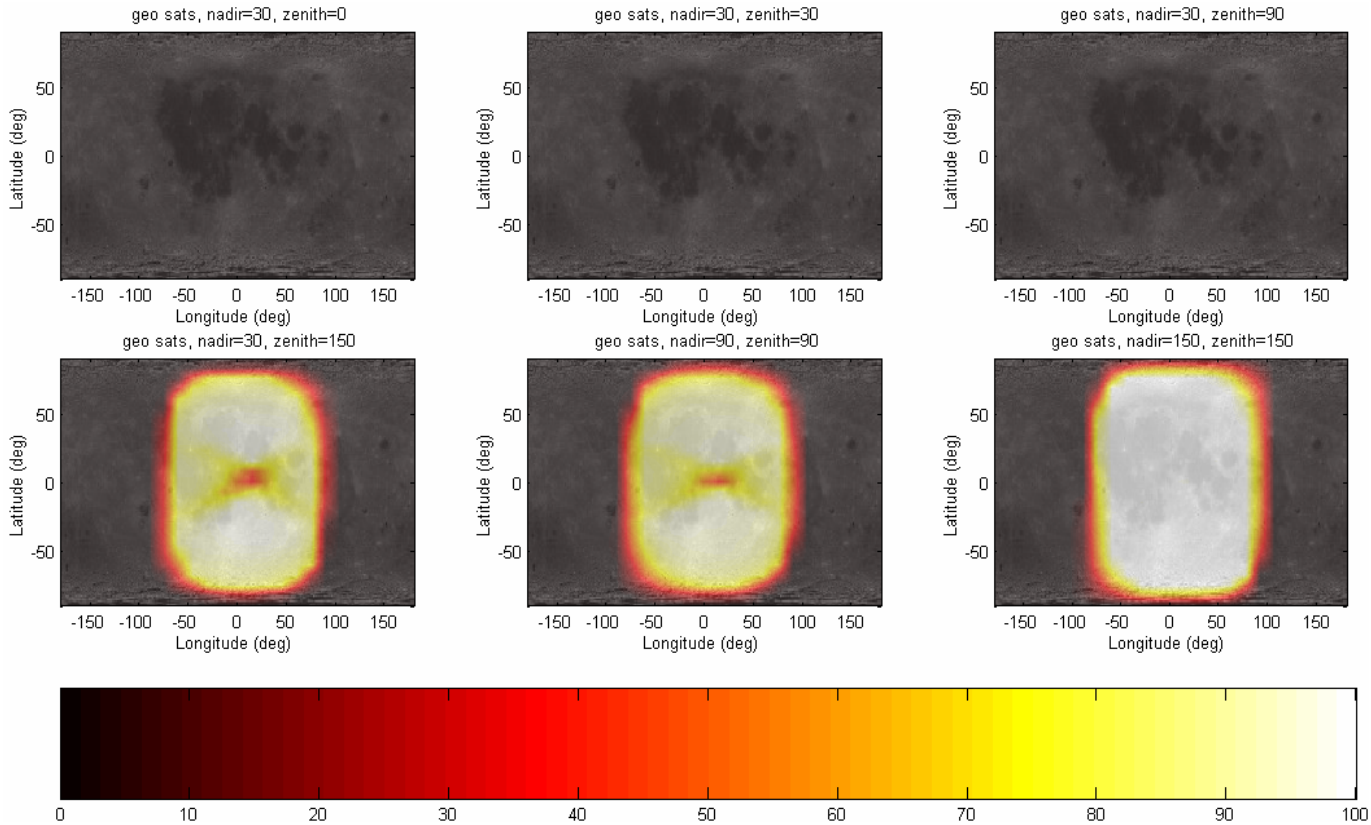

Figure B.4.1.1.—GEO system availability results.

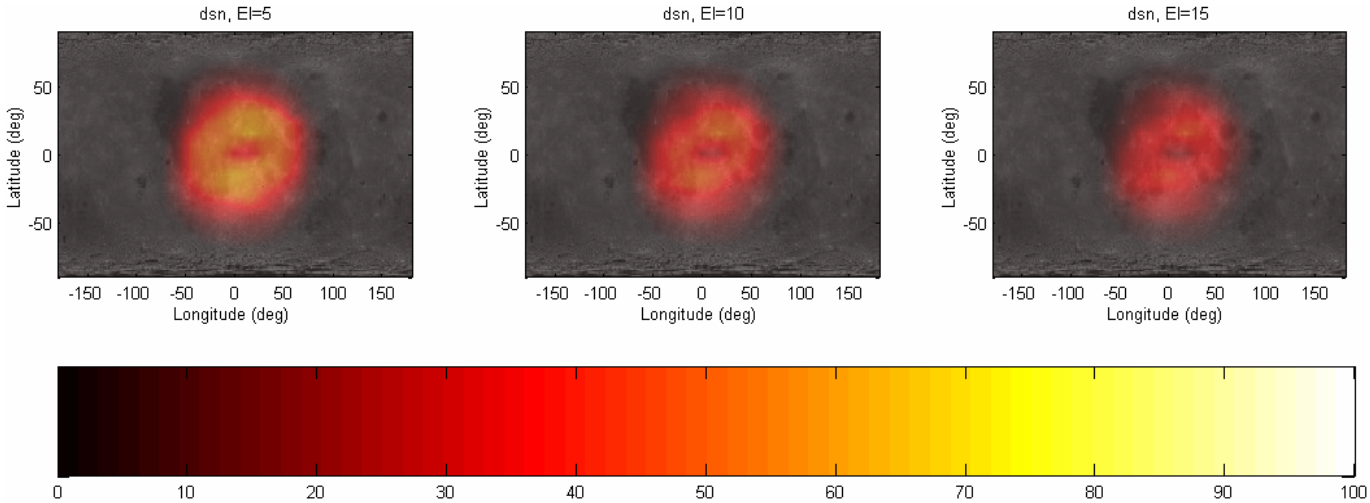

Figure B.4.1.2.—DSN system availability results.

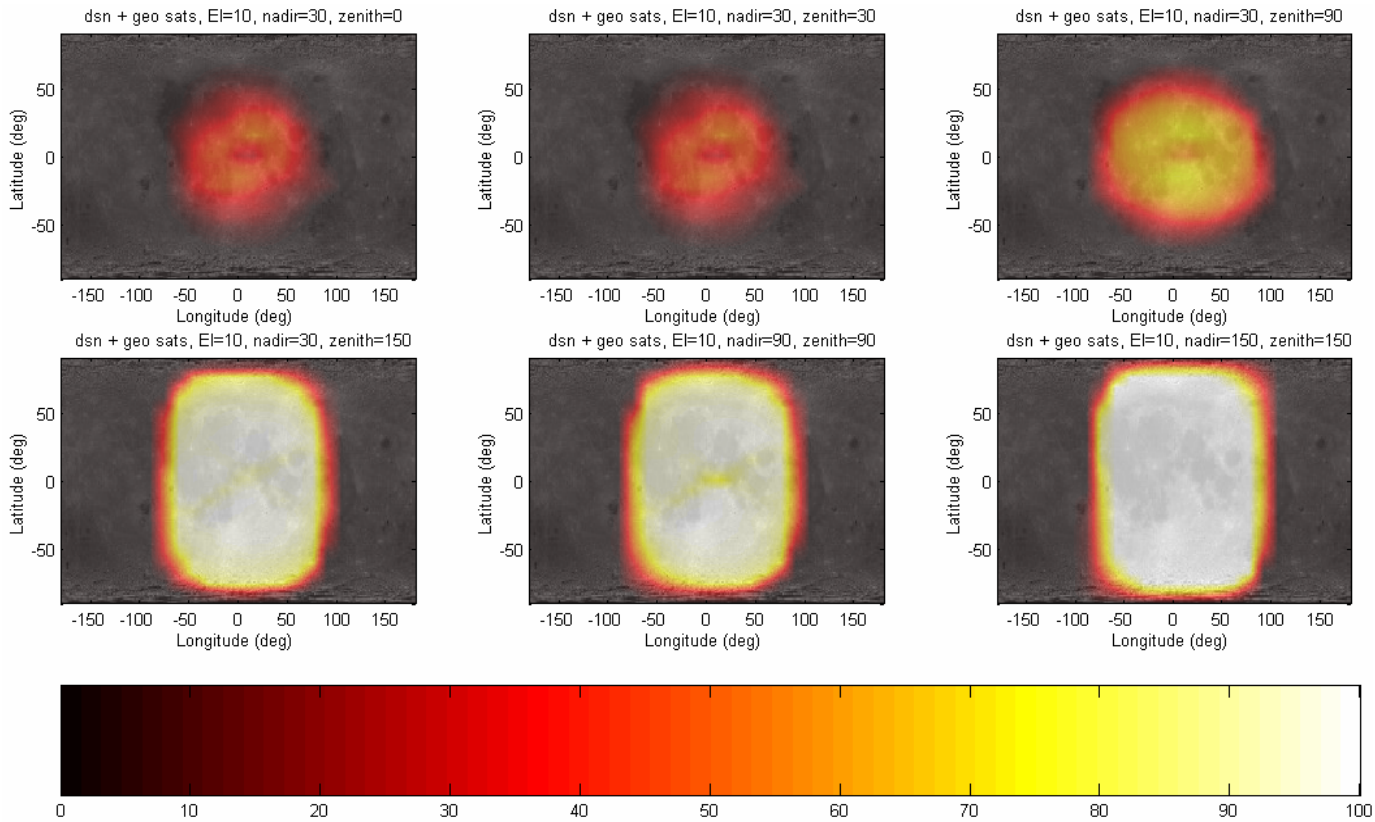

Figure B.4.1.3.—DSNGEO system availability results.

TABLE B.4.1.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	0.00	0.00	0.00	0.00	0.00
GEO 90/30	0.00	0.00	0.00	0.00	0.00
GEO 150/30	37.42	5.70	72.19	0.00	83.60
GEO 90/90	39.94	7.26	75.55	0.00	85.70
GEO 150/150	45.90	21.74	87.10	0.00	99.55
DSN 5	10.98	0.00	26.08	0.00	51.09
DSN 10	8.24	0.00	19.61	0.00	39.61
DSN 15	6.51	0.00	15.49	0.00	32.49
DSN+GEO 10/0/30	9.02	0.00	21.51	0.00	41.84
DSN+GEO 10/30/30	9.28	0.00	22.12	0.00	42.79
DSN+GEO 10/90/30	19.18	0.00	45.16	0.00	66.98
DSN+GEO 10/150/30	41.01	6.11	80.53	0.00	96.86
DSN+GEO 10/90/90	41.49	7.93	81.19	0.00	94.93
DSN+GEO 10/150/150	46.08	21.88	87.49	0.00	99.74

TABLE B.4.1.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	0.00	0.00	0.00	0.00	0.00
GEO 90/30	0.00	0.00	0.00	0.00	0.00
GEO 150/30	18.13	3.37	34.36	0.00	38.83
GEO 90/90	11.68	2.77	20.56	0.00	23.27
GEO 150/150	2.98	5.16	5.67	0.00	6.80
DSN 5	6.68	0.00	15.83	0.00	28.96
DSN 10	5.57	0.00	13.29	0.00	25.85
DSN 15	4.50	0.00	10.76	0.00	21.71
DSN+GEO 10/0/30 -v1	5.61	0.00	13.38	0.00	25.15
DSN+GEO 10/0/30 -v2	8.70	0.00	20.73	0.00	40.39
DSN+GEO 10/30/30 -v1	5.67	0.00	13.52	0.00	25.41
DSN+GEO 10/30/30 -v2	8.70	0.00	20.72	0.00	40.15
DSN+GEO 10/90/30 -v1	6.12	0.00	14.08	0.00	17.64
DSN+GEO 10/90/30 -v2	8.62	0.00	19.83	0.00	24.84
DSN+GEO 10/150/30 -v1	1.03	0.11	2.39	0.00	3.83
DSN+GEO 10/150/30 -v2	5.66	2.66	9.59	0.00	10.24
DSN+GEO 10/90/90 -v1	0.80	0.17	1.73	0.00	2.63
DSN+GEO 10/90/90 -v2	6.53	1.98	12.41	0.00	13.23
DSN+GEO 10/150/150 -v1	0.07	0.10	0.14	0.00	0.03
DSN+GEO 10/150/150 -v2	1.75	4.46	2.90	0.00	2.35

B.4.2 Dynamic (15 min).—Figures B.4.2.1 to B.4.2.3 show the system availability results for the 15 Earth-based constellations when the system is operating in one-way mode with terrain information and clock synchronization (solving with 15-min dynamic measurements). Table B.4.2.1 tabulates the weighted system availabilities from figures B.4.2.1 to B.4.2.3. Table B.4.2.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

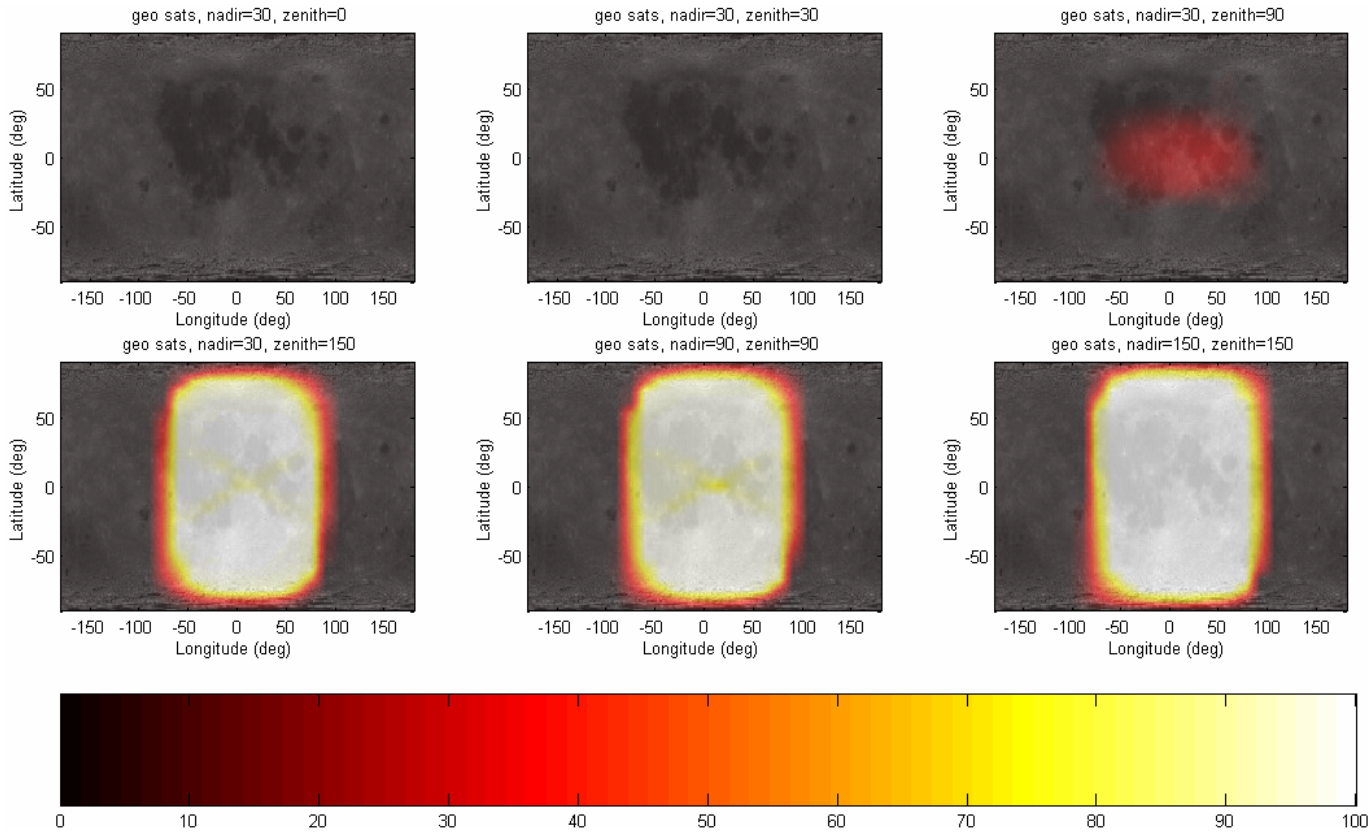

Figure B.4.2.1.—GEO system availability results.

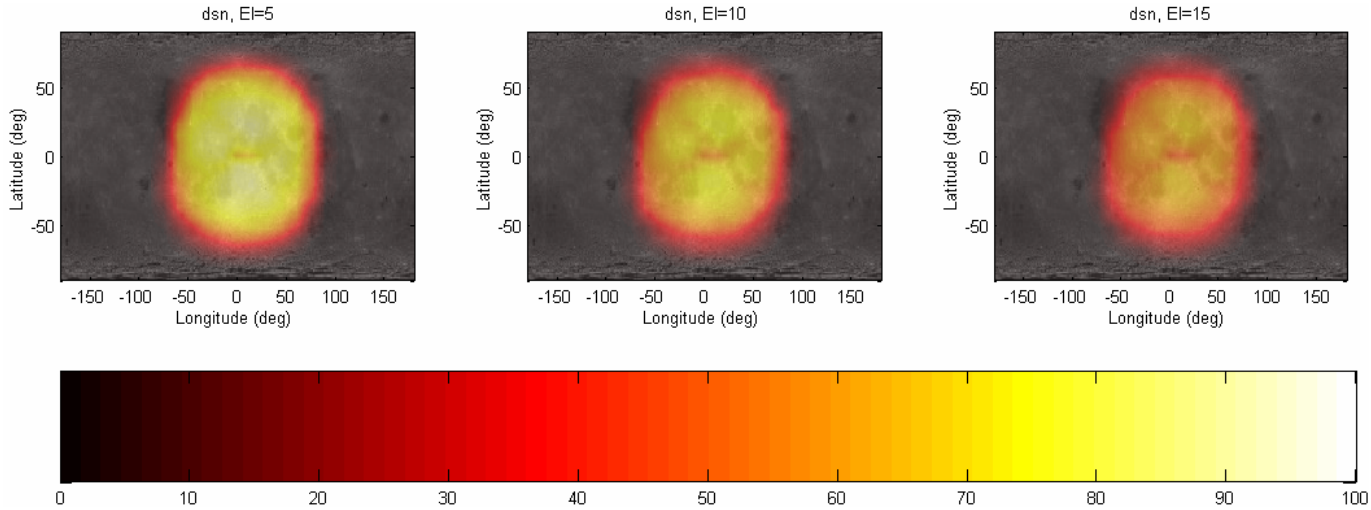

Figure B.4.2.2.—DSN system availability results.

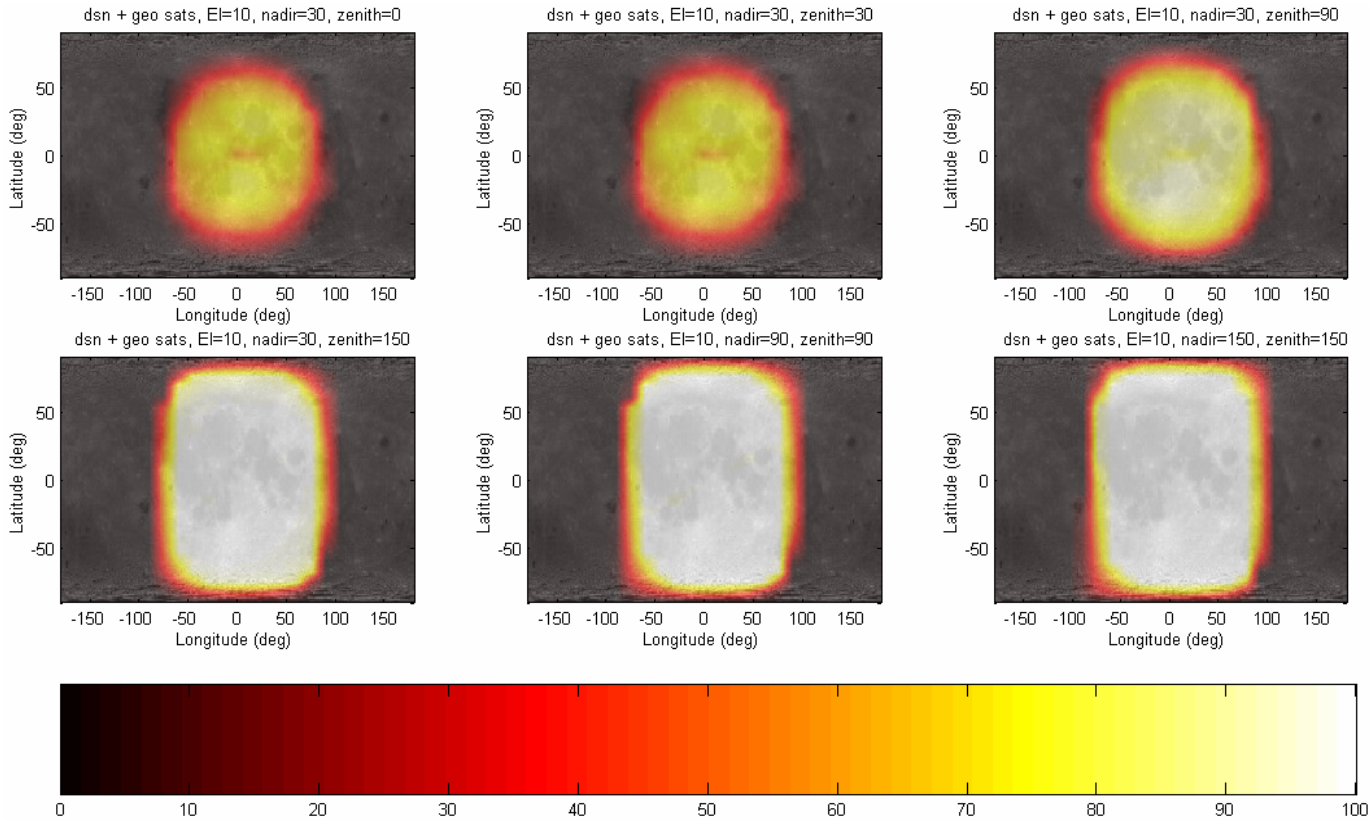

Figure B.4.2.3.—DSNGEO system availability results.

TABLE B.4.2.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	0.00	0.00	0.00	0.00	0.00
GEO 90/30	3.99	0.01	9.75	0.00	19.44
GEO 150/30	42.09	12.50	80.84	0.00	97.32
GEO 90/90	43.49	16.87	82.71	0.00	94.83
GEO 150/150	46.59	24.67	87.91	0.00	99.96
DSN 5	25.30	0.00	55.27	0.00	80.94
DSN 10	21.18	0.00	46.86	0.00	70.12
DSN 15	18.03	0.00	39.95	0.00	61.11
DSN+GEO 10/0/30	22.64	0.00	50.22	0.00	73.48
DSN+GEO 10/30/30	23.09	0.00	51.17	0.00	74.47
DSN+GEO 10/90/30	33.02	0.08	70.45	0.00	90.26
DSN+GEO 10/150/30	43.87	14.49	84.40	0.00	99.82
DSN+GEO 10/90/90	45.34	19.00	86.30	0.00	99.52
DSN+GEO 10/150/150	46.74	24.90	88.20	0.00	99.98

TABLE B.4.2.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	0.00	0.00	0.00	0.00	0.00
GEO 90/30	1.40	0.00	3.42	0.00	6.66
GEO 150/30	16.28	6.74	29.63	0.00	30.37
GEO 90/90	9.43	5.79	17.79	0.00	19.93
GEO 150/150	1.68	4.98	2.73	0.00	1.58
DSN 5	13.44	0.00	28.96	0.00	40.83
DSN 10	13.14	0.00	29.02	0.00	42.10
DSN 15	12.26	0.00	27.30	0.00	40.68
DSN+GEO 10/0/30 -v1	12.18	0.00	26.78	0.00	37.52
DSN+GEO 10/0/30 -v2	19.52	0.00	42.82	0.00	60.73
DSN+GEO 10/30/30 -v1	12.07	0.00	26.47	0.00	36.66
DSN+GEO 10/30/30 -v2	18.37	0.00	40.02	0.00	55.17
DSN+GEO 10/90/30 -v1	5.01	0.05	8.97	0.00	9.16
DSN+GEO 10/90/30 -v2	7.10	0.04	12.91	0.00	12.55
DSN+GEO 10/150/30 -v1	0.34	0.66	0.66	0.00	0.51
DSN+GEO 10/150/30 -v2	2.97	4.07	5.13	0.00	5.44
DSN+GEO 10/90/90 -v1	0.60	0.80	1.16	0.00	1.41
DSN+GEO 10/90/90 -v2	4.48	4.13	8.10	0.00	8.29
DSN+GEO 10/150/150 -v1	0.05	0.18	0.11	0.00	0.00
DSN+GEO 10/150/150 -v2	1.01	3.59	1.44	0.00	0.17

B.4.3 Dynamic (1 hr).—Figures B.4.3.1 to B.4.3.3 show the system availability results for the 15 Earth-based constellations when the system is operating in one-way mode with terrain information and clock synchronization (solving with 1-hr dynamic measurements). Table B.4.3.1 tabulates the weighted system availabilities from figures B.4.3.1 to B.4.3.3. Table B.4.3.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

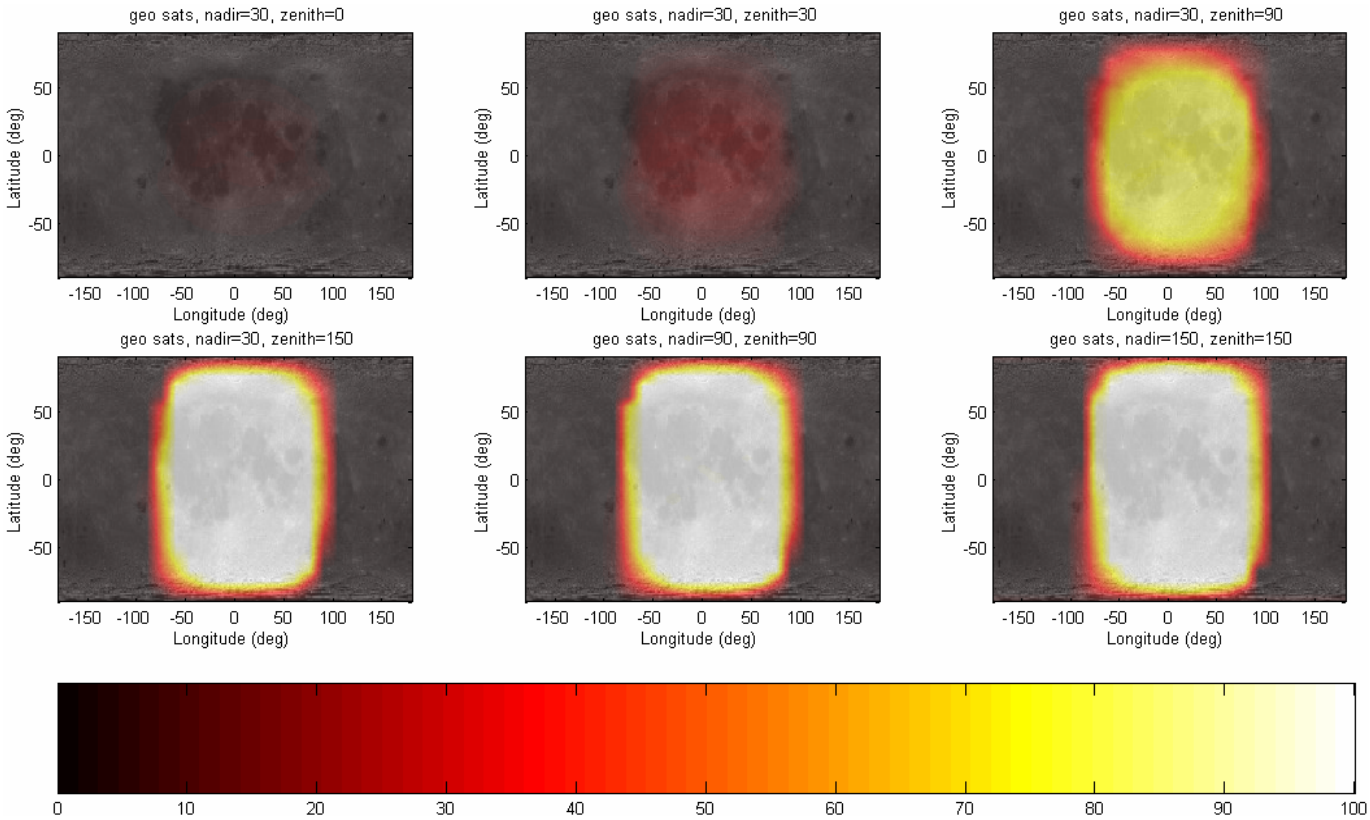

Figure B.4.3.1.—GEO system availability results.

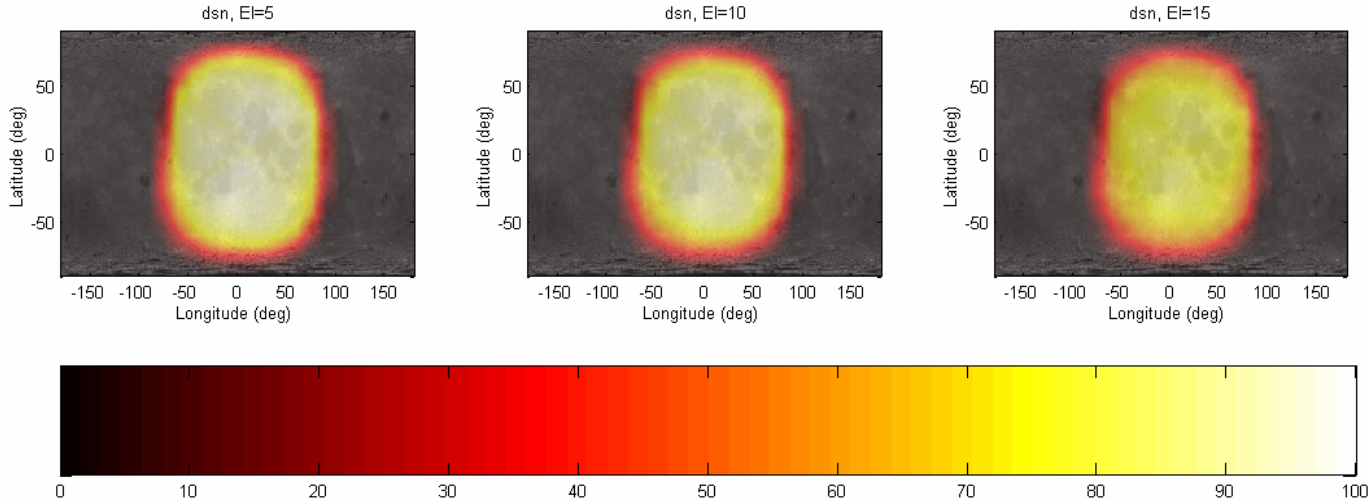

Figure B.4.3.2.—DSN system availability results.

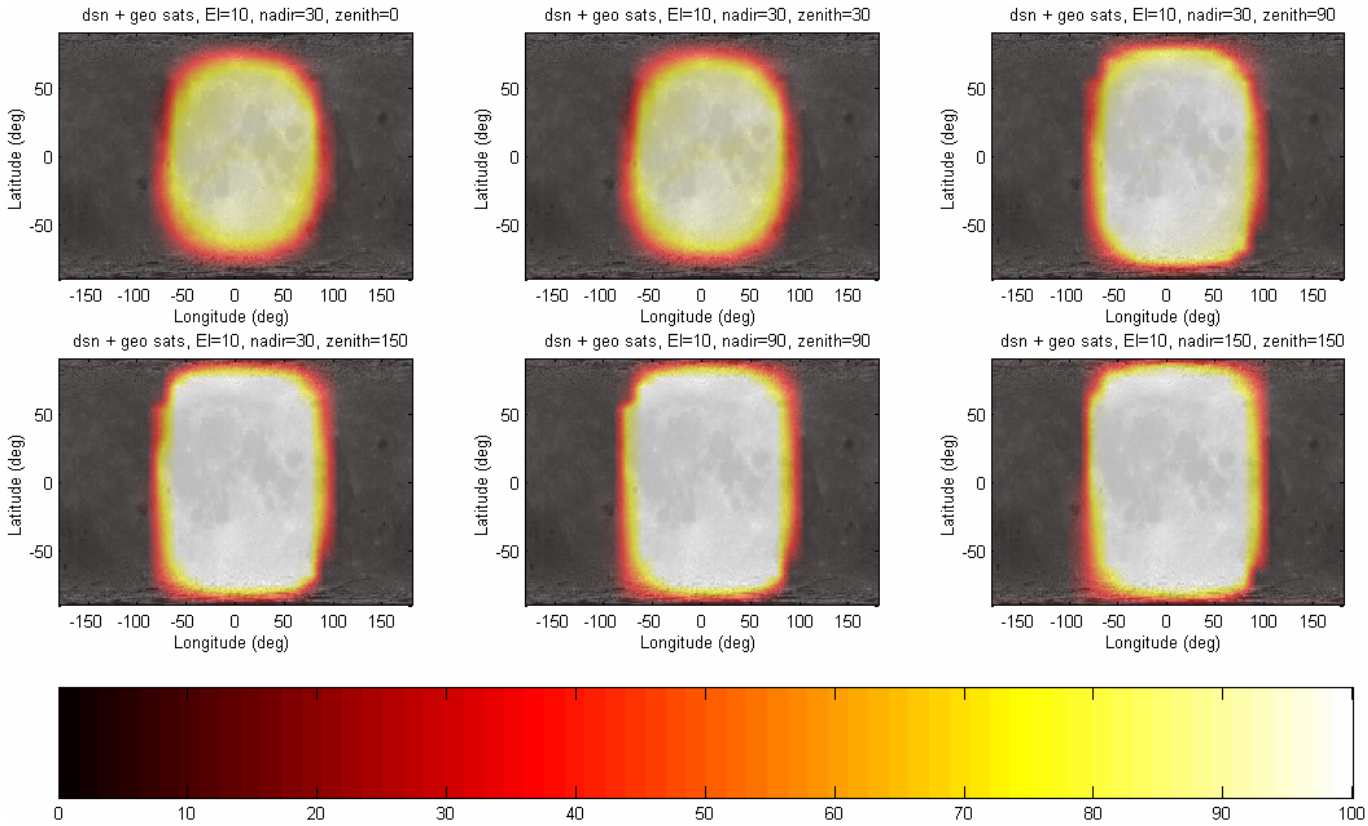

Figure B.4.3.3.—DSNGEO system availability results.

TABLE B.4.3.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	1.35	0.08	3.05	0.00	4.81
GEO 30/30	4.55	0.59	9.79	0.00	13.69
GEO 90/30	32.74	5.40	65.96	0.00	80.54
GEO 150/30	44.79	17.42	85.59	0.00	99.88
GEO 90/90	45.31	19.38	86.20	0.00	99.28
GEO 150/150	47.33	26.29	89.27	0.00	100.00
DSN 5	34.92	1.33	71.50	0.00	92.76
DSN 10	32.70	1.03	67.91	0.00	90.29
DSN 15	28.51	0.80	59.49	0.00	80.42
DSN+GEO 10/0/30	34.55	1.13	71.58	0.00	92.76
DSN+GEO 10/30/30	36.04	1.71	74.02	0.00	94.21
DSN+GEO 10/90/30	42.64	8.73	83.41	0.00	99.11
DSN+GEO 10/150/30	45.39	19.40	86.52	0.00	99.98
DSN+GEO 10/90/90	45.86	20.72	87.13	0.00	99.95
DSN+GEO 10/150/150	47.41	26.54	89.42	0.00	100.00

TABLE B.4.3.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.56	0.02	1.29	0.00	2.06
GEO 30/30	1.75	0.19	3.82	0.00	5.39
GEO 90/30	11.20	1.83	22.41	0.00	26.78
GEO 150/30	11.37	7.46	21.30	0.00	24.11
GEO 90/90	6.33	4.28	11.86	0.00	13.37
GEO 150/150	0.97	4.58	1.38	0.00	0.05
DSN 5	16.22	0.74	32.89	0.00	41.17
DSN 10	17.61	0.52	36.20	0.00	45.73
DSN 15	17.73	0.38	36.89	0.00	48.01
DSN+GEO 10/0/30 -v1	14.38	0.53	28.96	0.00	34.13
DSN+GEO 10/0/30 -v2	18.73	1.02	36.73	0.00	37.91
DSN+GEO 10/30/30 -v1	13.81	0.57	27.57	0.00	32.23
DSN+GEO 10/30/30 -v2	15.37	1.25	29.45	0.00	27.79
DSN+GEO 10/90/30 -v1	2.44	1.32	4.21	0.00	4.47
DSN+GEO 10/90/30 -v2	3.79	2.57	6.43	0.00	6.42
DSN+GEO 10/150/30 -v1	0.19	0.90	0.32	0.00	0.15
DSN+GEO 10/150/30 -v2	1.08	3.02	1.72	0.00	1.05
DSN+GEO 10/90/90 -v1	0.19	0.56	0.33	0.00	0.23
DSN+GEO 10/90/90 -v2	2.63	2.80	4.73	0.00	5.20
DSN+GEO 10/150/150 -v1	0.03	0.24	0.05	0.00	0.00
DSN+GEO 10/150/150 -v2	0.78	3.21	1.13	0.00	0.02

B.4.4 Dynamic (2 hr).—Figures B.4.4.1 to B.4.4.3 show the system availability results for the 15 Earth-based constellations when the system is operating in one-way mode with terrain information and clock synchronization (solving with 2-hr dynamic measurements). Table B.4.4.1 tabulates the weighted system availabilities from figures B.4.4.1 to B.4.4.3. Table B.4.4.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

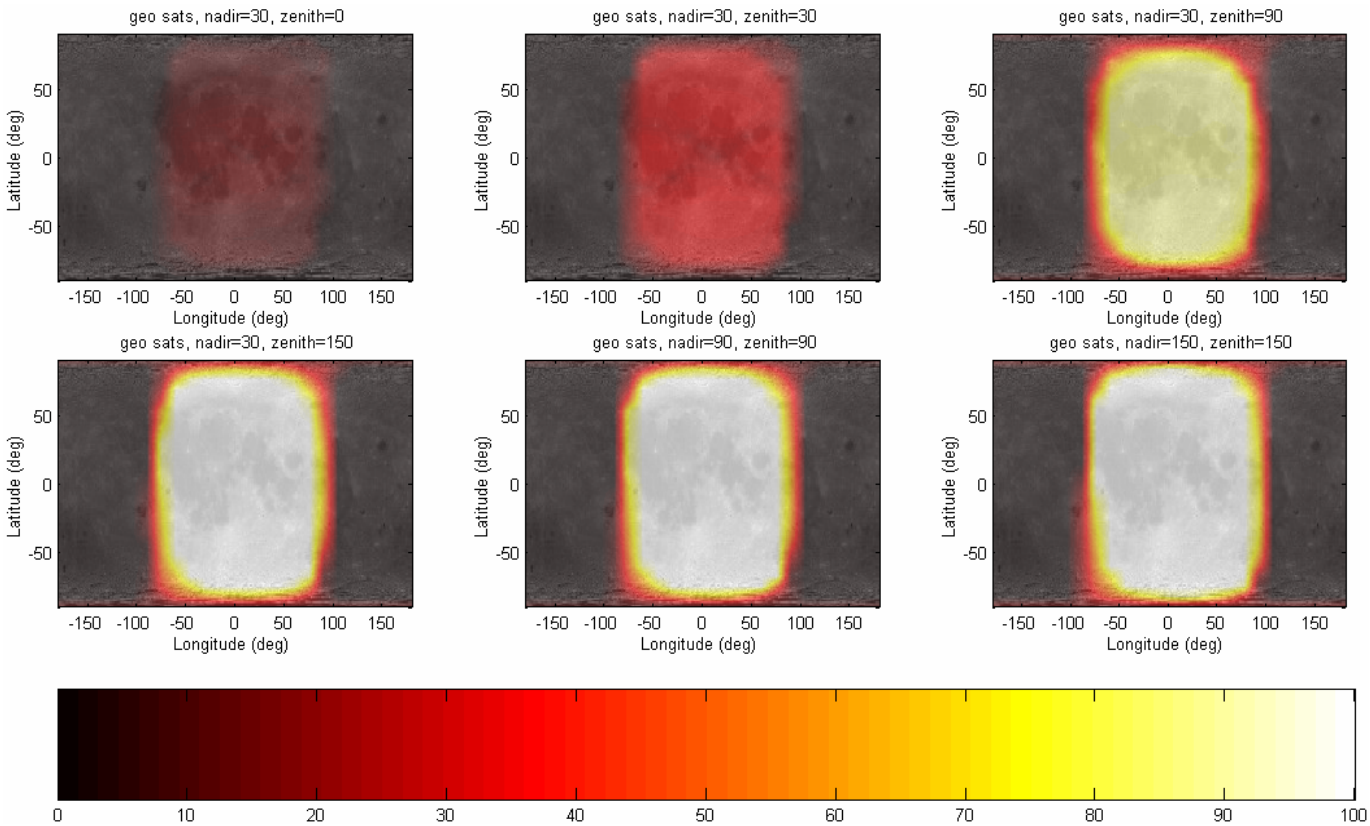

Figure B.4.4.1.—GEO system availability results.

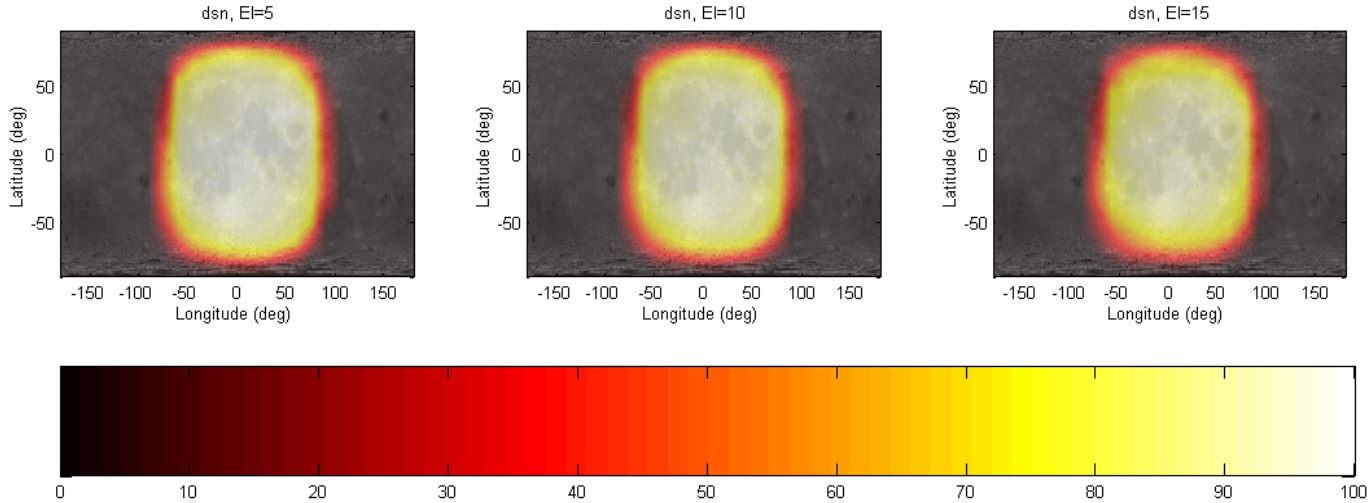

Figure B.4.4.2.—DSN system availability results.

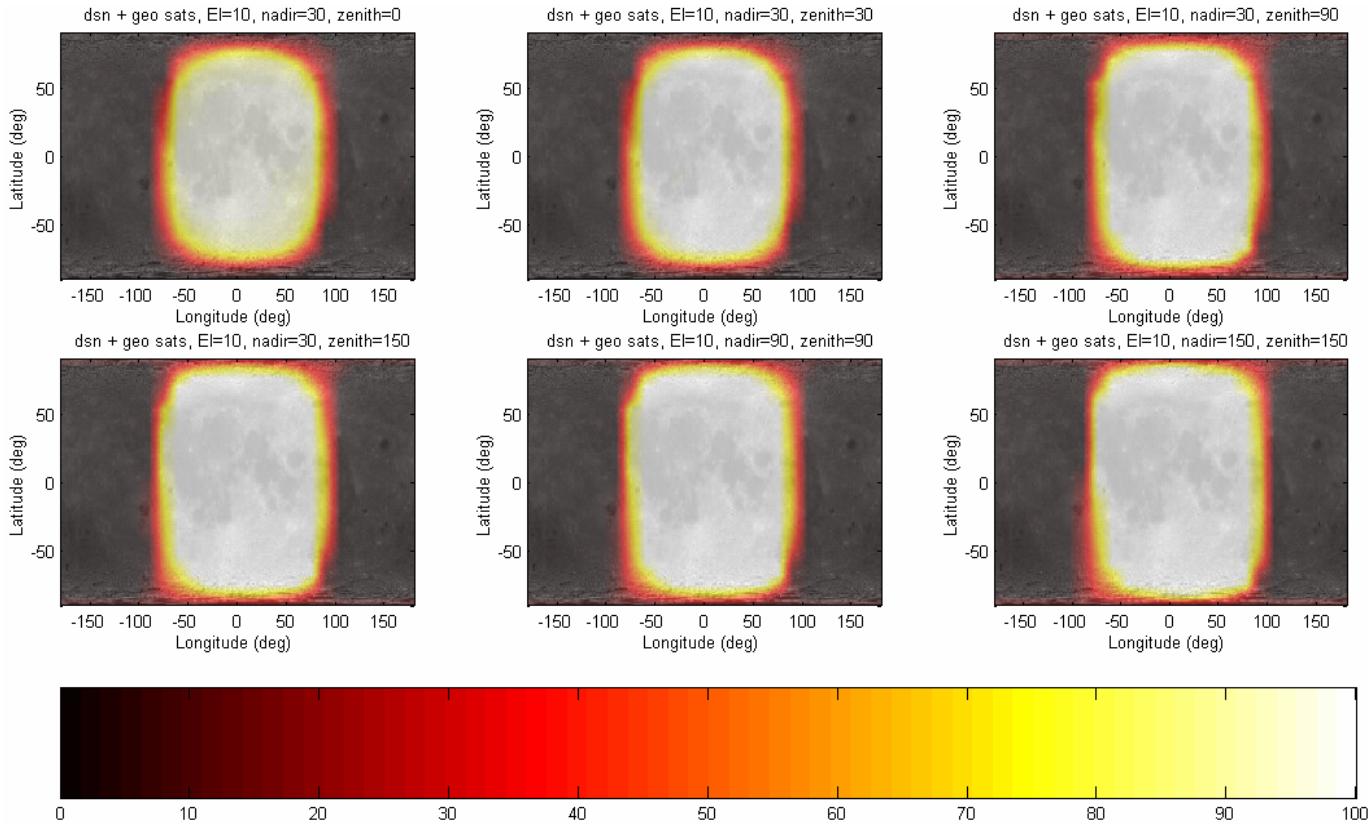

Figure B.4.4.3.—DSNGEO system availability results.

TABLE B.4.4.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	5.21	1.22	10.46	0.00	14.10
GEO 30/30	13.58	5.18	25.92	0.00	30.05
GEO 90/30	39.10	13.46	75.59	0.01	88.91
GEO 150/30	46.21	24.60	87.77	0.01	100.00
GEO 90/90	46.18	22.97	87.39	0.01	99.97
GEO 150/150	48.03	31.20	90.29	0.01	100.00
DSN 5	38.68	3.68	77.47	0.00	96.64
DSN 10	37.23	2.61	75.21	0.00	94.95
DSN 15	35.27	2.01	72.28	0.00	93.31
DSN+GEO 10/0/30	40.81	4.94	80.78	0.00	97.92
DSN+GEO 10/30/30	42.62	8.53	83.34	0.00	99.28
DSN+GEO 10/90/30	45.12	19.28	86.15	0.01	99.97
DSN+GEO 10/150/30	46.54	25.80	88.20	0.01	100.00
DSN+GEO 10/90/90	46.39	24.29	87.66	0.01	99.99
DSN+GEO 10/150/150	48.04	31.58	90.32	0.01	100.00

TABLE B.4.4.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	1.94	0.43	3.87	0.00	5.25
GEO 30/30	4.75	1.76	9.14	0.00	10.57
GEO 90/30	10.93	3.77	21.22	0.00	25.18
GEO 150/30	9.59	6.12	18.20	0.00	20.06
GEO 90/90	3.07	3.28	5.57	0.00	5.84
GEO 150/150	0.82	4.36	1.20	0.00	0.00
DSN 5	11.42	1.87	21.65	0.00	22.59
DSN 10	12.92	1.06	24.82	0.00	26.58
DSN 15	15.06	0.72	29.68	0.00	32.86
DSN+GEO 10/0/30 -v1	9.99	1.16	18.35	0.00	18.85
DSN+GEO 10/0/30 -v2	8.00	2.64	13.83	0.00	11.57
DSN+GEO 10/30/30 -v1	8.59	1.26	15.66	0.00	15.69
DSN+GEO 10/30/30 -v2	6.36	2.80	10.59	0.00	8.39
DSN+GEO 10/90/30 -v1	1.22	1.78	2.06	0.00	2.02
DSN+GEO 10/90/30 -v2	1.89	4.31	3.01	0.00	2.94
DSN+GEO 10/150/30 -v1	0.09	0.61	0.13	0.00	0.00
DSN+GEO 10/150/30 -v2	0.60	1.84	1.01	0.00	0.08
DSN+GEO 10/90/90 -v1	0.07	0.76	0.10	0.00	0.00
DSN+GEO 10/90/90 -v2	1.51	2.18	2.63	0.00	2.57
DSN+GEO 10/150/150 -v1	0.00	0.38	0.01	0.00	0.00
DSN+GEO 10/150/150 -v2	0.72	3.71	1.10	0.00	0.00

B.4.5 Dynamic (4 hr).—Figures B.4.5.1 to B.4.5.3 show the system availability results for the 15 Earth-based constellations when the system is operating in one-way mode with terrain information and clock synchronization (solving with 4-hr dynamic measurements). Table B.4.5.1 tabulates the weighted system availabilities from figures B.4.5.1 to B.4.5.3. Table B.4.5.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

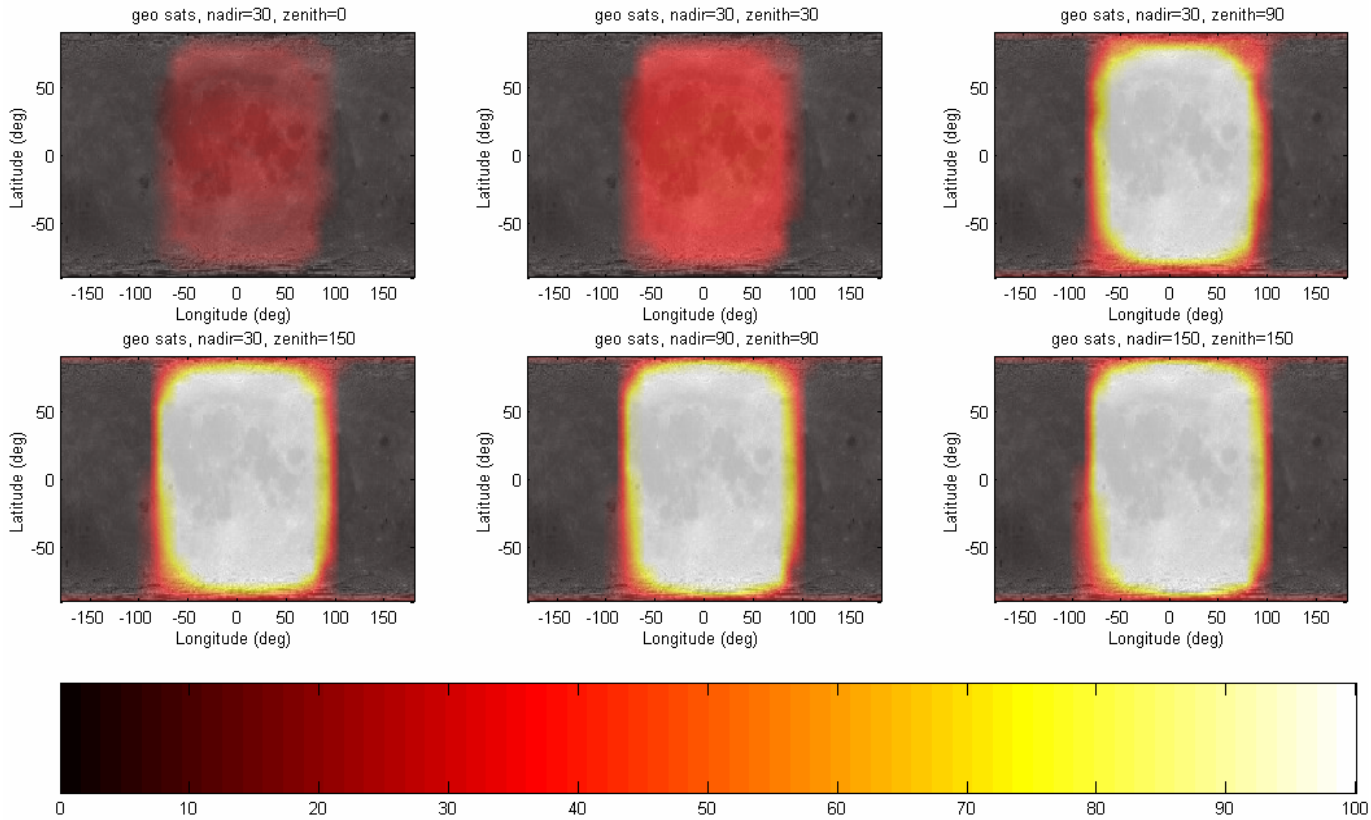

Figure B.4.5.1.—GEO system availability results.

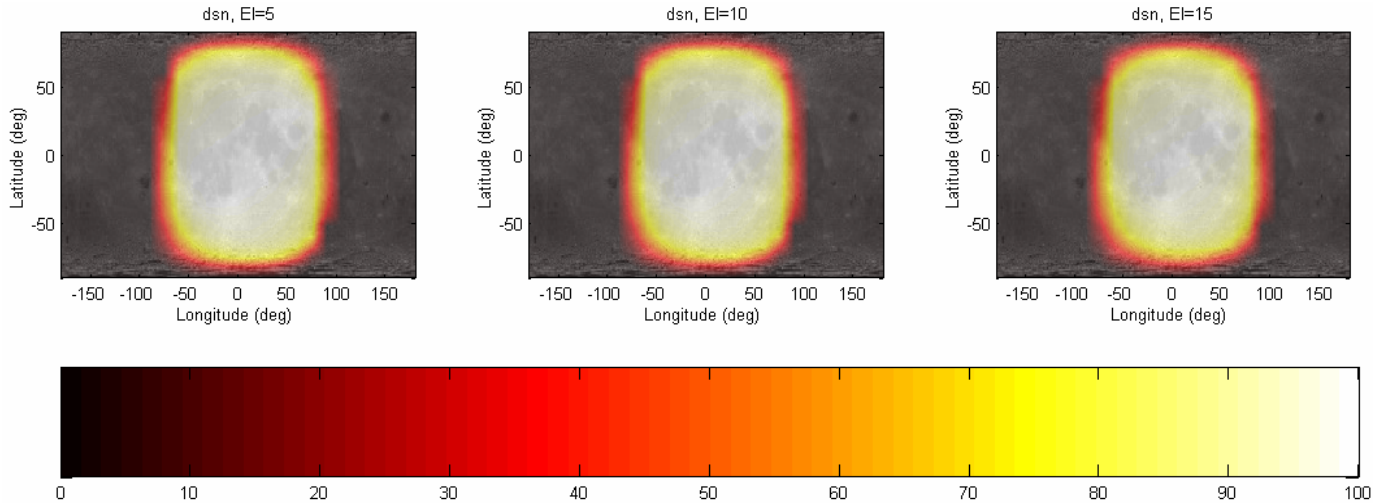

Figure B.4.5.2.—DSN system availability results.

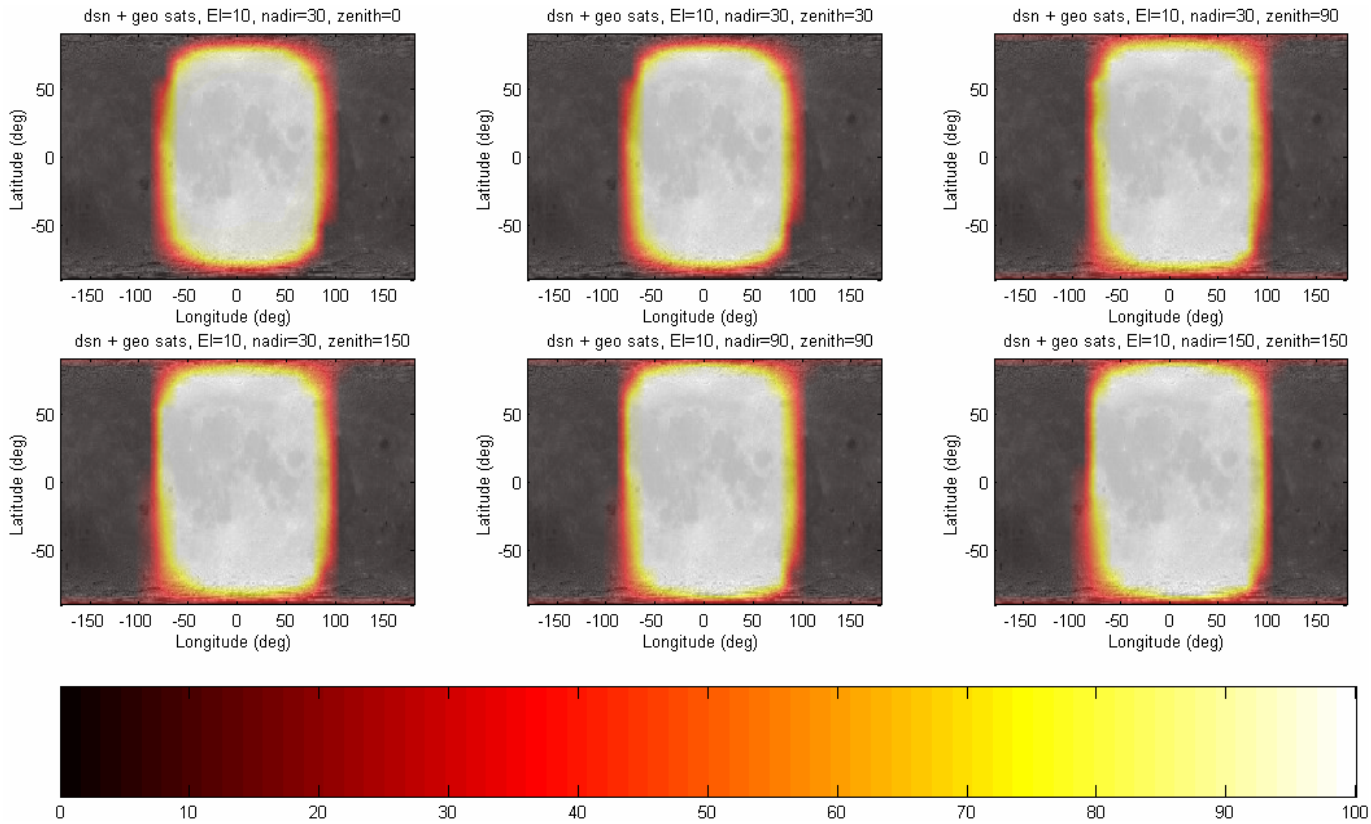

Figure B.4.5.3.—DSNGEO system availability results.

TABLE B.4.5.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	9.38	2.98	18.53	0.00	24.40
GEO 30/30	16.66	6.64	32.19	0.00	38.79
GEO 90/30	45.15	20.76	86.07	0.02	99.97
GEO 150/30	47.44	27.62	89.54	0.02	100.00
GEO 90/90	47.17	32.63	88.48	0.02	100.00
GEO 150/150	48.57	35.29	91.10	0.02	100.00
DSN 5	41.32	8.43	81.35	0.00	98.79
DSN 10	40.51	7.08	80.22	0.00	98.45
DSN 15	39.34	5.85	78.61	0.00	97.63
DSN+GEO 10/0/30	43.56	11.27	84.38	0.00	99.69
DSN+GEO 10/30/30	44.20	14.26	85.09	0.00	99.87
DSN+GEO 10/90/30	46.11	25.87	86.98	0.02	100.00
DSN+GEO 10/150/30	47.51	28.27	89.57	0.02	100.00
DSN+GEO 10/90/90	47.20	33.03	88.51	0.02	100.00
DSN+GEO 10/150/150	48.57	35.29	91.10	0.02	100.00

TABLE B.4.5.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	3.23	0.93	6.41	0.00	8.36
GEO 30/30	3.86	1.76	7.57	0.00	9.37
GEO 90/30	10.17	5.08	19.38	0.01	22.37
GEO 150/30	6.31	4.73	11.86	0.01	11.99
GEO 90/90	0.61	4.94	0.69	0.01	0.01
GEO 150/150	0.60	2.88	0.97	0.01	0.00
DSN 5	6.60	2.58	11.86	0.00	12.69
DSN 10	7.99	1.91	14.47	0.00	15.81
DSN 15	9.60	1.41	17.58	0.00	19.30
DSN+GEO 10/0/30 -v1	5.61	2.07	9.79	0.00	10.54
DSN+GEO 10/0/30 -v2	2.74	4.71	4.21	0.00	3.19
DSN+GEO 10/30/30 -v1	4.66	2.17	7.95	0.00	8.20
DSN+GEO 10/30/30 -v2	1.71	4.70	2.31	0.00	1.57
DSN+GEO 10/90/30 -v1	0.24	0.57	0.25	0.00	0.00
DSN+GEO 10/90/30 -v2	0.56	2.95	0.56	0.01	0.02
DSN+GEO 10/150/30 -v1	0.02	0.29	0.01	0.00	0.00
DSN+GEO 10/150/30 -v2	0.70	1.71	1.16	0.01	0.00
DSN+GEO 10/90/90 -v1	0.01	0.14	0.01	0.00	0.00
DSN+GEO 10/90/90 -v2	0.44	3.21	0.51	0.01	0.00
DSN+GEO 10/150/150 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/150/150 -v2	0.59	2.64	0.96	0.01	0.00

B.4.6 Dynamic (8 hr).—Figures B.4.6.1 to B.4.6.3 show the system availability results for the 15 Earth-based constellations when the system is operating in one-way mode with terrain information and clock synchronization (solving with 8-hr dynamic measurements). Table B.4.6.1 tabulates the weighted system availabilities from figures B.4.6.1 to B.4.6.3. Table B.4.6.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

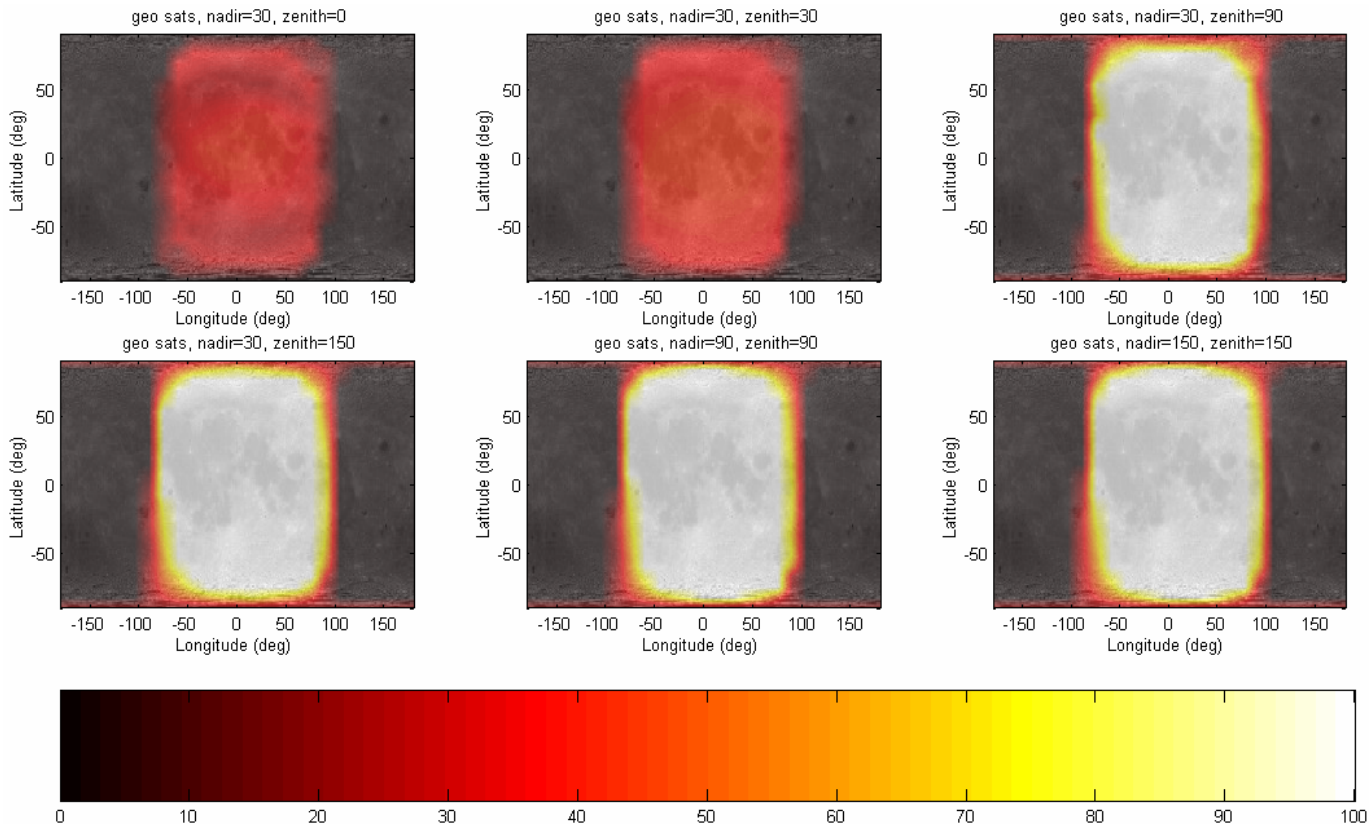

Figure B.4.6.1.—GEO system availability results.

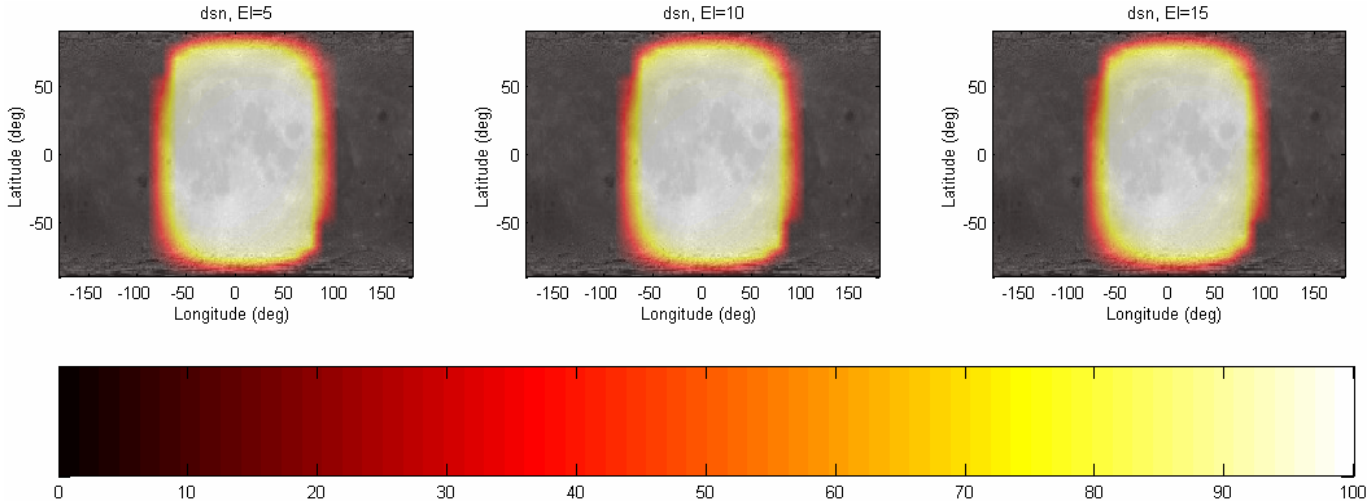

Figure B.4.6.2.—DSN system availability results.

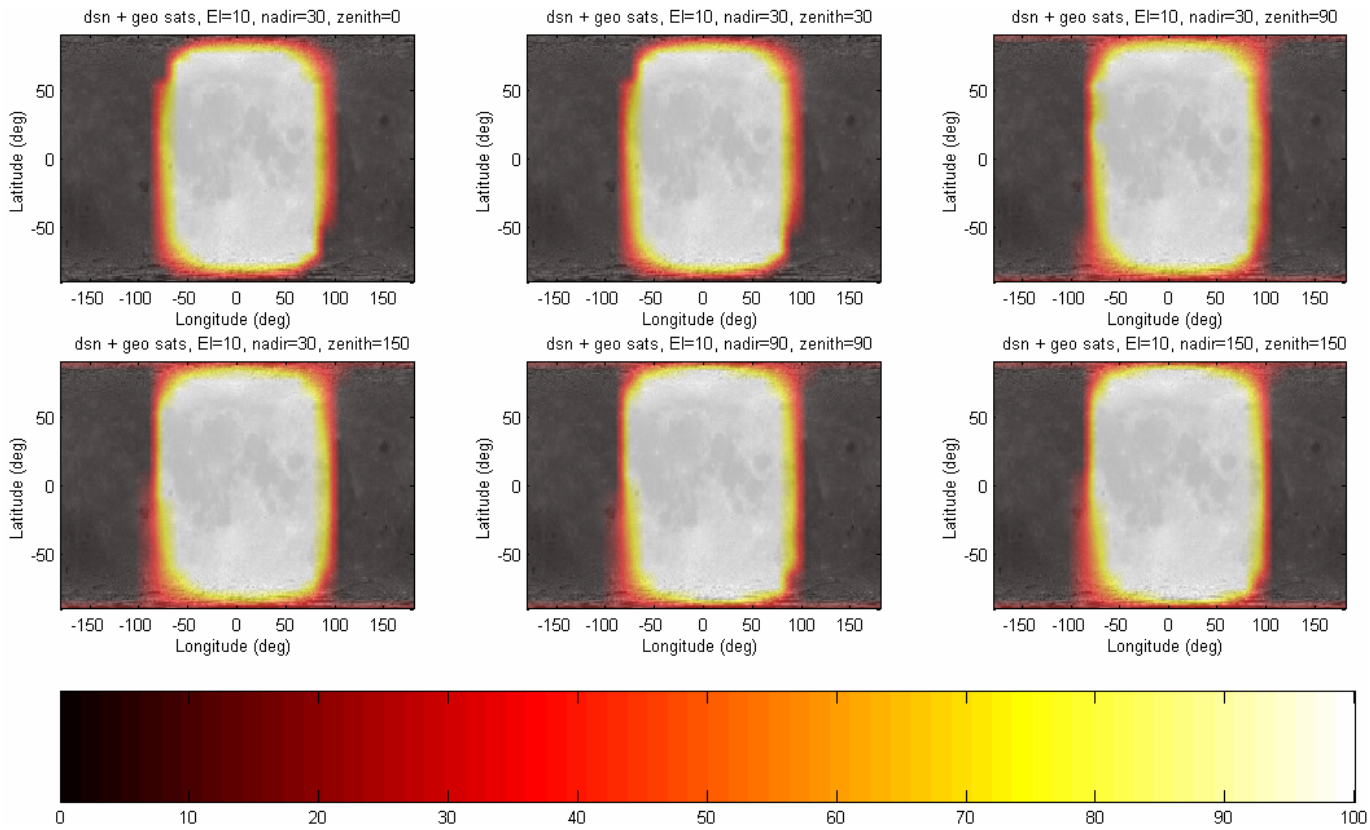

Figure B.4.6.3.—DSNGEO system availability results.

TABLE B.4.6.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	15.30	6.24	29.99	0.00	39.02
GEO 30/30	18.27	8.15	35.30	0.00	42.92
GEO 90/30	46.35	25.68	87.55	0.02	100.00
GEO 150/30	48.06	29.10	90.52	0.02	100.00
GEO 90/90	47.84	35.27	89.48	0.02	100.00
GEO 150/150	48.81	36.37	91.44	0.02	100.00
DSN 5	43.43	13.94	84.08	0.00	99.83
DSN 10	42.96	12.81	83.47	0.00	99.65
DSN 15	42.31	11.21	82.65	0.00	99.42
DSN+GEO 10/0/30	45.02	18.87	85.80	0.00	100.00
DSN+GEO 10/30/30	45.10	20.28	85.86	0.00	100.00
DSN+GEO 10/90/30	46.72	27.87	87.82	0.02	100.00
DSN+GEO 10/150/30	48.09	29.77	90.52	0.02	100.00
DSN+GEO 10/90/90	47.84	35.27	89.48	0.02	100.00
DSN+GEO 10/150/150	48.81	36.37	91.44	0.02	100.00

TABLE B.4.6.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	4.80	2.30	9.43	0.00	12.18
GEO 30/30	1.29	1.42	2.56	0.00	3.27
GEO 90/30	4.52	4.12	8.31	0.00	8.80
GEO 150/30	0.81	1.78	1.40	0.00	0.00
GEO 90/90	0.31	2.86	0.26	0.00	0.00
GEO 150/150	0.28	1.30	0.45	0.00	0.00
DSN 5	2.57	3.65	4.06	0.00	3.56
DSN 10	3.48	3.74	5.73	0.00	5.31
DSN 15	4.64	3.59	7.78	0.00	7.56
DSN+GEO 10/0/30 -v1	1.83	3.02	2.85	0.00	2.67
DSN+GEO 10/0/30 -v2	0.77	3.94	0.91	0.00	0.36
DSN+GEO 10/30/30 -v1	1.71	2.74	2.62	0.00	2.32
DSN+GEO 10/30/30 -v2	0.46	3.30	0.40	0.00	0.00
DSN+GEO 10/90/30 -v1	0.08	0.84	0.08	0.00	0.00
DSN+GEO 10/90/30 -v2	0.39	1.37	0.51	0.00	0.00
DSN+GEO 10/150/30 -v1	0.01	0.43	0.00	0.00	0.00
DSN+GEO 10/150/30 -v2	0.58	1.42	0.98	0.00	0.00
DSN+GEO 10/90/90 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/90/90 -v2	0.28	2.20	0.26	0.00	0.00
DSN+GEO 10/150/150 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/150/150 -v2	0.28	1.30	0.45	0.00	0.00

B.4.7 Dynamic (12 hr).—Figures B.4.7.1 to B.4.7.3 show the system availability results for the 15 Earth-based constellations when the system is operating in one-way mode with terrain information and clock synchronization (solving with 12-hr dynamic measurements). Table B.4.7.1 tabulates the weighted system availabilities from figures B.4.7.1 to B.4.7.3. Table B.4.7.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

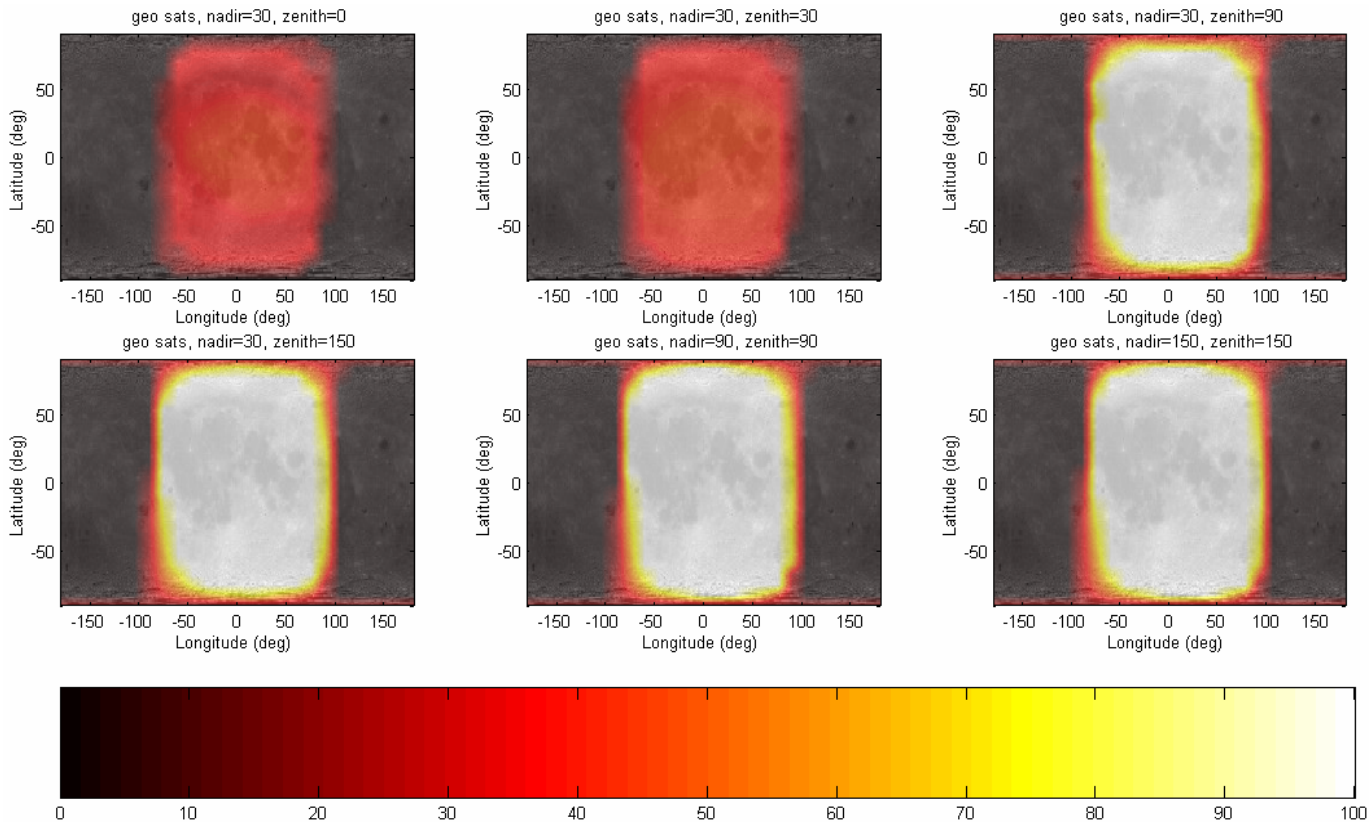

Figure B.4.7.1.—GEO system availability results.

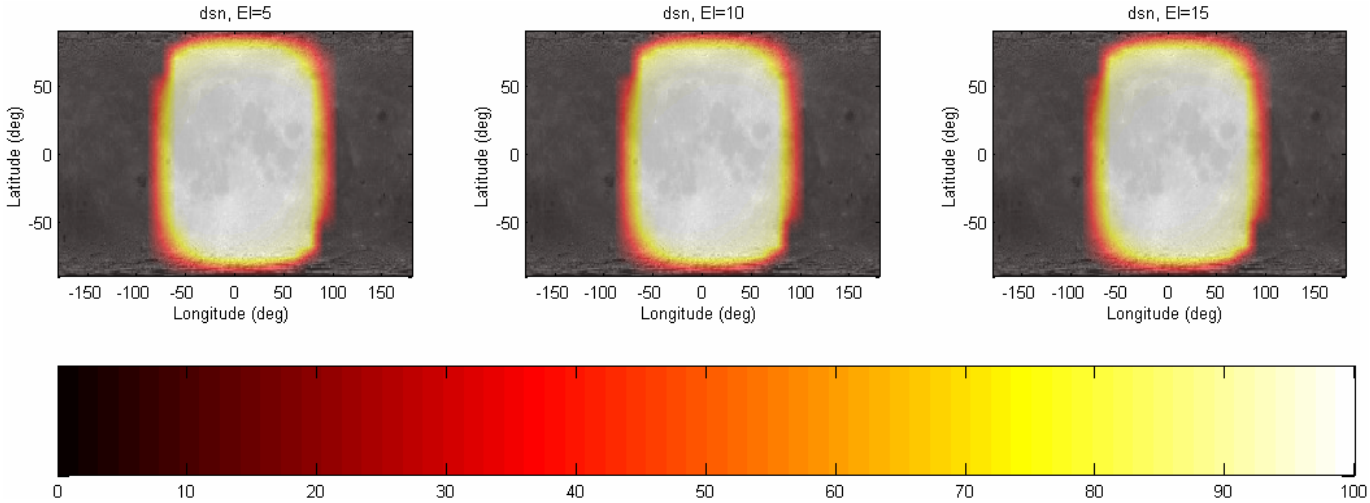

Figure B.4.7.2.—DSN system availability results.

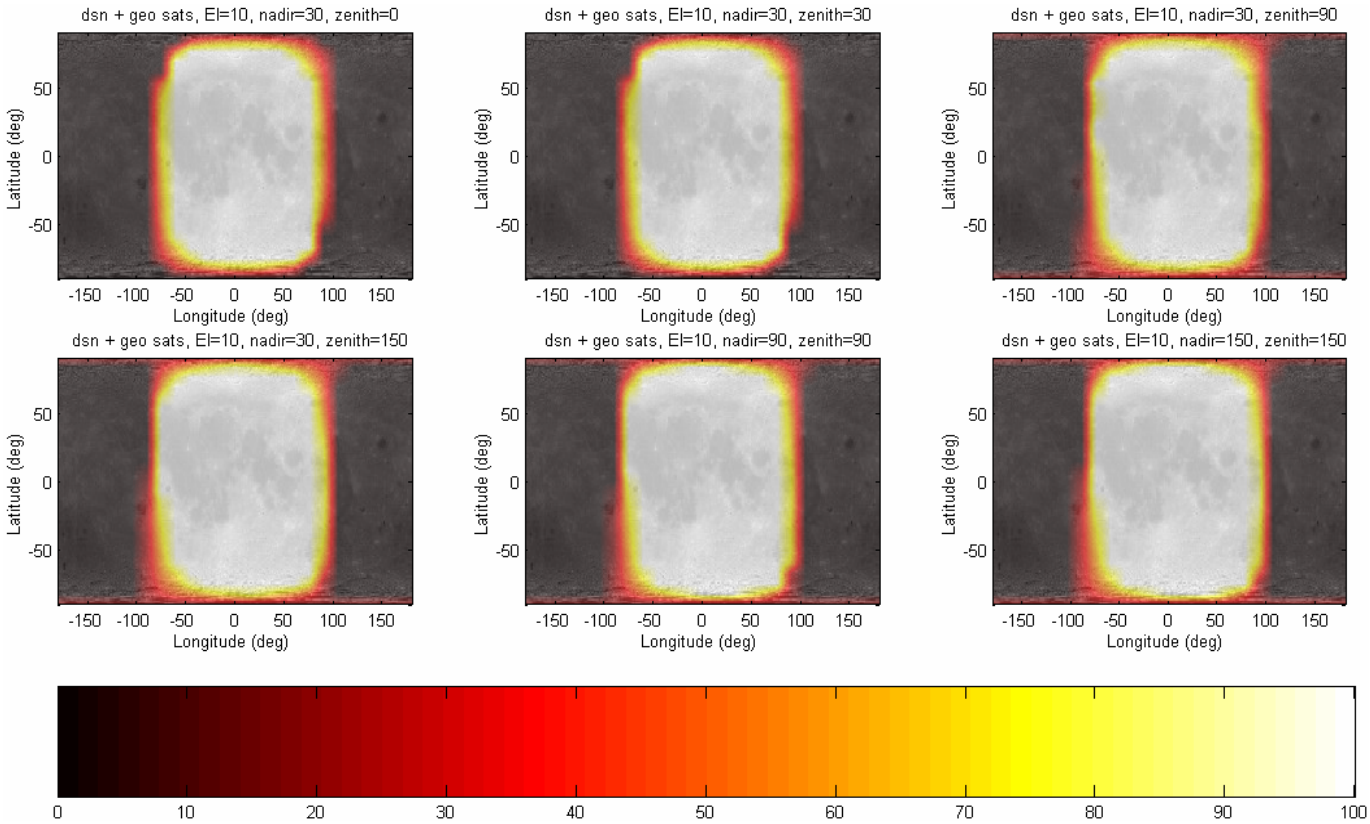

Figure B.4.7.3.—DSNGEO system availability results.

TABLE B.4.7.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	17.04	7.23	33.31	0.00	42.29
GEO 30/30	18.92	9.12	36.41	0.00	43.97
GEO 90/30	46.73	26.77	88.19	0.03	100.00
GEO 150/30	48.25	29.38	90.85	0.03	100.00
GEO 90/90	47.96	35.56	89.65	0.03	100.00
GEO 150/150	48.92	36.64	91.62	0.03	100.00
DSN 5	44.13	15.51	85.00	0.00	99.97
DSN 10	43.83	14.84	84.64	0.00	99.94
DSN 15	43.40	13.95	84.10	0.00	99.89
DSN+GEO 10/0/30	45.24	20.01	86.08	0.00	100.00
DSN+GEO 10/30/30	45.34	21.57	86.15	0.00	100.00
DSN+GEO 10/90/30	47.02	28.40	88.39	0.03	100.00
DSN+GEO 10/150/30	48.29	30.17	90.85	0.03	100.00
DSN+GEO 10/90/90	47.96	35.56	89.65	0.03	100.00
DSN+GEO 10/150/150	48.92	36.64	91.62	0.03	100.00

TABLE B.4.7.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	3.23	2.17	6.28	0.00	7.39
GEO 30/30	0.90	1.82	1.65	0.00	1.59
GEO 90/30	0.57	1.22	0.95	0.01	0.21
GEO 150/30	0.30	0.85	0.48	0.01	0.00
GEO 90/90	0.17	1.02	0.19	0.01	0.00
GEO 150/150	0.16	0.69	0.27	0.01	0.00
DSN 5	1.46	3.58	2.10	0.00	1.26
DSN 10	1.79	3.49	2.54	0.00	1.58
DSN 15	2.29	3.71	3.15	0.00	2.03
DSN+GEO 10/0/30 -v1	0.57	2.31	0.59	0.00	0.03
DSN+GEO 10/0/30 -v2	0.21	1.13	0.24	0.00	0.00
DSN+GEO 10/30/30 -v1	0.56	2.26	0.56	0.00	0.00
DSN+GEO 10/30/30 -v2	0.20	1.29	0.21	0.00	0.00
DSN+GEO 10/90/30 -v1	0.05	1.07	0.04	0.00	0.00
DSN+GEO 10/90/30 -v2	0.33	0.70	0.56	0.01	0.00
DSN+GEO 10/150/30 -v1	0.02	0.56	0.00	0.00	0.00
DSN+GEO 10/150/30 -v2	0.27	0.72	0.45	0.01	0.00
DSN+GEO 10/90/90 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/90/90 -v2	0.17	1.01	0.19	0.01	0.00
DSN+GEO 10/150/150 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/150/150 -v2	0.16	0.69	0.27	0.01	0.00

B.5 No Terrain, Two-Way Mode

B.5.1 Kinematic.—Figures B.5.1.1 to B.5.1.3 show the system availability results for the 15 Earth-based constellations when the system is operating in two-way mode without terrain information (solving with kinematic measurements). Table B.5.1.1 tabulates the weighted system availabilities from figures B.5.1.1 to B.5.1.3. Table B.5.1.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

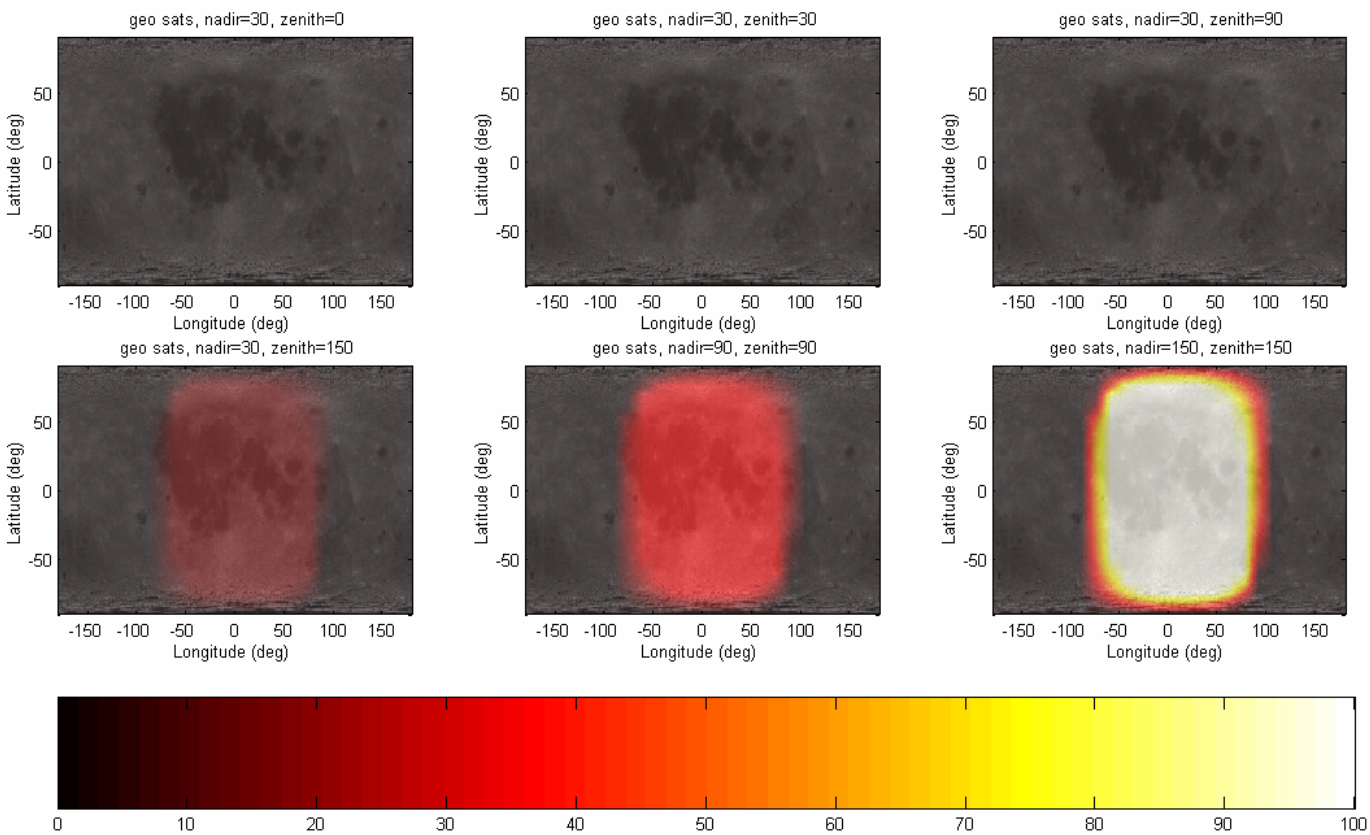

Figure B.5.1.1.—GEO system availability results.

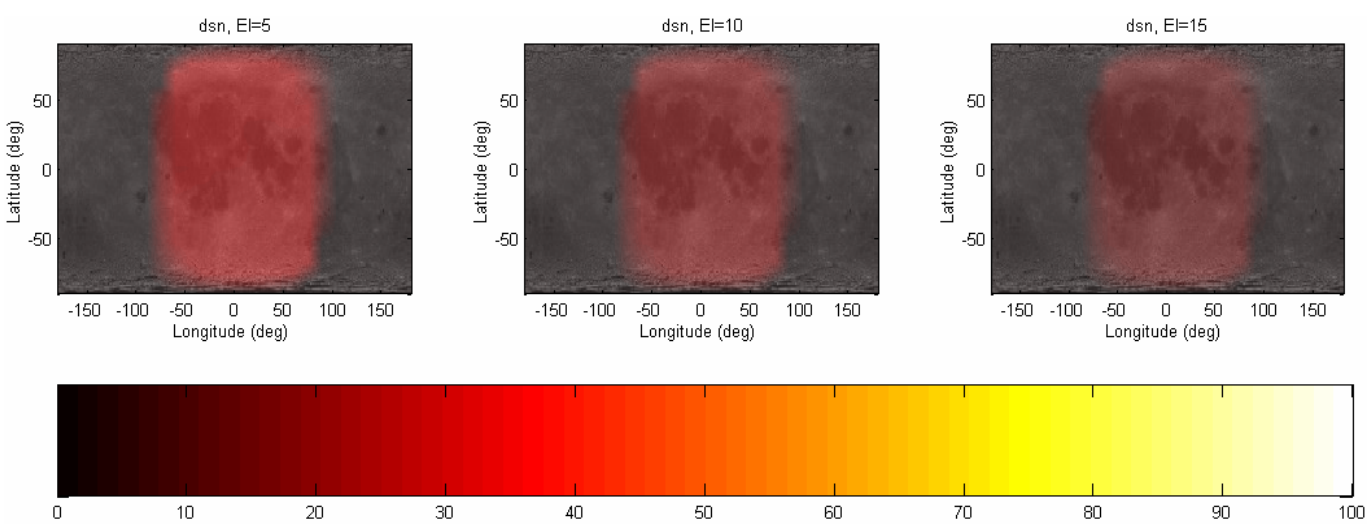

Figure B.5.1.2.—DSN system availability results.

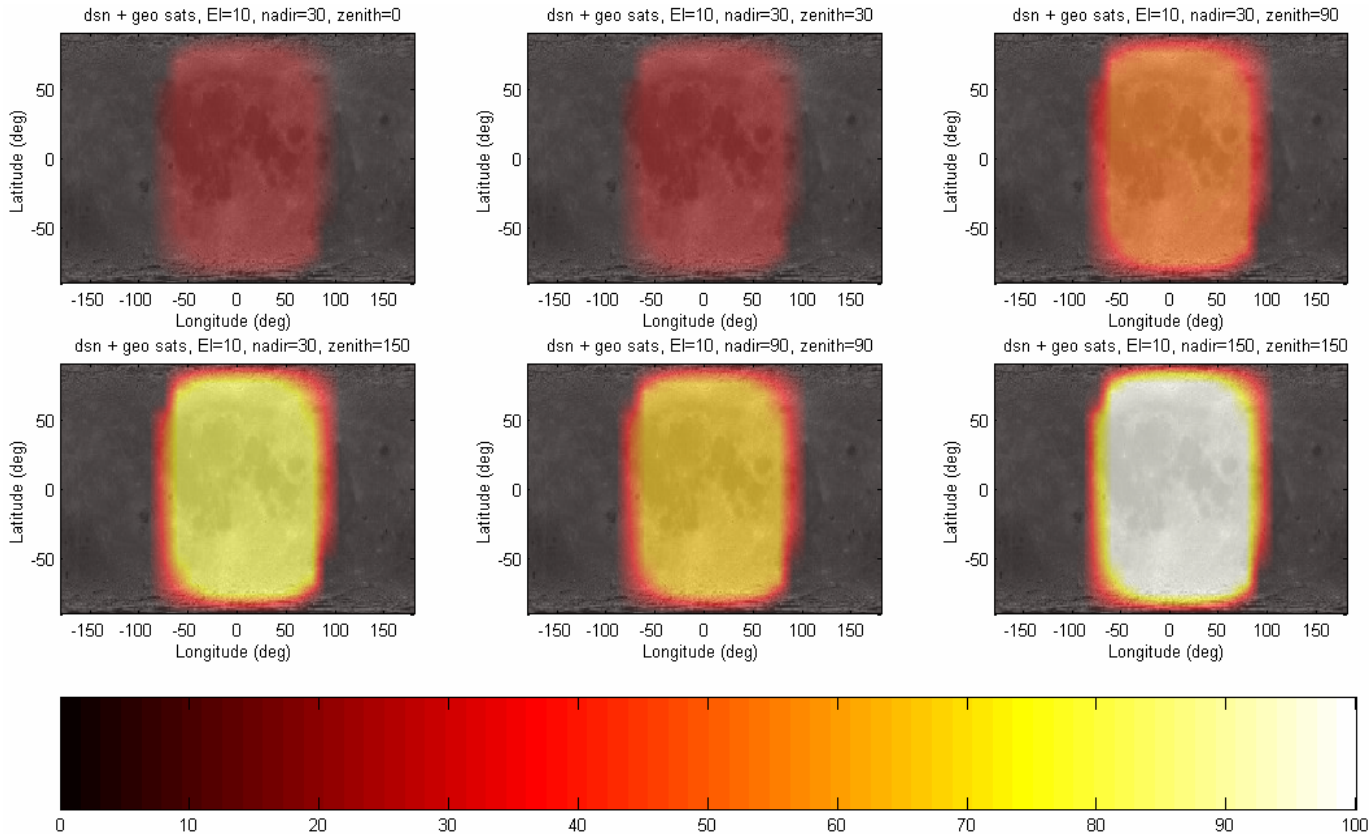

Figure B.5.1.3.—DSNGEO system availability results.

TABLE B.5.1.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	0.00	0.00	0.00	0.00	0.00
GEO 90/30	0.00	0.00	0.00	0.00	0.00
GEO 150/30	6.63	2.62	12.62	0.00	15.31
GEO 90/90	16.18	6.08	30.92	0.00	36.34
GEO 150/150	43.38	17.69	82.67	0.00	97.07
DSN 5	11.20	5.15	21.32	0.00	29.99
DSN 10	8.03	3.83	15.28	0.00	17.91
DSN 15	5.95	2.93	11.32	0.00	13.28
DSN+GEO 10/0/30	8.79	3.83	16.74	0.00	19.63
DSN+GEO 10/30/30	9.56	3.89	18.19	0.00	21.33
DSN+GEO 10/90/30	23.03	8.68	43.92	0.00	51.57
DSN+GEO 10/150/30	36.02	12.95	68.63	0.00	80.81
DSN+GEO 10/90/90	29.83	12.33	56.78	0.00	66.30
DSN+GEO 10/150/150	44.41	20.37	84.29	0.00	98.22

TABLE B.5.1.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	0.00	0.00	0.00	0.00	0.00
GEO 90/30	0.00	0.00	0.00	0.00	0.00
GEO 150/30	3.46	1.42	6.57	0.00	7.97
GEO 90/90	10.67	4.00	20.38	0.00	23.94
GEO 150/150	16.64	8.14	31.61	0.00	35.83
DSN 5	7.14	2.81	13.61	0.00	20.92
DSN 10	5.13	1.97	9.78	0.00	11.43
DSN 15	3.83	1.47	7.30	0.00	8.55
DSN+GEO 10/0/30 -v1	5.33	1.97	10.17	0.00	11.89
DSN+GEO 10/0/30 -v2	8.20	3.83	15.62	0.00	18.30
DSN+GEO 10/30/30 -v1	5.74	2.02	10.93	0.00	12.78
DSN+GEO 10/30/30 -v2	8.60	3.88	16.35	0.00	19.16
DSN+GEO 10/90/30 -v1	8.02	2.93	15.28	0.00	17.87
DSN+GEO 10/90/30 -v2	10.11	4.29	19.24	0.00	22.51
DSN+GEO 10/150/30 -v1	9.51	2.48	18.12	0.00	21.13
DSN+GEO 10/150/30 -v2	10.83	3.62	20.67	0.00	24.27
DSN+GEO 10/90/90 -v1	3.98	1.91	7.54	0.00	8.63
DSN+GEO 10/90/90 -v2	10.20	5.12	19.33	0.00	22.27
DSN+GEO 10/150/150 -v1	0.36	1.25	0.58	0.00	0.38
DSN+GEO 10/150/150 -v2	7.66	4.78	14.40	0.00	16.01

B.5.2 Dynamic (15 min).—Figures B.5.2.1 to B.5.2.3 show the system availability results for the 15 Earth-based constellations when the system is operating in two-way mode without terrain information (solving with 15-min dynamic measurements). Table B.5.2.1 tabulates the weighted system availabilities from figures B.5.2.1 to B.5.2.3. Table B.5.2.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

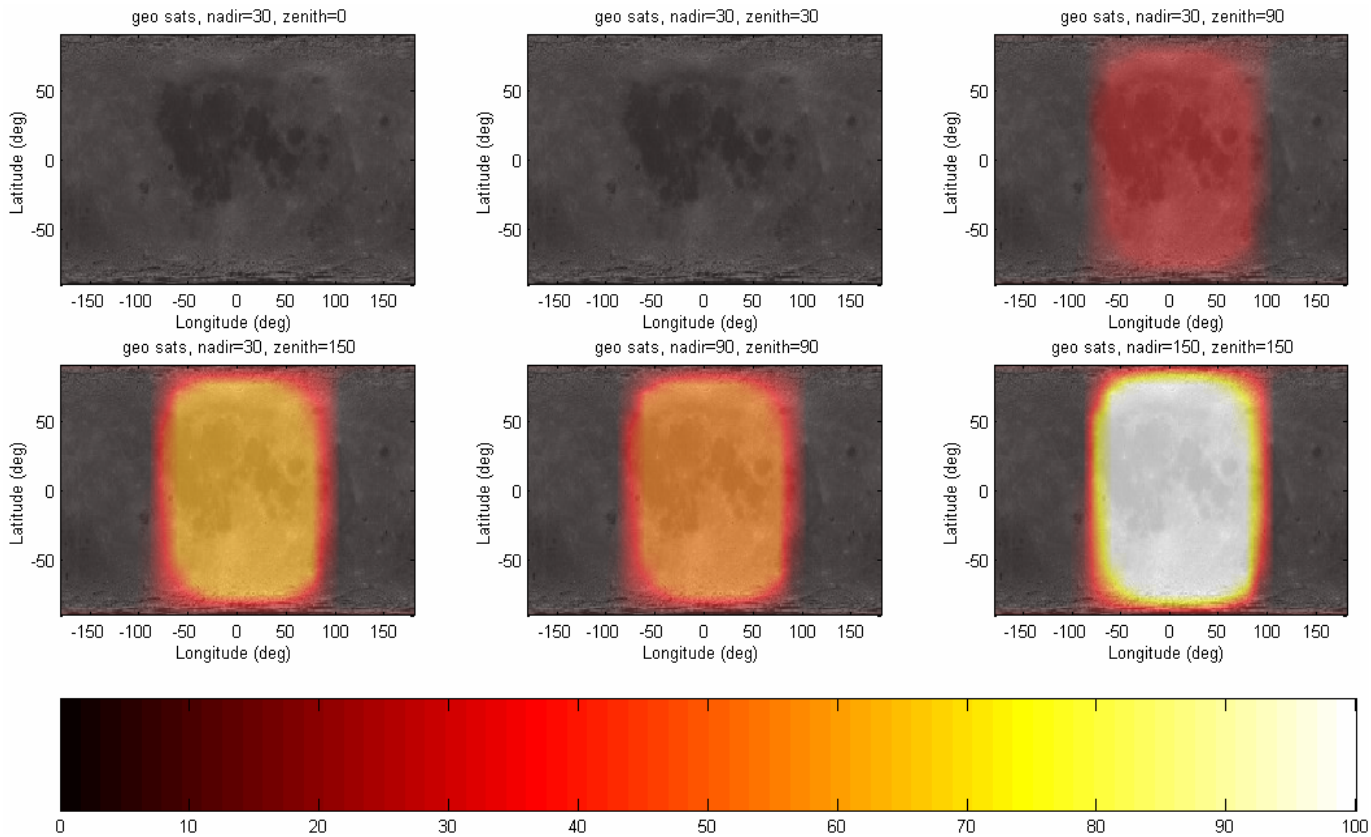

Figure B.5.2.1.—GEO system availability results.

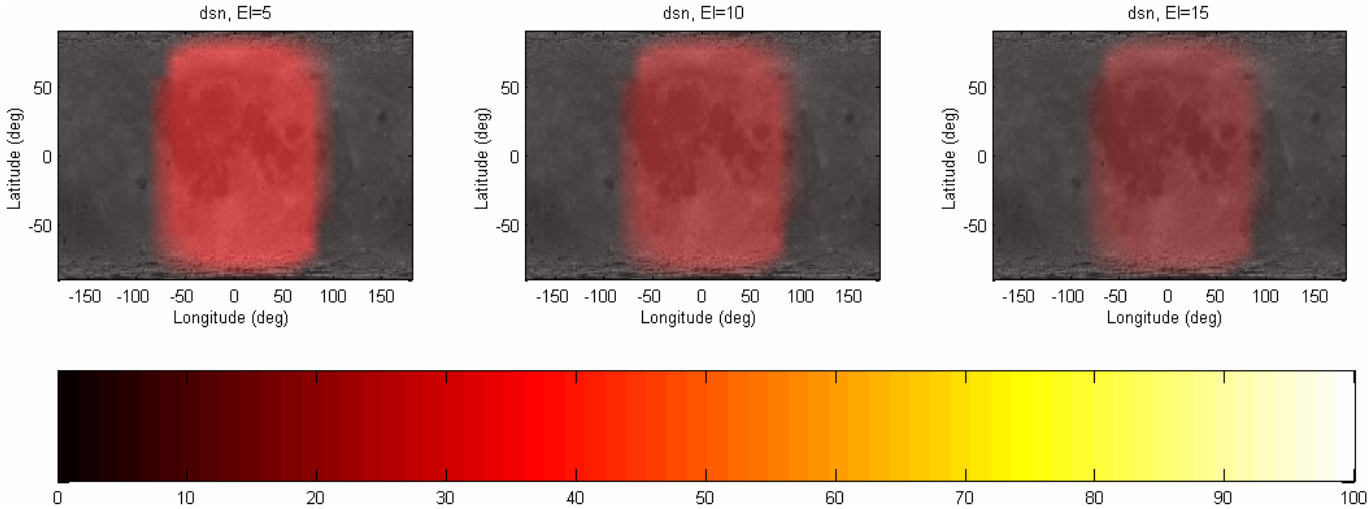

Figure B.5.2.2.—DSN system availability results.

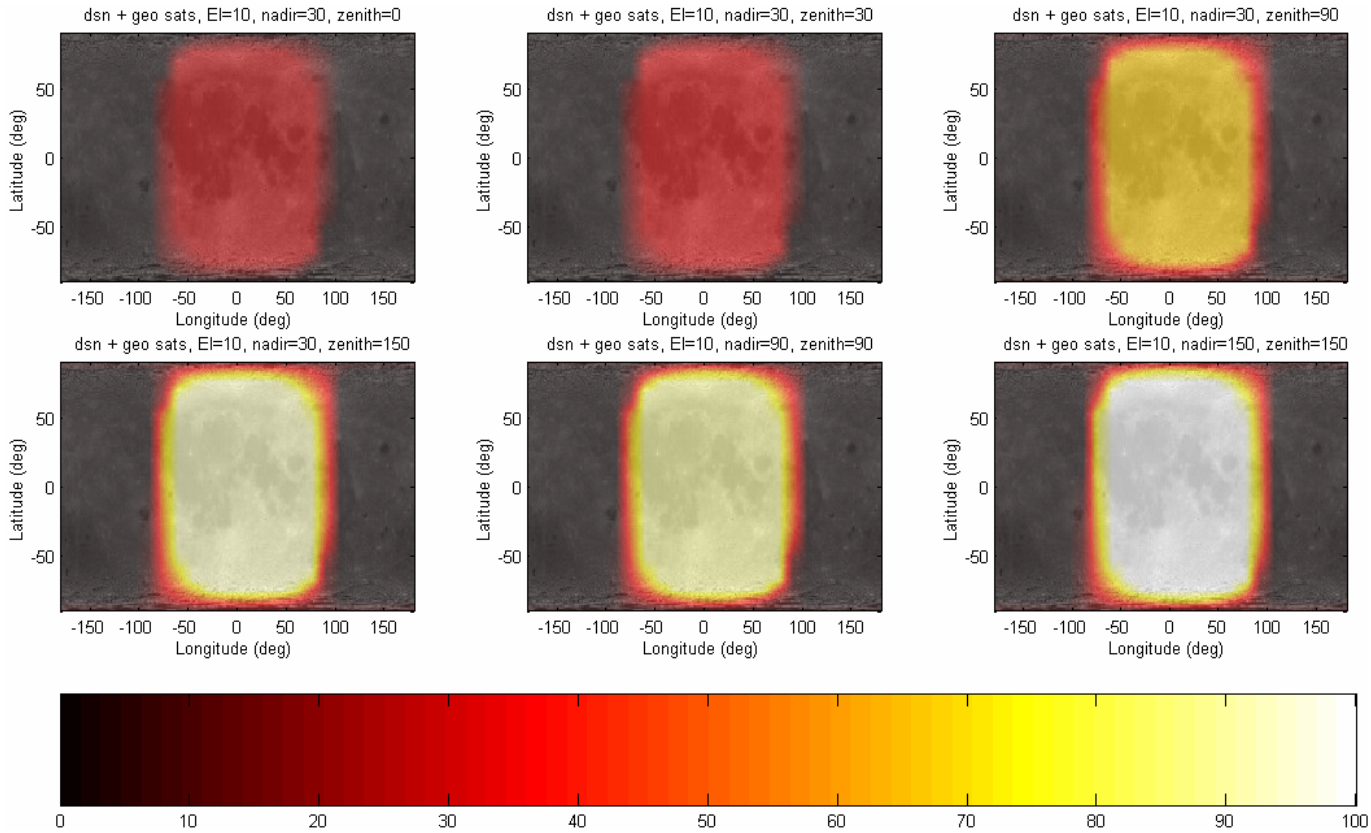

Figure B.5.2.3.—DSNGEO system availability results.

TABLE B.5.2.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	0.00	0.00	0.00	0.00	0.00
GEO 90/30	11.16	5.64	21.18	0.00	24.71
GEO 150/30	28.09	13.87	53.30	0.01	61.76
GEO 90/90	24.10	11.25	45.77	0.00	53.44
GEO 150/150	45.47	24.29	86.01	0.01	98.68
DSN 5	14.79	6.89	28.13	0.00	33.00
DSN 10	10.56	5.12	20.09	0.00	23.57
DSN 15	7.83	3.90	14.89	0.00	17.48
DSN+GEO 10/0/30	12.31	5.39	23.41	0.00	27.49
DSN+GEO 10/30/30	13.57	5.84	25.80	0.00	30.29
DSN+GEO 10/90/30	30.06	13.66	57.07	0.00	66.79
DSN+GEO 10/150/30	42.42	20.08	80.44	0.01	93.31
DSN+GEO 10/90/90	40.88	18.61	77.56	0.00	90.27
DSN+GEO 10/150/150	46.09	25.87	86.95	0.01	99.13

TABLE B.5.2.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	0.00	0.00	0.00	0.00	0.00
GEO 90/30	3.72	1.94	7.06	0.00	8.24
GEO 150/30	8.57	4.54	16.25	0.01	18.64
GEO 90/90	12.00	5.52	22.78	0.00	26.57
GEO 150/150	11.18	7.44	21.00	0.01	23.09
DSN 5	9.18	3.81	17.48	0.00	20.48
DSN 10	6.45	2.65	12.29	0.00	14.39
DSN 15	4.87	1.99	9.29	0.00	10.88
DSN+GEO 10/0/30 -v1	6.74	2.61	12.83	0.00	15.03
DSN+GEO 10/0/30 -v2	10.88	5.11	20.69	0.00	24.27
DSN+GEO 10/30/30 -v1	7.08	2.86	13.47	0.00	15.76
DSN+GEO 10/30/30 -v2	10.88	5.14	20.69	0.00	24.24
DSN+GEO 10/90/30 -v1	5.50	2.60	10.43	0.00	12.11
DSN+GEO 10/90/30 -v2	10.96	5.25	20.78	0.00	24.24
DSN+GEO 10/150/30 -v1	4.01	2.09	7.57	0.00	8.67
DSN+GEO 10/150/30 -v2	11.82	6.02	22.43	0.01	25.82
DSN+GEO 10/90/90 -v1	4.32	2.34	8.18	0.00	9.38
DSN+GEO 10/90/90 -v2	9.36	5.32	17.64	0.00	20.12
DSN+GEO 10/150/150 -v1	0.18	0.99	0.27	0.00	0.10
DSN+GEO 10/150/150 -v2	2.37	4.39	5.65	0.01	5.41

B.5.3 Dynamic (1 hr).—Figures B.5.3.1 to B.5.3.3 show the system availability results for the 15 Earth-based constellations when the system is operating in two-way mode without terrain information (solving with 1-hr dynamic measurements). Table B.5.3.1 tabulates the weighted system availabilities from figures B.5.3.1 to B.5.3.3. Table B.5.3.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

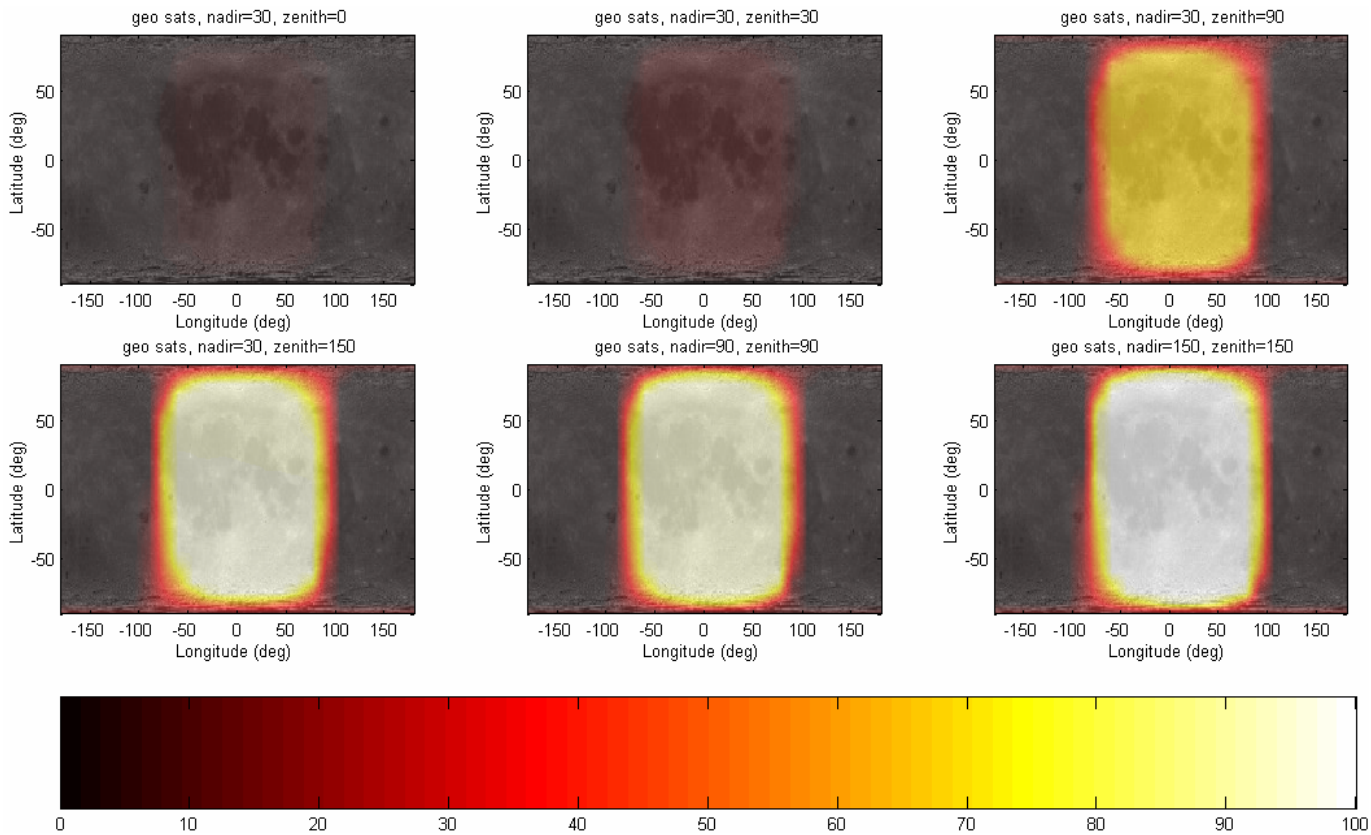

Figure B.5.3.1.—GEO system availability results.

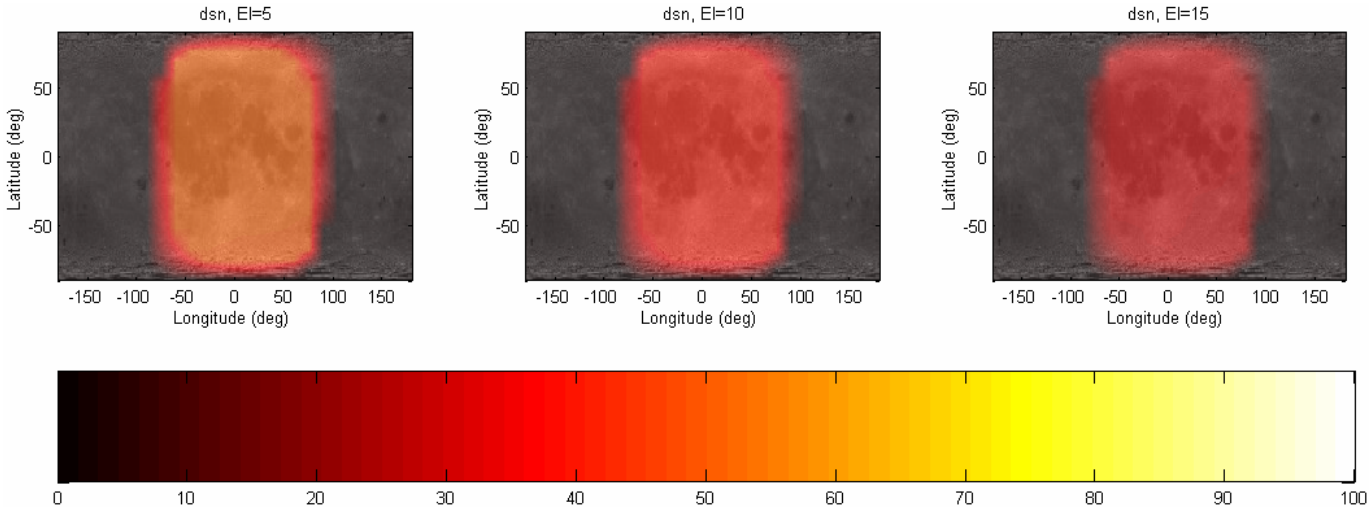

Figure B.5.3.2.—DSN system availability results.

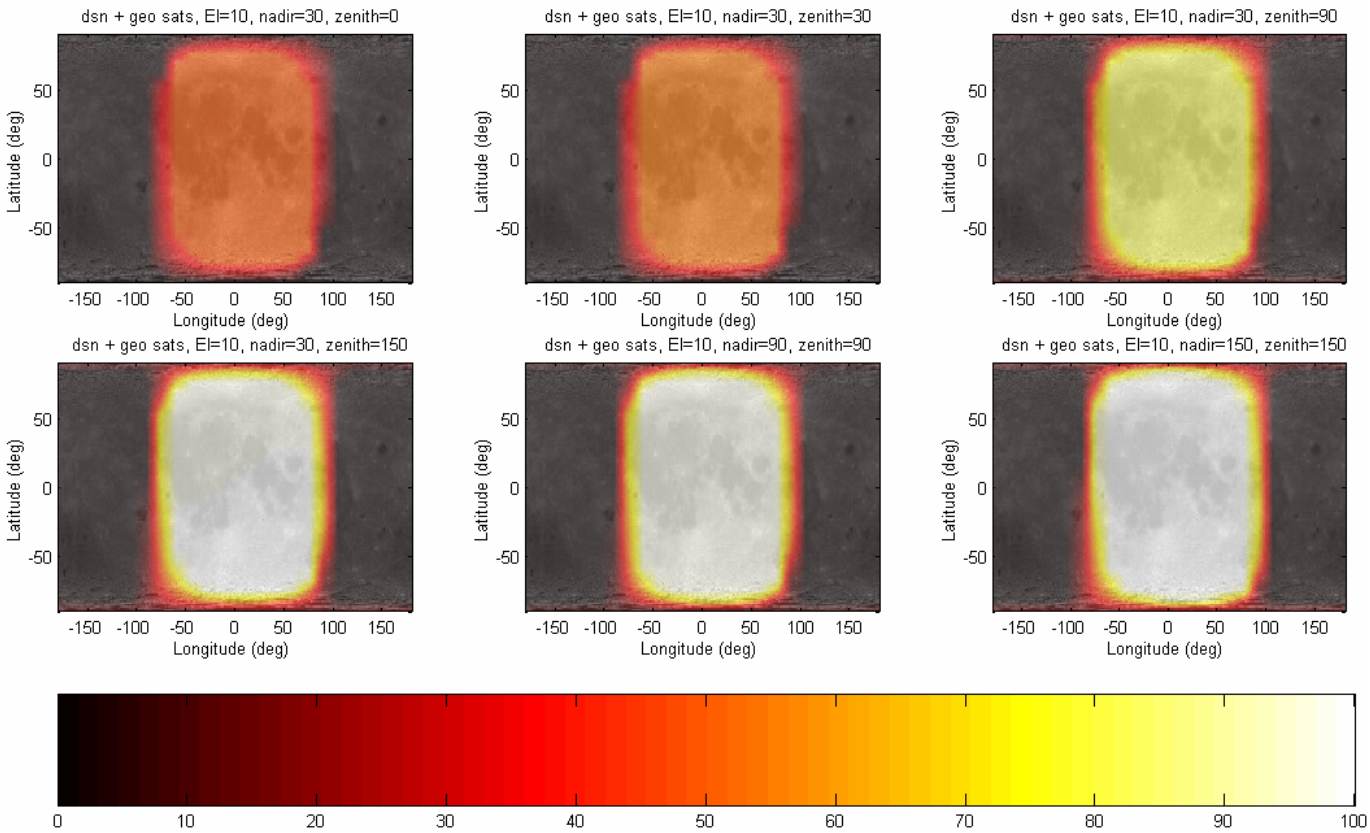

Figure B.5.3.3.—DSNGEO system availability results.

TABLE B.5.3.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	1.52	0.63	2.89	0.00	3.40
GEO 30/30	3.16	1.49	5.99	0.00	7.05
GEO 90/30	30.53	15.35	57.85	0.01	67.33
GEO 150/30	43.94	23.31	83.18	0.01	95.44
GEO 90/90	43.37	25.17	81.81	0.01	94.52
GEO 150/150	47.41	32.95	88.97	0.01	99.58
DSN 5	22.60	10.53	42.95	0.00	50.24
DSN 10	18.11	8.67	34.42	0.00	40.30
DSN 15	13.43	6.61	25.52	0.00	29.90
DSN+GEO 10/0/30	22.00	9.87	41.79	0.00	48.99
DSN+GEO 10/30/30	24.06	10.98	45.68	0.00	53.54
DSN+GEO 10/90/30	38.03	19.38	71.94	0.01	83.51
DSN+GEO 10/150/30	45.61	24.58	86.17	0.01	98.45
DSN+GEO 10/90/90	44.88	26.69	84.56	0.01	97.38
DSN+GEO 10/150/150	47.52	33.16	89.17	0.01	99.64

TABLE B.5.3.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.48	0.21	0.91	0.00	1.06
GEO 30/30	1.05	0.50	1.98	0.00	2.33
GEO 90/30	10.76	5.42	20.39	0.00	23.74
GEO 150/30	11.68	6.74	22.08	0.00	24.91
GEO 90/90	9.42	6.81	17.62	0.00	20.15
GEO 150/150	1.80	5.19	2.98	0.00	1.96
DSN 5	11.30	4.37	21.52	0.00	25.15
DSN 10	9.13	3.42	17.38	0.00	20.35
DSN 15	6.40	2.26	12.19	0.00	14.29
DSN+GEO 10/0/30 -v1	9.48	3.43	18.04	0.00	21.14
DSN+GEO 10/0/30 -v2	12.15	5.58	23.09	0.00	27.03
DSN+GEO 10/30/30 -v1	8.80	3.34	16.73	0.00	19.56
DSN+GEO 10/30/30 -v2	11.48	5.35	21.80	0.00	25.48
DSN+GEO 10/90/30 -v1	2.01	1.58	3.75	0.00	4.25
DSN+GEO 10/90/30 -v2	8.65	5.00	16.25	0.00	18.66
DSN+GEO 10/150/30 -v1	0.67	1.03	1.20	0.00	1.23
DSN+GEO 10/150/30 -v2	7.49	5.00	14.06	0.00	15.38
DSN+GEO 10/90/90 -v1	0.39	0.59	0.71	0.00	0.69
DSN+GEO 10/90/90 -v2	4.72	5.11	8.65	0.00	9.51
DSN+GEO 10/150/150 -v1	0.03	0.13	0.05	0.00	0.00
DSN+GEO 10/150/150 -v2	1.31	4.65	2.13	0.00	1.12

B.5.4 Dynamic (2 hr).—Figures B.5.4.1 to B.5.4.3 show the system availability results for the 15 Earth-based constellations when the system is operating in two-way mode without terrain information (solving with 2-hr dynamic measurements). Table B.5.4.1 tabulates the weighted system availabilities from figures B.5.4.1 to B.5.4.3. Table B.5.4.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

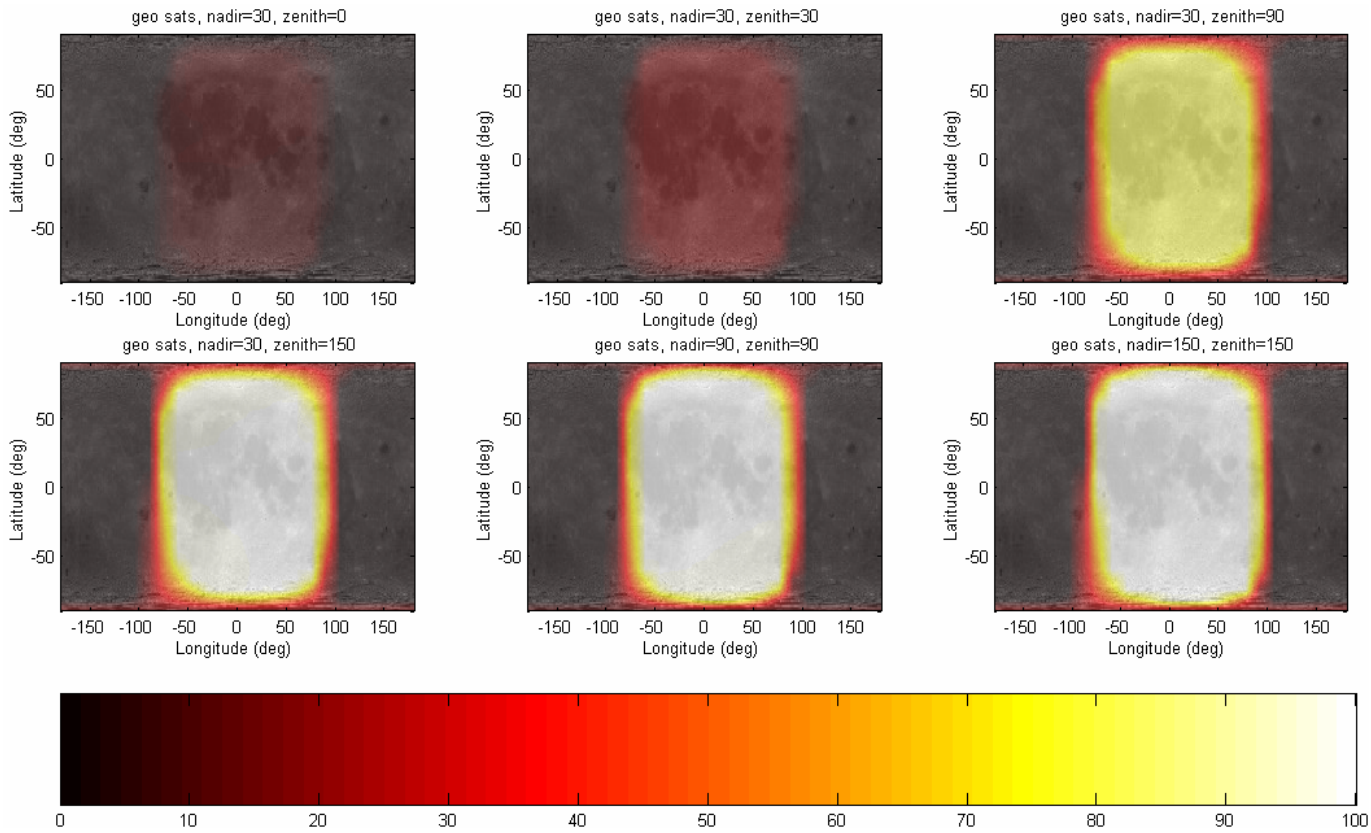

Figure B.5.4.1.—GEO system availability results.

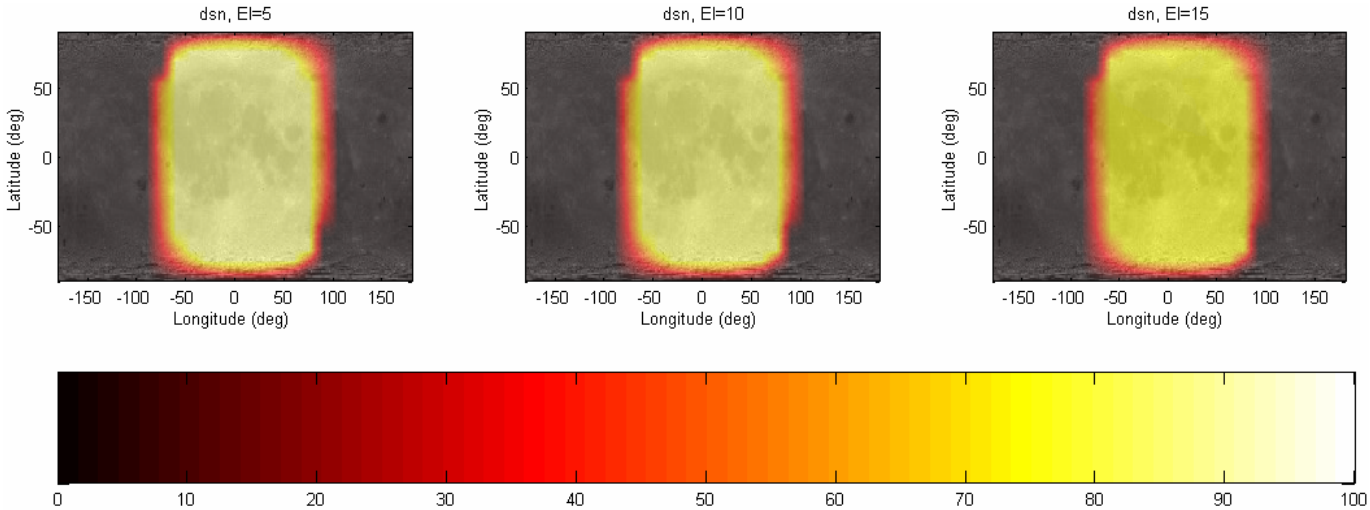

Figure B.5.4.2.—DSN system availability results.

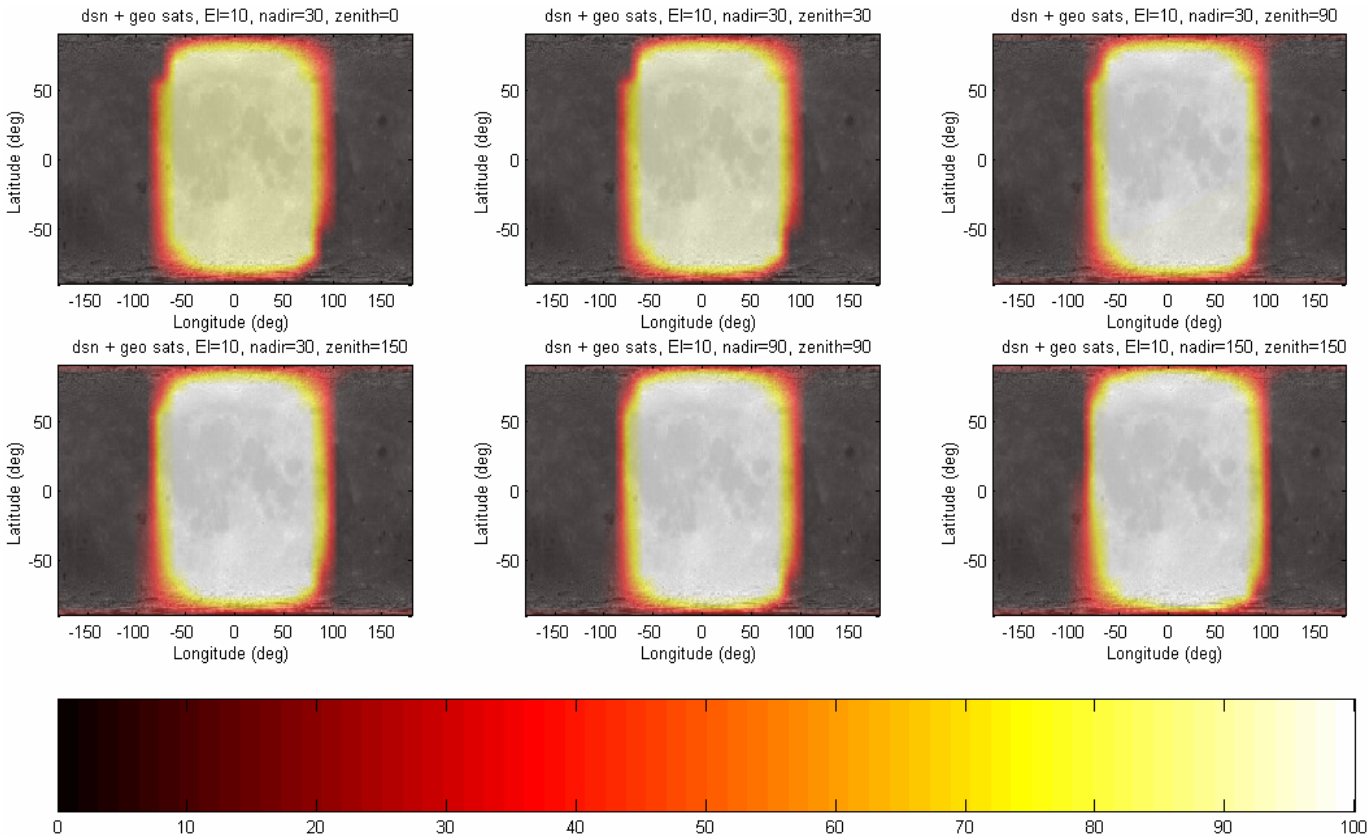

Figure B.5.4.3.—DSNGEO system availability results.

TABLE B.5.4.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	3.48	1.47	6.62	0.00	7.82
GEO 30/30	6.73	3.16	12.75	0.00	15.00
GEO 90/30	38.00	19.41	71.97	0.01	83.34
GEO 150/30	45.96	25.58	86.90	0.02	98.55
GEO 90/90	45.78	28.73	86.11	0.01	98.64
GEO 150/150	48.19	34.93	90.33	0.02	99.80
DSN 5	39.01	17.58	74.06	0.00	86.14
DSN 10	37.67	16.77	71.53	0.00	83.24
DSN 15	33.87	15.48	64.32	0.00	74.91
DSN+GEO 10/0/30	41.21	18.30	78.23	0.00	91.12
DSN+GEO 10/30/30	42.72	19.48	81.07	0.00	94.46
DSN+GEO 10/90/30	45.35	24.38	85.65	0.01	98.59
DSN+GEO 10/150/30	46.73	27.49	88.08	0.02	99.39
DSN+GEO 10/90/90	46.25	30.02	86.88	0.01	99.12
DSN+GEO 10/150/150	48.27	35.10	90.47	0.02	99.88

TABLE B.5.4.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	1.08	0.50	2.05	0.00	2.40
GEO 30/30	2.16	1.08	4.09	0.00	4.81
GEO 90/30	13.08	6.76	24.77	0.00	28.69
GEO 150/30	10.63	6.69	20.07	0.01	22.07
GEO 90/90	6.07	6.35	11.14	0.00	12.27
GEO 150/150	1.11	4.49	1.74	0.01	0.45
DSN 5	11.91	6.00	22.61	0.00	26.19
DSN 10	12.70	5.98	24.12	0.00	28.00
DSN 15	11.96	5.52	22.73	0.00	26.41
DSN+GEO 10/0/30 -v1	12.16	5.71	23.10	0.00	26.81
DSN+GEO 10/0/30 -v2	9.66	4.37	18.30	0.00	22.23
DSN+GEO 10/30/30 -v1	10.28	5.03	19.52	0.00	22.59
DSN+GEO 10/30/30 -v2	8.01	3.54	15.17	0.00	17.54
DSN+GEO 10/90/30 -v1	1.75	2.07	3.22	0.00	3.47
DSN+GEO 10/90/30 -v2	3.62	2.92	6.69	0.00	7.29
DSN+GEO 10/150/30 -v1	0.18	1.31	0.25	0.00	0.09
DSN+GEO 10/150/30 -v2	1.98	3.02	3.53	0.01	2.98
DSN+GEO 10/90/90 -v1	0.11	0.50	0.18	0.00	0.06
DSN+GEO 10/90/90 -v2	2.56	4.14	4.53	0.00	4.71
DSN+GEO 10/150/150 -v1	0.01	0.08	0.01	0.00	0.00
DSN+GEO 10/150/150 -v2	0.97	4.06	1.52	0.01	0.36

B.5.5 Dynamic (4 hr).—Figures B.5.5.1 to B.5.5.3 show the system availability results for the 15 Earth-based constellations when the system is operating in two-way mode without terrain information (solving with 4-hr dynamic measurements). Table B.5.5.1 tabulates the weighted system availabilities from figures B.5.5.1 to B.5.5.3. Table B.5.5.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

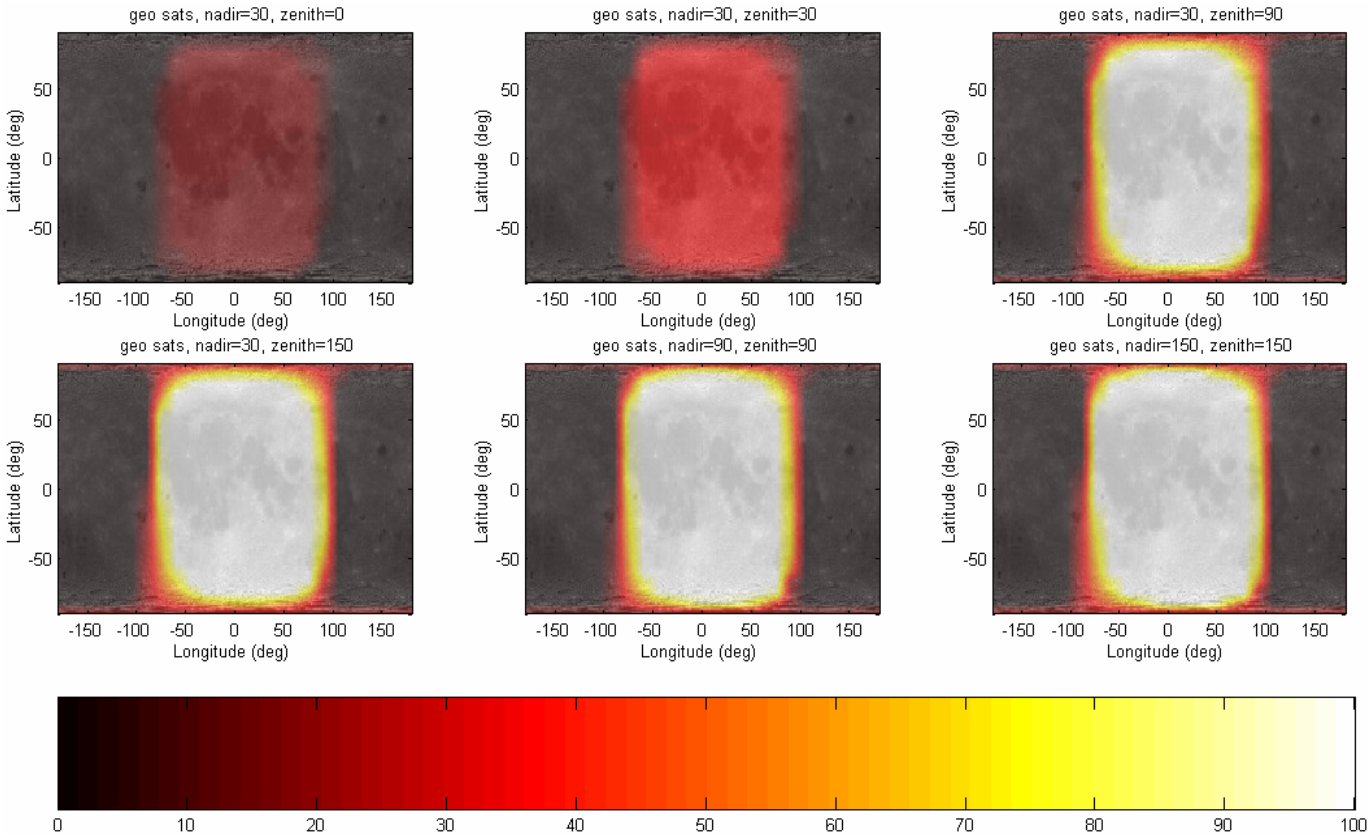

Figure B.5.5.1.—GEO system availability results.

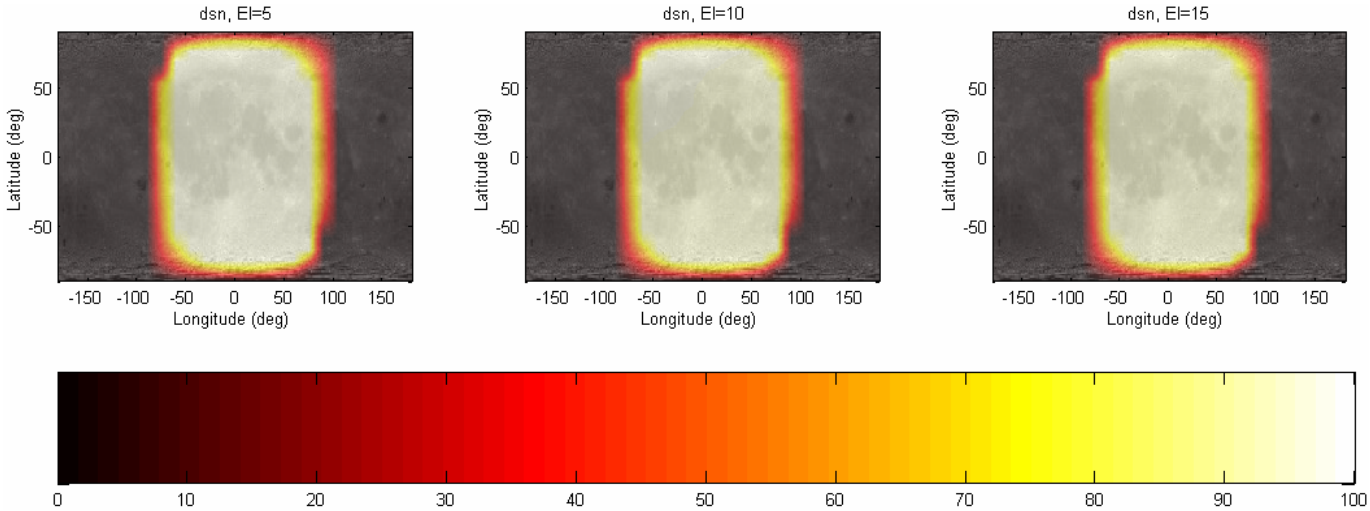

Figure B.5.5.2.—DSN system availability results.

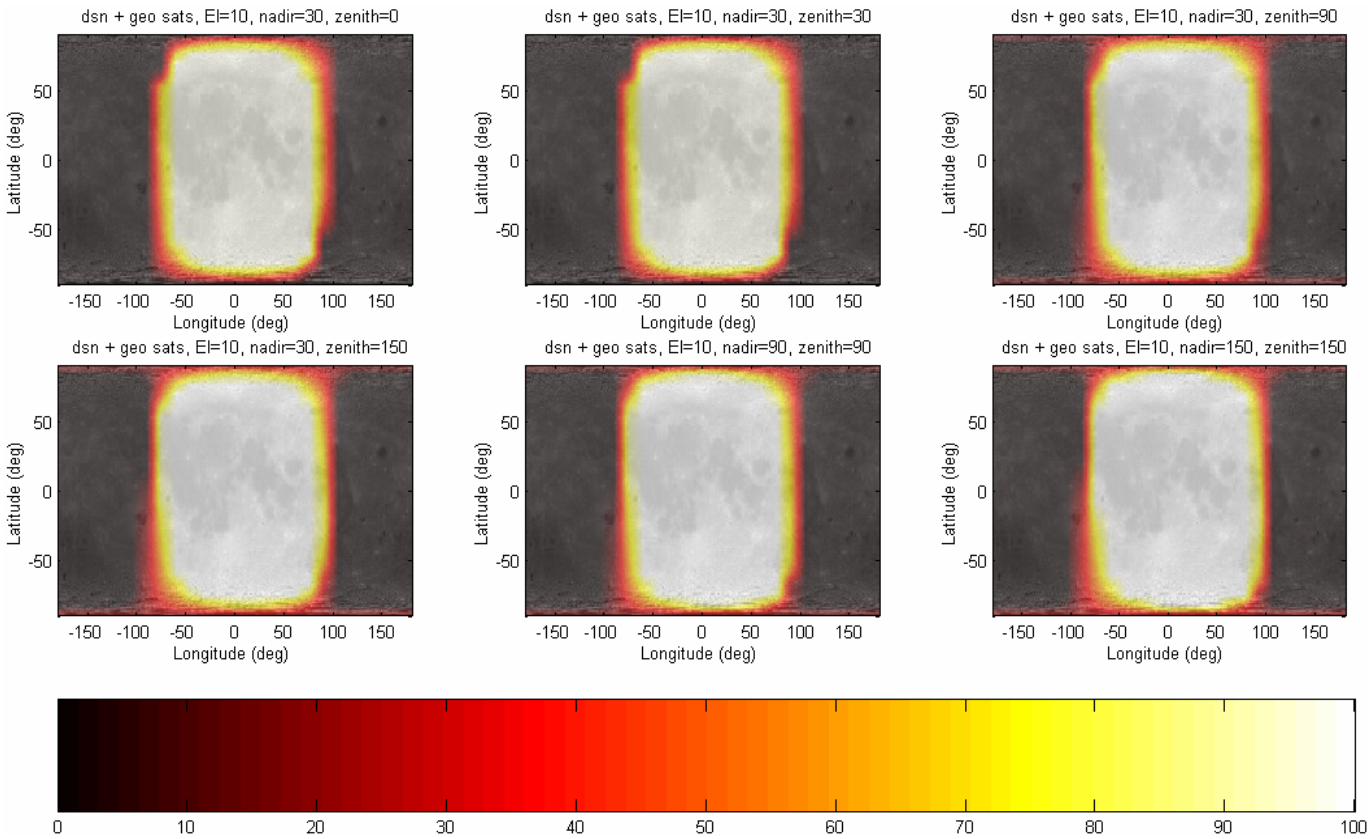

Figure B.5.5.3.—DSNGEO system availability results.

TABLE B.5.5.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	7.70	3.28	14.62	0.00	17.27
GEO 30/30	15.62	7.28	29.57	0.00	34.77
GEO 90/30	45.57	24.25	86.13	0.02	98.75
GEO 150/30	47.54	28.19	89.64	0.02	99.69
GEO 90/90	47.13	33.32	88.26	0.02	99.57
GEO 150/150	48.85	37.03	91.49	0.02	100.00
DSN 5	43.58	20.66	82.64	0.00	95.97
DSN 10	43.21	20.11	81.97	0.00	95.26
DSN 15	42.67	19.51	80.97	0.00	94.16
DSN+GEO 10/0/30	44.34	20.87	84.06	0.00	97.70
DSN+GEO 10/30/30	44.64	21.61	84.60	0.00	98.28
DSN+GEO 10/90/30	46.39	26.93	87.36	0.02	99.55
DSN+GEO 10/150/30	47.74	29.68	89.85	0.02	99.86
DSN+GEO 10/90/90	47.33	33.73	88.62	0.02	99.94
DSN+GEO 10/150/150	48.85	37.04	91.49	0.02	100.00

TABLE B.5.5.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	2.37	1.08	4.49	0.00	5.29
GEO 30/30	5.58	2.70	10.55	0.00	12.42
GEO 90/30	12.82	7.36	24.16	0.01	27.50
GEO 150/30	7.44	5.71	13.91	0.00	14.07
GEO 90/90	1.11	5.50	1.57	0.01	0.91
GEO 150/150	0.77	3.67	1.20	0.00	0.00
DSN 5	9.13	5.70	17.29	0.00	19.89
DSN 10	11.00	6.11	20.87	0.00	24.11
DSN 15	12.45	6.22	23.65	0.00	27.40
DSN+GEO 10/0/30 -v1	8.66	5.17	16.41	0.00	18.88
DSN+GEO 10/0/30 -v2	5.49	2.51	10.34	0.00	11.84
DSN+GEO 10/30/30 -v1	6.47	3.91	12.26	0.00	13.92
DSN+GEO 10/30/30 -v2	3.76	1.56	7.06	0.00	7.98
DSN+GEO 10/90/30 -v1	0.14	1.61	0.18	0.00	0.04
DSN+GEO 10/90/30 -v2	1.03	2.25	1.67	0.01	1.15
DSN+GEO 10/150/30 -v1	0.04	1.12	0.03	0.00	0.00
DSN+GEO 10/150/30 -v2	1.04	2.37	1.75	0.00	0.44
DSN+GEO 10/90/90 -v1	0.01	0.09	0.02	0.00	0.00
DSN+GEO 10/90/90 -v2	0.57	3.98	0.67	0.01	0.04
DSN+GEO 10/150/150 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/150/150 -v2	0.74	3.43	1.17	0.00	0.00

B.5.6 Dynamic (8 hr).—Figures B.5.6.1 to B.5.6.3 show the system availability results for the 15 Earth-based constellations when the system is operating in two-way mode without terrain information (solving with 8-hr dynamic measurements). Table B.5.6.1 tabulates the weighted system availabilities from figures B.5.6.1 to B.5.6.3. Table B.5.6.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

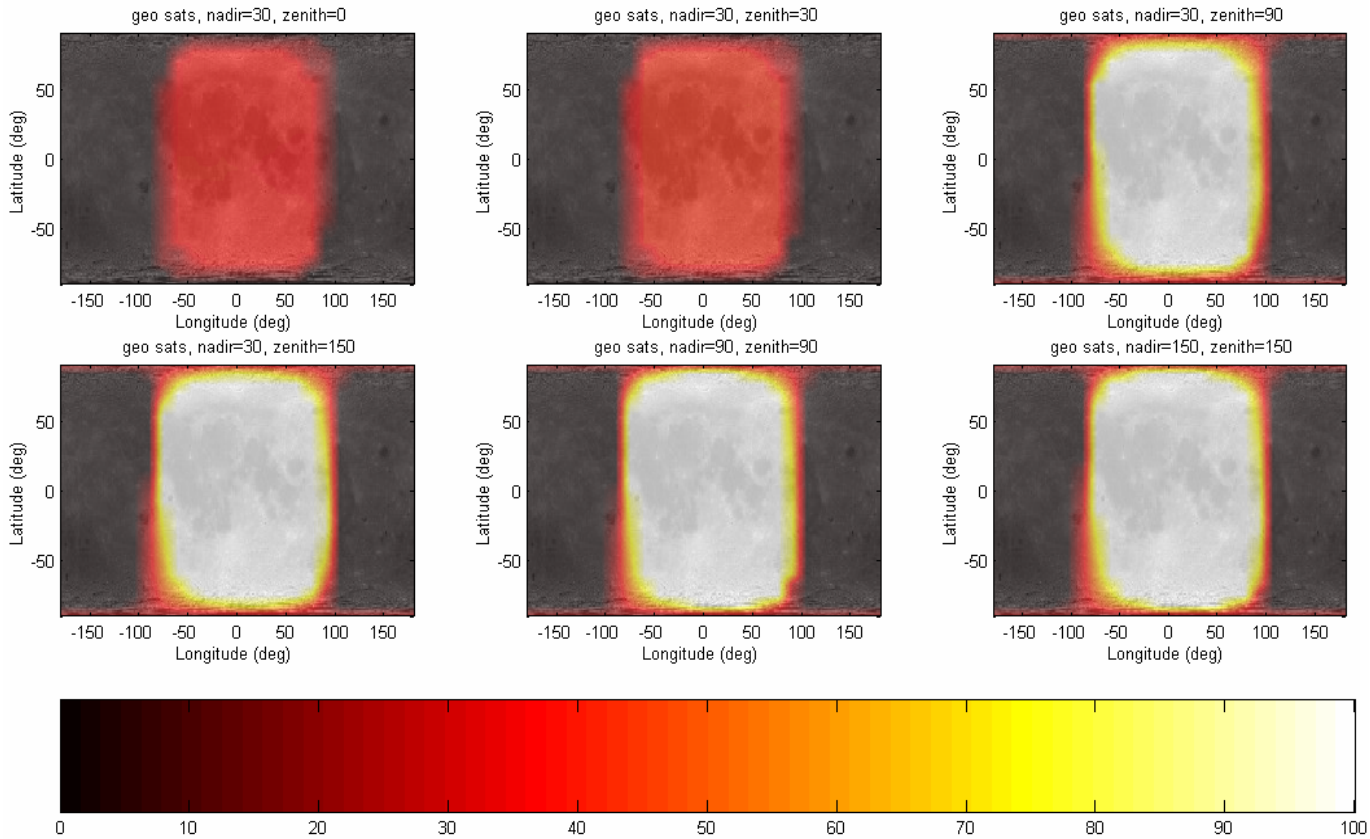

Figure B.5.6.1.—GEO system availability results.

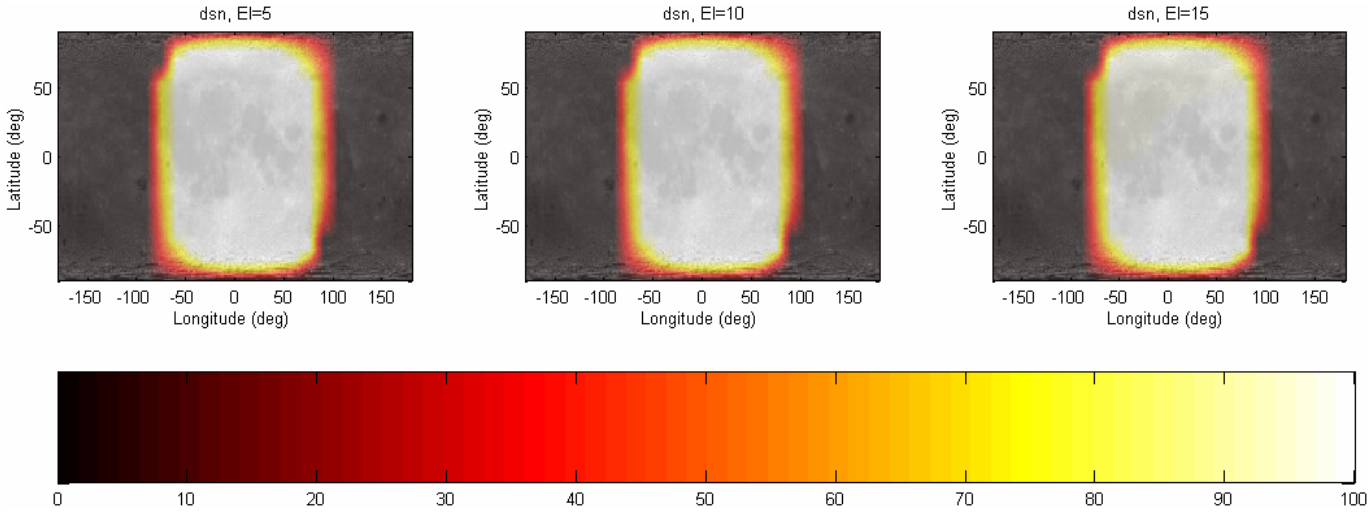

Figure B.5.6.2.—DSN system availability results.

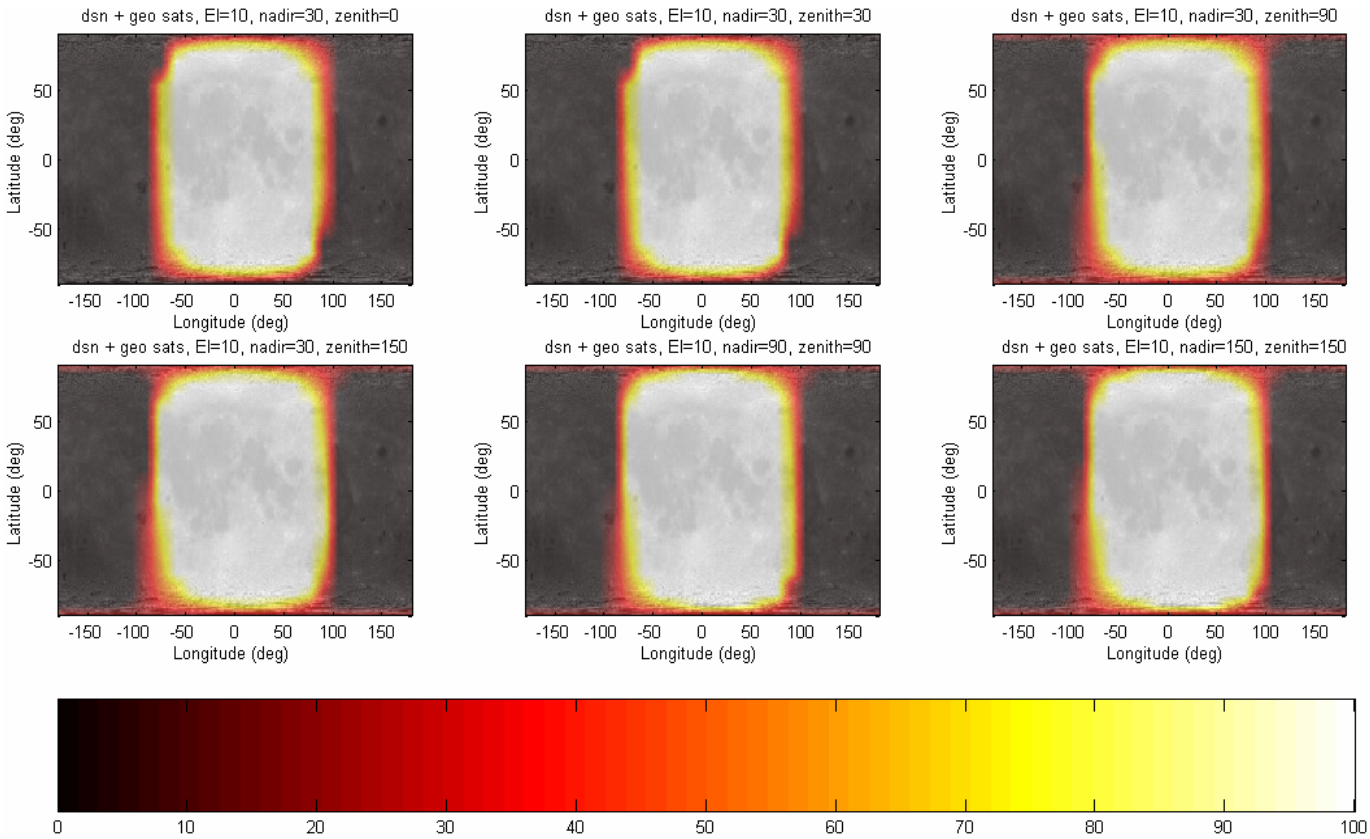

Figure B.5.6.3.—DSNGEO system availability results.

TABLE B.5.6.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	17.07	7.23	32.38	0.00	38.26
GEO 30/30	18.83	9.27	35.59	0.00	41.74
GEO 90/30	47.19	26.48	88.96	0.03	100.00
GEO 150/30	48.55	30.59	91.41	0.03	100.00
GEO 90/90	48.24	36.27	90.14	0.03	100.00
GEO 150/150	49.11	37.74	91.97	0.03	100.00
DSN 5	45.09	22.64	85.36	0.00	98.91
DSN 10	44.97	22.29	85.19	0.00	98.76
DSN 15	44.81	21.88	84.92	0.00	98.49
DSN+GEO 10/0/30	45.47	23.00	86.06	0.00	99.76
DSN+GEO 10/30/30	45.65	23.74	86.39	0.00	100.00
DSN+GEO 10/90/30	47.34	28.77	88.98	0.03	100.00
DSN+GEO 10/150/30	48.60	31.59	91.41	0.03	100.00
DSN+GEO 10/90/90	48.24	36.28	90.14	0.03	100.00
DSN+GEO 10/150/150	49.11	37.74	91.97	0.03	100.00

TABLE B.5.6.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	5.88	2.66	11.13	0.00	13.13
GEO 30/30	2.54	1.84	4.74	0.00	5.51
GEO 90/30	5.91	4.33	11.03	0.01	11.51
GEO 150/30	1.11	2.58	1.94	0.01	0.10
GEO 90/90	0.53	3.58	0.63	0.01	0.00
GEO 150/150	0.35	1.57	0.28	0.01	0.00
DSN 5	3.85	5.23	7.18	0.00	8.13
DSN 10	5.57	5.55	10.46	0.00	11.86
DSN 15	7.43	5.65	13.28	0.00	15.16
DSN+GEO 10/0/30 -v1	3.03	4.21	5.66	0.00	6.22
DSN+GEO 10/0/30 -v2	0.62	0.62	1.06	0.00	1.03
DSN+GEO 10/30/30 -v1	2.58	3.23	4.84	0.00	5.29
DSN+GEO 10/30/30 -v2	0.45	0.42	0.75	0.00	0.66
DSN+GEO 10/90/30 -v1	0.04	1.60	0.01	0.00	0.00
DSN+GEO 10/90/30 -v2	0.55	1.26	0.84	0.01	0.00
DSN+GEO 10/150/30 -v1	0.02	0.97	0.00	0.00	0.00
DSN+GEO 10/150/30 -v2	0.78	1.65	1.37	0.01	0.00
DSN+GEO 10/90/90 -v1	0.00	0.01	0.00	0.00	0.00
DSN+GEO 10/90/90 -v2	0.46	2.61	0.60	0.01	0.00
DSN+GEO 10/150/150 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/150/150 -v2	0.35	1.53	0.58	0.01	0.00

B.5.7 Dynamic (12 hr).—Figures B.5.7.1 to B.5.7.3 show the system availability results for the 15 Earth-based constellations when the system is operating in two-way mode without terrain information (solving with 12-hr dynamic measurements). Table B.5.7.1 tabulates the weighted system availabilities from figures B.5.7.1 to B.5.7.3. Table B.5.7.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

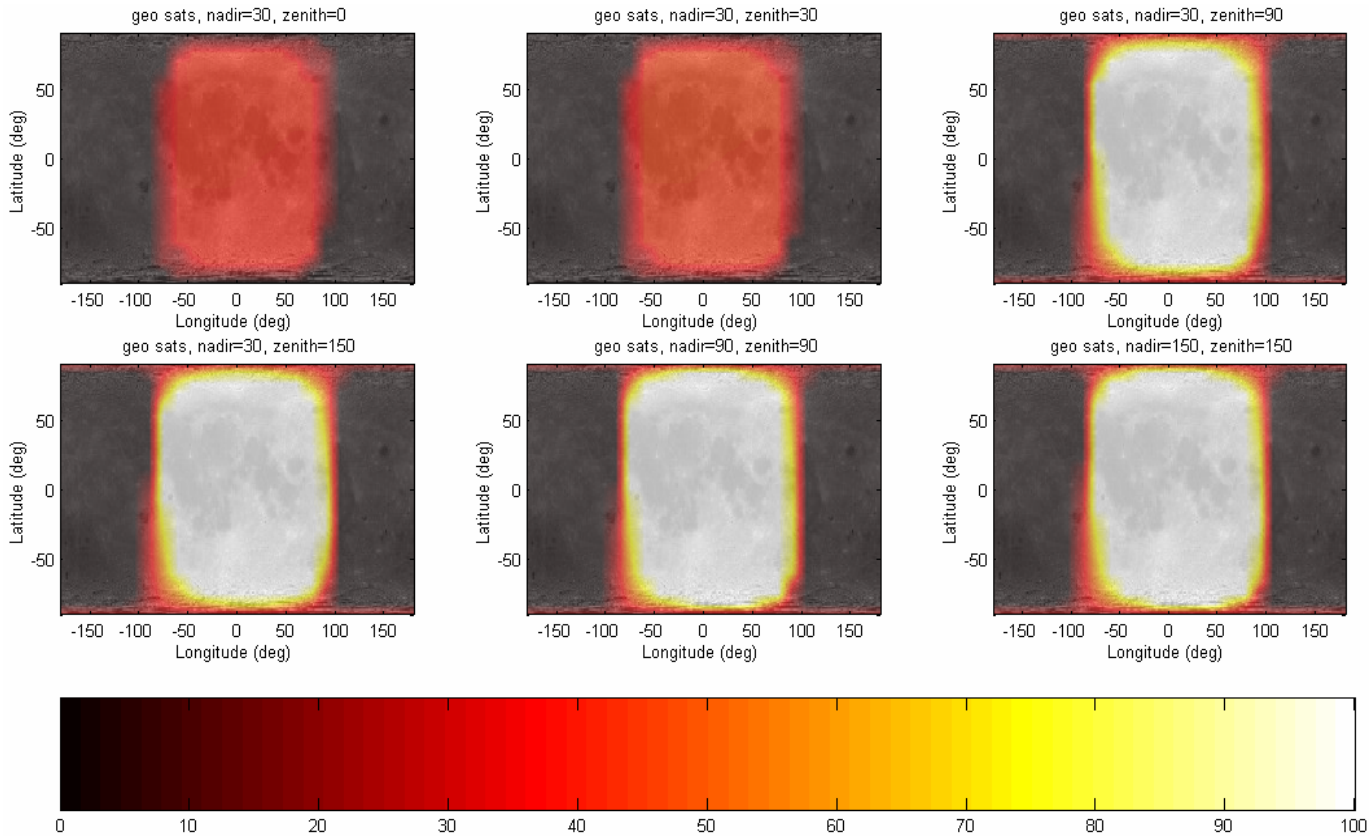

Figure B.5.7.1.—GEO system availability results.

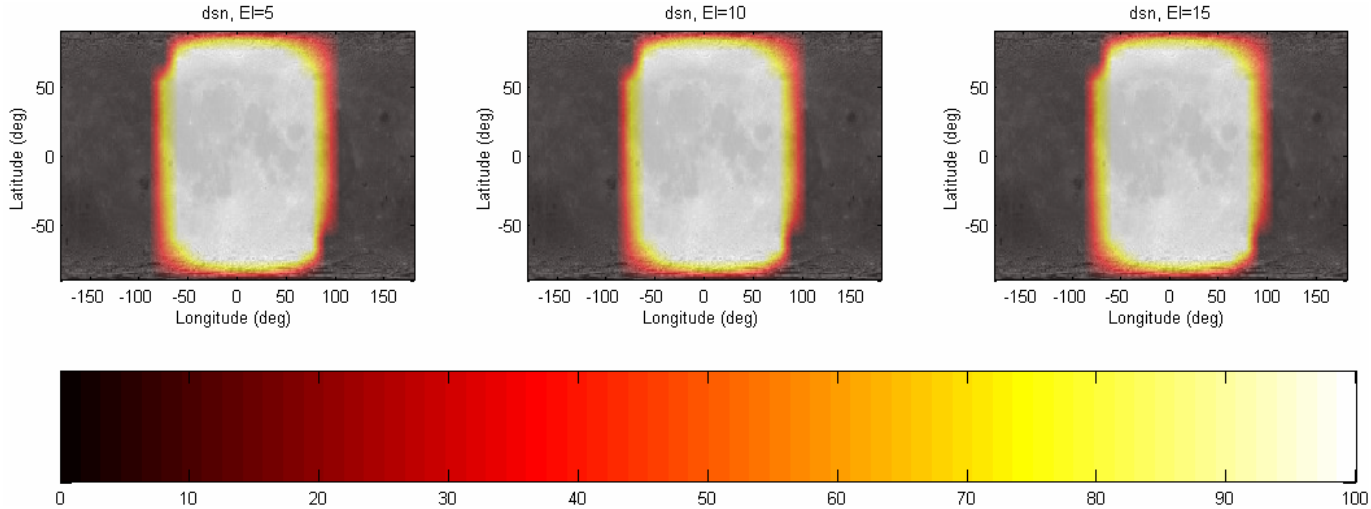

Figure B.5.7.2.—DSN system availability results.

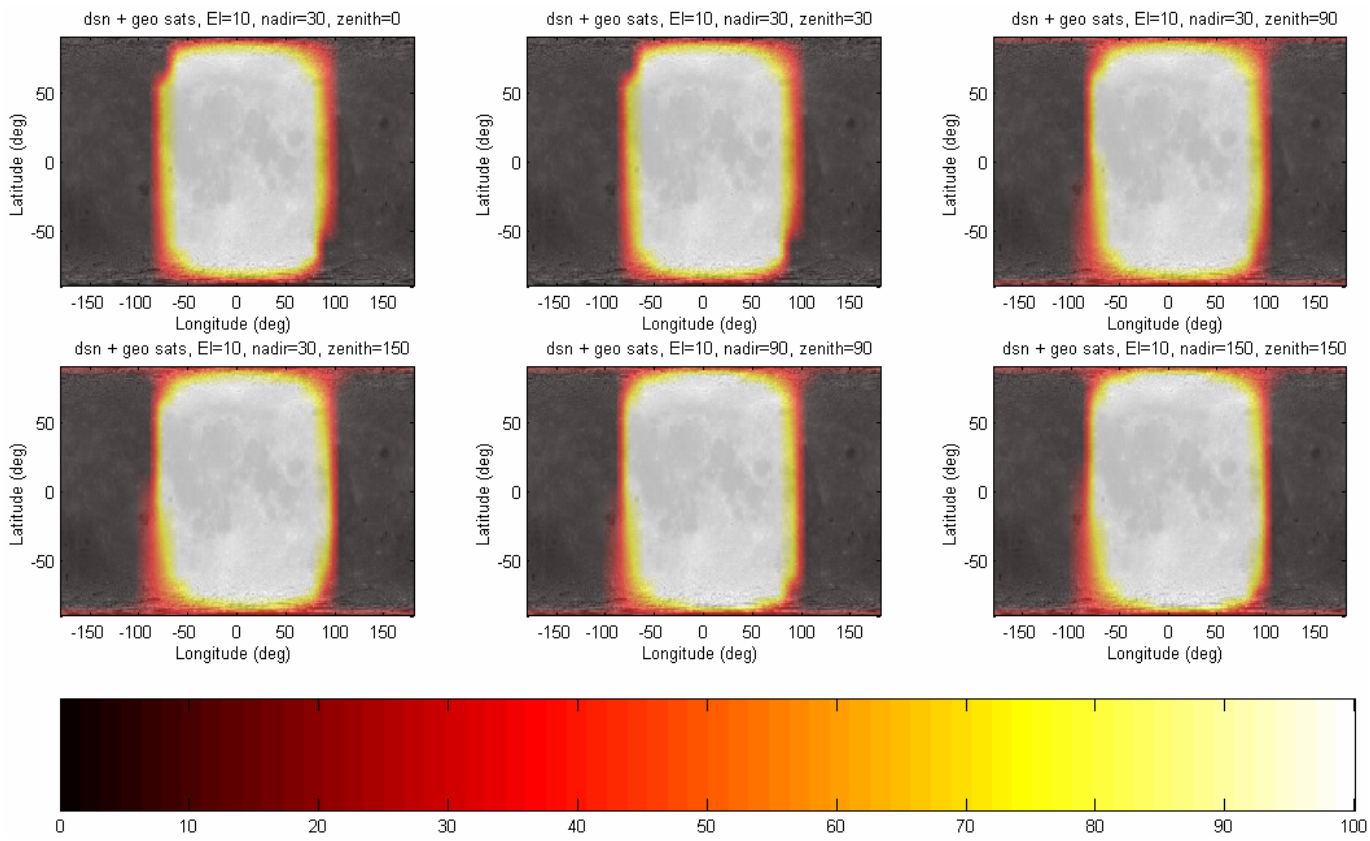

Figure B.5.7.3.—DSNGEO system availability results.

TABLE B.5.7.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	18.34	7.61	34.79	0.00	41.02
GEO 30/30	19.76	9.94	37.33	0.00	43.70
GEO 90/30	47.37	27.17	89.24	0.03	100.00
GEO 150/30	48.66	30.81	91.60	0.03	100.00
GEO 90/90	48.34	36.64	90.27	0.03	100.00
GEO 150/150	49.18	37.87	92.08	0.03	100.00
DSN 5	45.50	23.73	86.07	0.00	99.58
DSN 10	45.38	23.37	85.90	0.00	99.43
DSN 15	45.28	22.99	85.72	0.00	99.27
DSN+GEO 10/0/30	45.70	24.06	86.43	0.00	100.00
DSN+GEO 10/30/30	45.79	24.55	86.56	0.00	100.00
DSN+GEO 10/90/30	47.52	29.56	89.26	0.03	100.00
DSN+GEO 10/150/30	48.71	31.94	91.60	0.03	100.00
DSN+GEO 10/90/90	48.34	36.65	90.27	0.03	100.00
DSN+GEO 10/150/150	49.18	37.87	92.08	0.03	100.00

TABLE B.5.7.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	3.86	1.81	7.28	0.00	8.48
GEO 30/30	1.53	1.52	2.84	0.00	3.23
GEO 90/30	0.96	1.53	1.72	0.01	1.18
GEO 150/30	0.39	1.09	0.69	0.00	0.00
GEO 90/90	0.26	1.20	0.35	0.01	0.00
GEO 150/150	0.12	0.46	0.20	0.00	0.00
DSN 5	1.10	5.23	1.88	0.00	1.89
DSN 10	1.34	5.14	2.40	0.00	2.52
DSN 15	1.93	4.93	3.55	0.00	3.88
DSN+GEO 10/0/30 -v1	0.31	4.08	0.48	0.00	0.26
DSN+GEO 10/0/30 -v2	0.18	0.25	0.25	0.00	0.14
DSN+GEO 10/30/30 -v1	0.19	3.31	0.24	0.00	0.00
DSN+GEO 10/30/30 -v2	0.13	0.18	0.15	0.00	0.03
DSN+GEO 10/90/30 -v1	0.05	1.72	0.01	0.00	0.00
DSN+GEO 10/90/30 -v2	0.34	0.89	0.55	0.01	0.00
DSN+GEO 10/150/30 -v1	0.02	1.10	0.00	0.00	0.00
DSN+GEO 10/150/30 -v2	0.34	0.70	0.65	0.00	0.00
DSN+GEO 10/90/90 -v1	0.00	0.01	0.00	0.00	0.00
DSN+GEO 10/90/90 -v2	0.26	1.12	0.35	0.01	0.00
DSN+GEO 10/150/150 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/150/150 -v2	0.12	0.46	0.20	0.00	0.00

B.6 Good Terrain, Two-Way Mode

B.6.1 Kinematic.—Figures B.6.1.1 to B.6.1.3 show the system availability results for the 15 Earth-based constellations when the system is operating in two-way mode with terrain information (solving with kinematic measurements). Table B.6.1.1 tabulates the weighted system availabilities from figures B.6.1.1 to B.6.1.3. Table B.6.1.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

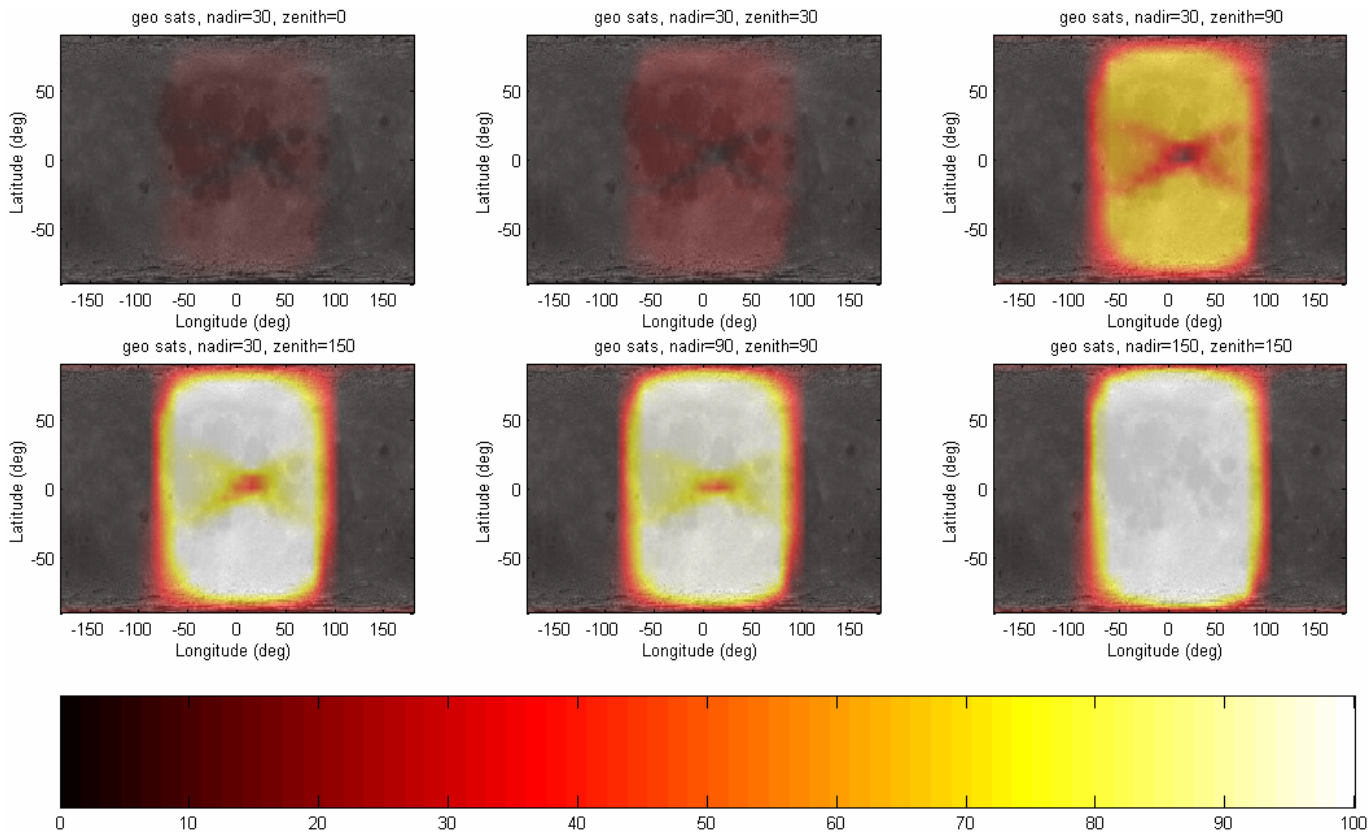

Figure B.6.1.1.—GEO system availability results.

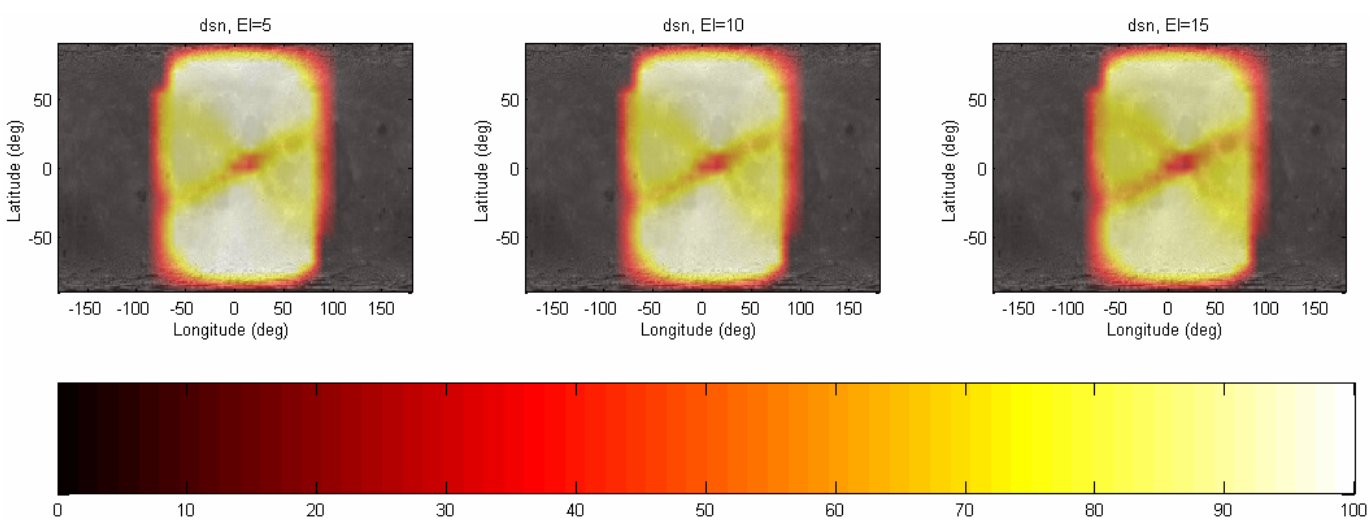

Figure B.6.1.2.—DSN system availability results.

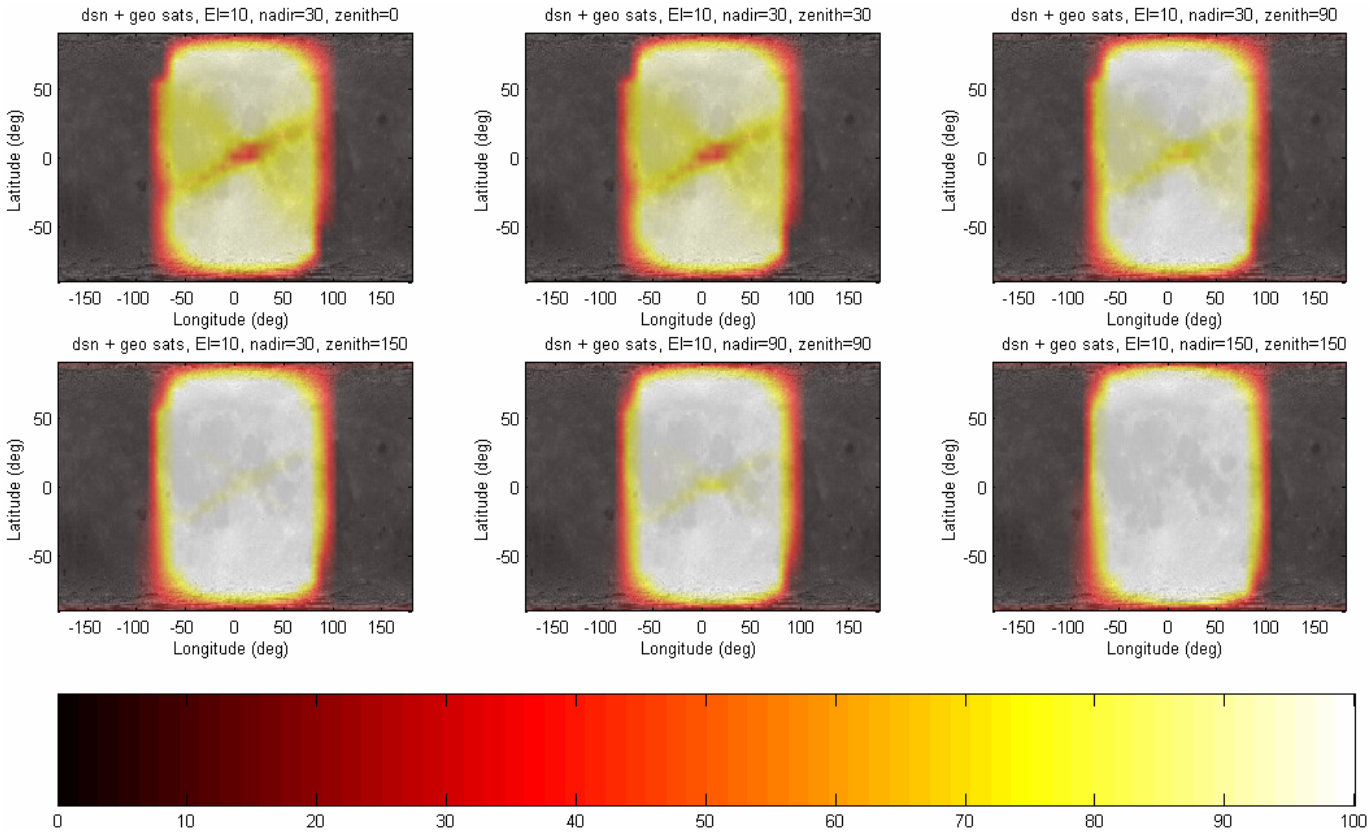

Figure B.6.1.3.—DSNGEO system availability results.

TABLE B.6.1.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	2.67	1.33	4.94	0.00	5.29
GEO 30/30	5.17	2.74	9.55	0.00	10.19
GEO 90/30	28.24	15.57	52.26	0.01	55.50
GEO 150/30	42.89	24.05	79.66	0.01	85.15
GEO 90/90	42.30	25.09	78.77	0.01	86.81
GEO 150/150	47.29	33.02	88.68	0.01	99.72
DSN 5	39.32	20.81	72.48	0.00	81.68
DSN 10	37.94	20.46	69.66	0.00	78.20
DSN 15	35.66	19.56	65.23	0.00	73.07
DSN+GEO 10/0/30	38.28	20.58	70.45	0.00	79.18
DSN+GEO 10/30/30	38.63	20.73	71.21	0.00	80.11
DSN+GEO 10/90/30	42.87	24.30	79.81	0.01	90.78
DSN+GEO 10/150/30	45.94	26.76	86.46	0.01	98.15
DSN+GEO 10/90/90	45.27	28.50	84.79	0.01	96.35
DSN+GEO 10/150/150	47.48	33.29	89.07	0.01	99.91

TABLE B.6.1.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.85	0.43	1.58	0.00	1.69
GEO 30/30	1.69	0.89	3.13	0.00	3.34
GEO 90/30	9.37	5.18	17.34	0.00	18.42
GEO 150/30	12.27	7.13	22.86	0.00	24.58
GEO 90/90	9.13	6.09	17.23	0.00	20.32
GEO 150/150	2.14	4.89	4.30	0.00	6.37
DSN 5	10.73	6.39	20.00	0.00	22.99
DSN 10	11.07	6.65	20.43	0.00	23.25
DSN 15	10.90	6.44	19.93	0.00	22.57
DSN+GEO 10/0/30 -v1	10.33	6.29	19.10	0.00	21.86
DSN+GEO 10/0/30 -v2	8.16	3.48	15.38	0.00	18.05
DSN+GEO 10/30/30 -v1	9.64	5.82	17.84	0.00	20.59
DSN+GEO 10/30/30 -v2	7.73	3.11	14.68	0.00	17.28
DSN+GEO 10/90/30 -v1	4.31	3.61	8.04	0.00	10.39
DSN+GEO 10/90/30 -v2	5.50	2.44	10.53	0.00	12.93
DSN+GEO 10/150/30 -v1	0.93	1.70	2.08	0.00	3.88
DSN+GEO 10/150/30 -v2	3.76	2.57	7.49	0.00	9.07
DSN+GEO 10/90/90 -v1	0.93	1.65	1.88	0.00	2.81
DSN+GEO 10/90/90 -v2	4.38	3.34	8.43	0.00	10.30
DSN+GEO 10/150/150 -v1	0.07	0.20	0.14	0.00	0.04
DSN+GEO 10/150/150 -v2	1.07	3.72	1.93	0.00	1.87

B.6.2 Dynamic (15 min).—Figures B.6.2.1 to B.6.2.3 show the system availability results for the 15 Earth-based constellations when the system is operating in two-way mode with terrain information (solving with 15-min dynamic measurements). Table B.6.2.1 tabulates the weighted system availabilities from figures B.6.2.1 to B.6.2.3. Table B.6.2.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

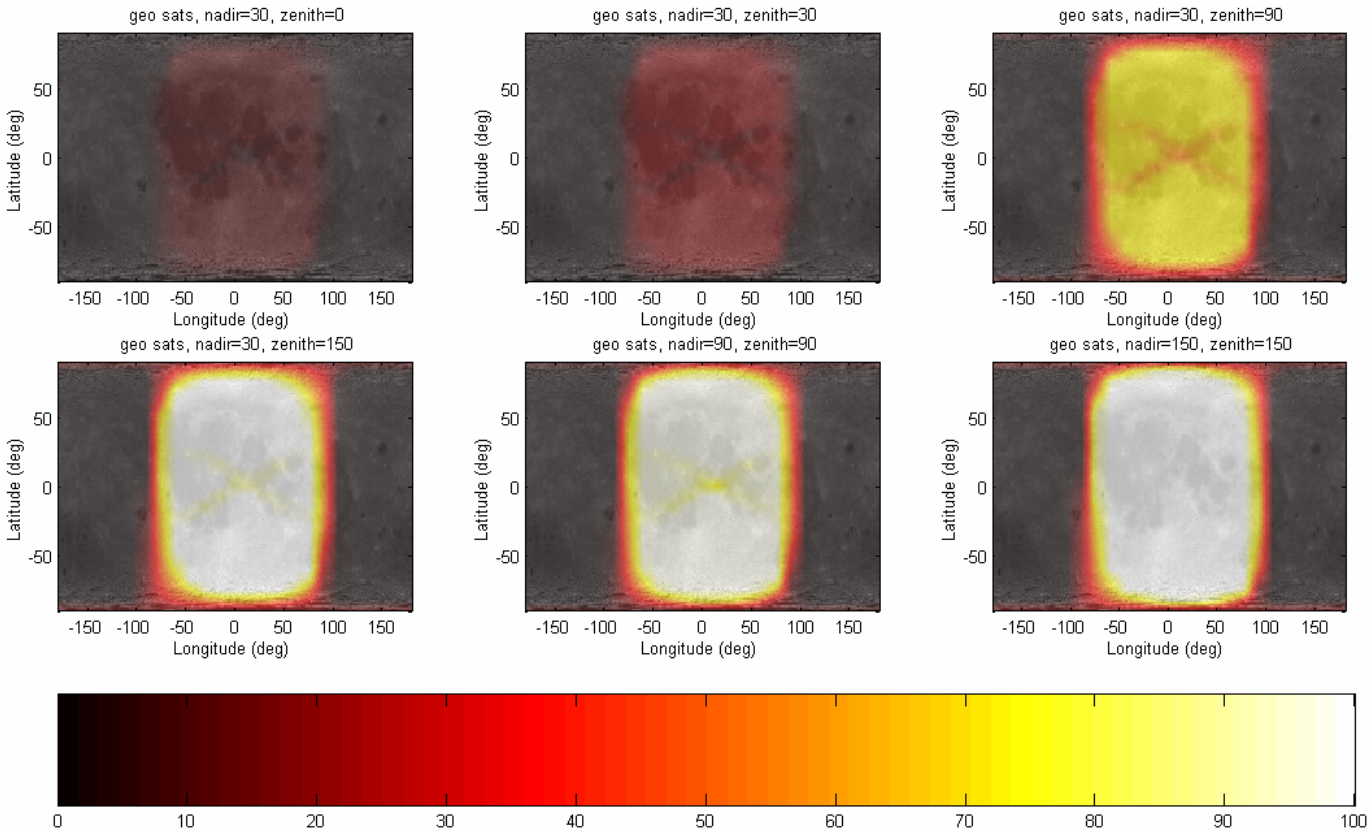

Figure B.6.2.1.—GEO system availability results.

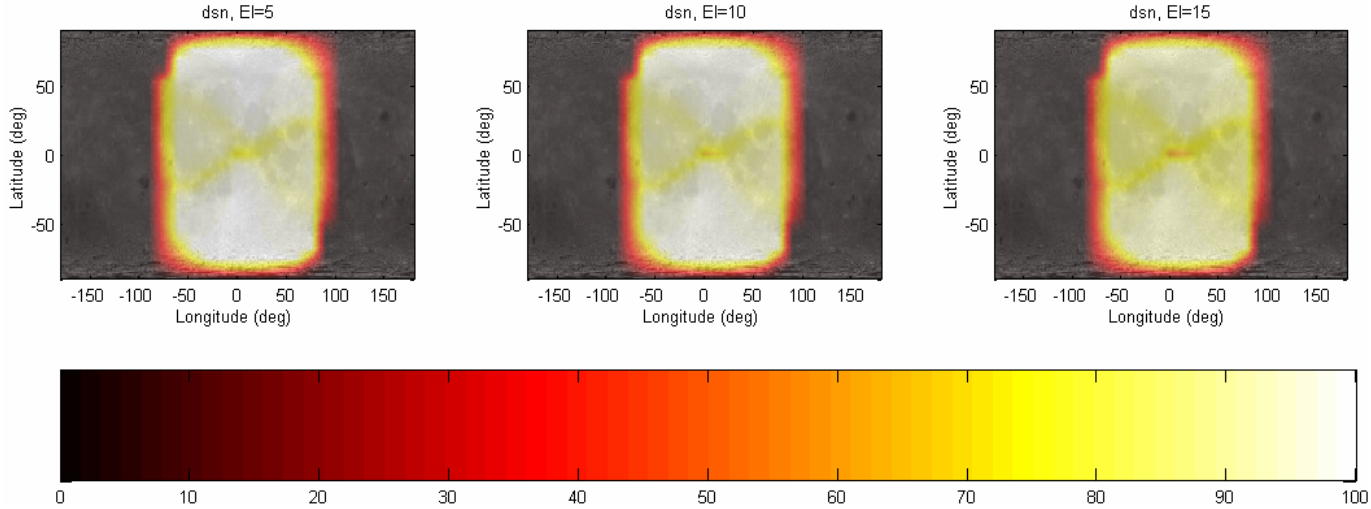

Figure B.6.2.2.—DSN system availability results.

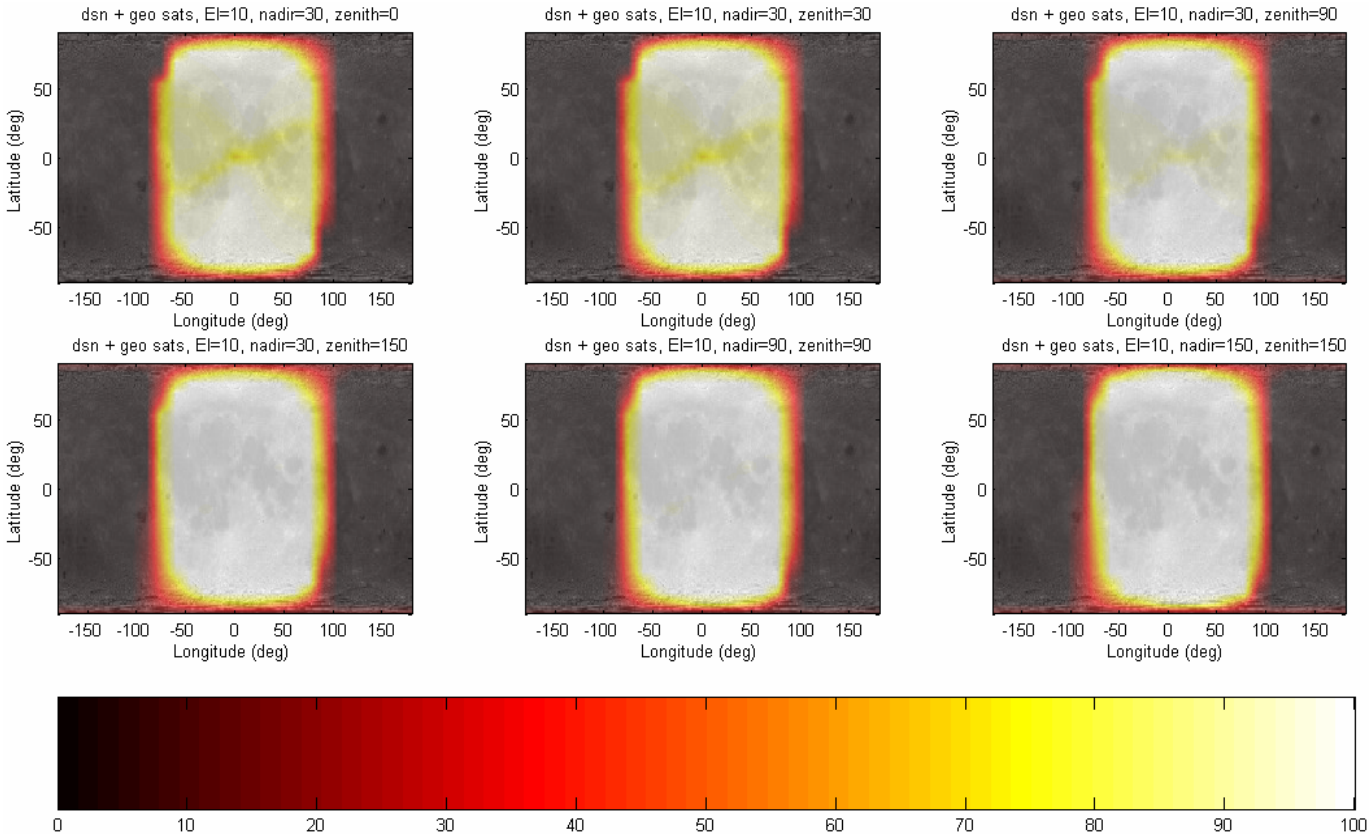

Figure B.6.2.3.—DSNGEO system availability results.

TABLE B.6.2.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	3.65	1.78	6.82	0.00	7.62
GEO 30/30	6.71	3.47	12.53	0.00	14.06
GEO 90/30	32.11	16.84	60.44	0.01	68.79
GEO 150/30	45.47	24.50	85.82	0.01	97.76
GEO 90/90	44.22	25.98	83.13	0.01	94.86
GEO 150/150	47.57	33.54	89.22	0.01	99.96
DSN 5	42.66	21.33	79.93	0.00	92.12
DSN 10	41.78	21.09	78.15	0.00	89.95
DSN 15	39.48	20.19	73.70	0.00	84.79
DSN+GEO 10/0/30	42.02	21.26	78.71	0.00	90.65
DSN+GEO 10/30/30	42.23	21.43	79.15	0.00	91.18
DSN+GEO 10/90/30	44.69	24.74	83.96	0.01	96.77
DSN+GEO 10/150/30	46.50	27.11	87.68	0.01	99.90
DSN+GEO 10/90/90	46.11	29.02	86.71	0.01	99.54
DSN+GEO 10/150/150	47.72	33.76	89.52	0.01	99.98

TABLE B.6.2.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	1.17	0.57	2.18	0.00	2.43
GEO 30/30	2.19	1.12	4.09	0.00	4.60
GEO 90/30	10.64	5.59	20.02	0.00	22.82
GEO 150/30	12.47	7.06	23.53	0.00	26.65
GEO 90/90	8.36	6.03	15.72	0.00	18.35
GEO 150/150	1.21	4.83	2.03	0.00	1.56
DSN 5	10.63	6.08	20.03	0.00	23.32
DSN 10	11.56	6.51	21.69	0.00	25.13
DSN 15	11.55	6.35	21.56	0.00	25.24
DSN+GEO 10/0/30 -v1	10.53	6.05	19.81	0.00	23.02
DSN+GEO 10/0/30 -v2	7.49	3.12	14.22	0.00	16.73
DSN+GEO 10/30/30 -v1	9.59	5.48	18.04	0.00	20.99
DSN+GEO 10/30/30 -v2	6.93	2.70	13.18	0.00	15.47
DSN+GEO 10/90/30 -v1	3.47	3.17	6.45	0.00	7.64
DSN+GEO 10/90/30 -v2	4.12	2.02	7.81	0.00	9.20
DSN+GEO 10/150/30 -v1	0.31	1.65	0.56	0.00	0.52
DSN+GEO 10/150/30 -v2	2.13	2.13	4.12	0.00	4.48
DSN+GEO 10/90/90 -v1	0.60	1.43	1.15	0.00	1.40
DSN+GEO 10/90/90 -v2	3.40	3.11	6.38	0.00	7.22
DSN+GEO 10/150/150 -v1	0.06	0.17	0.11	0.00	0.00
DSN+GEO 10/150/150 -v2	0.76	3.69	1.16	0.00	0.15

B.6.3 Dynamic (1 hr).—Figures B.6.3.1 to B.6.3.3 show the system availability results for the 15 Earth-based constellations when the system is operating in two-way mode with terrain information (solving with 1-hr dynamic measurements). Table B.6.3.1 tabulates the weighted system availabilities from figures B.6.3.1 to B.6.3.3. Table B.6.3.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

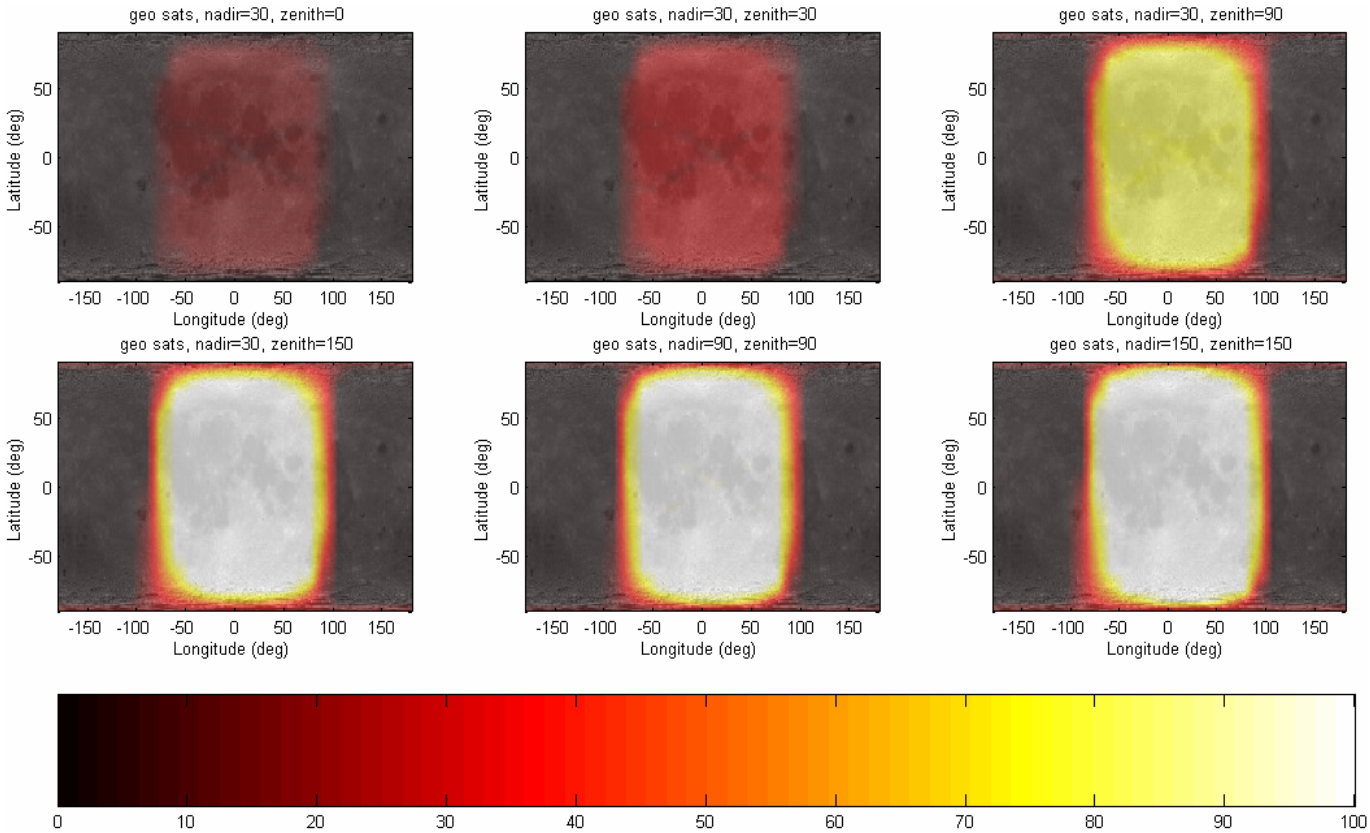

Figure B.6.3.1.—GEO system availability results.

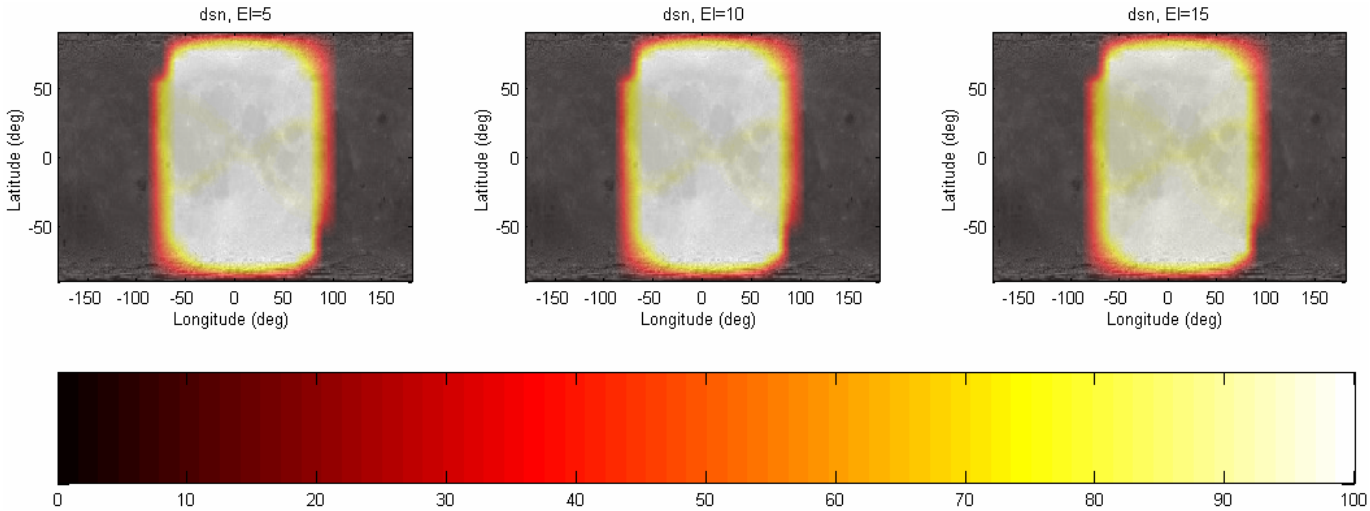

Figure B.6.3.2.—DSN system availability results.

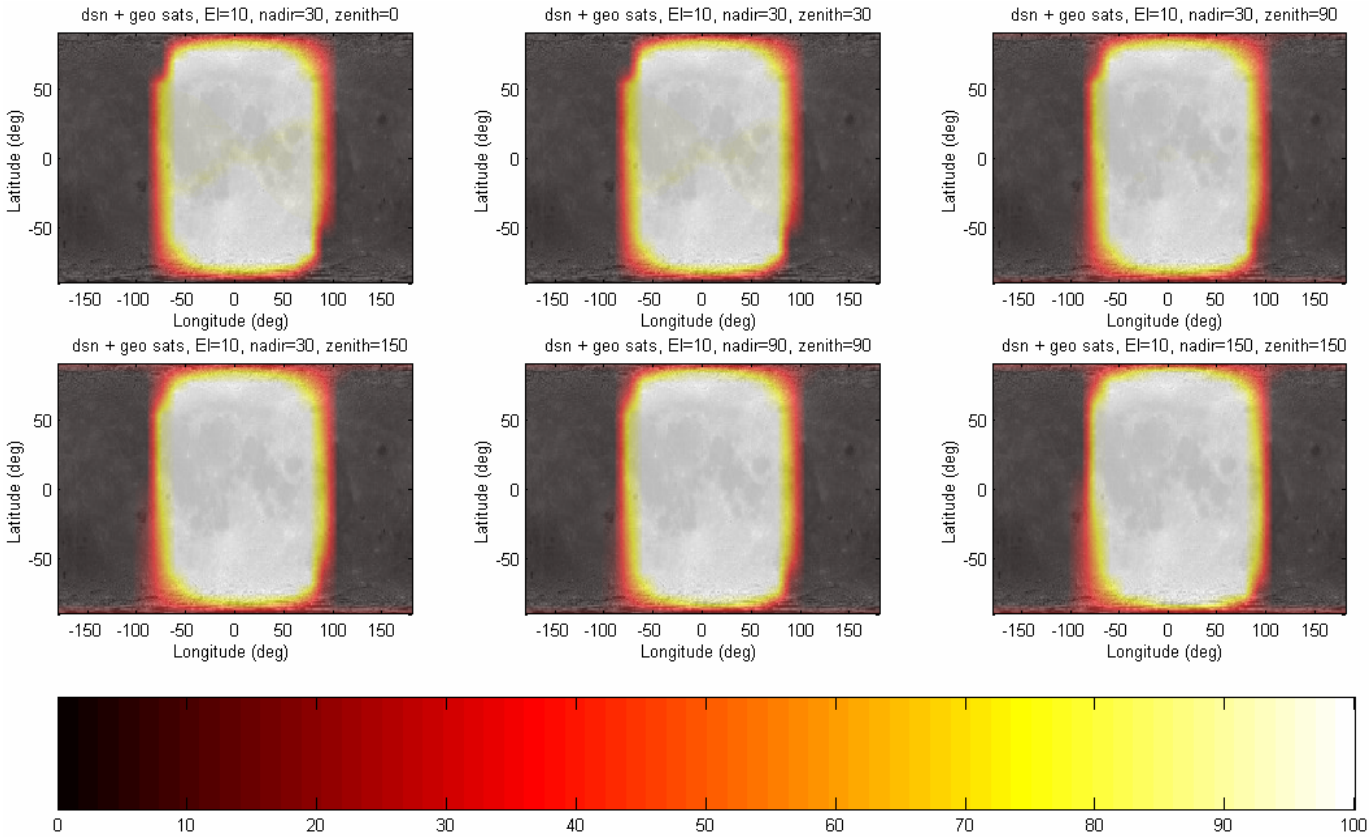

Figure B.6.3.3.—DSNGEO system availability results.

TABLE B.6.3.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	6.32	3.00	11.87	0.00	13.56
GEO 30/30	10.85	5.61	20.37	0.00	23.32
GEO 90/30	37.23	19.64	70.36	0.01	81.07
GEO 150/30	46.40	25.76	87.72	0.02	99.88
GEO 90/90	46.01	28.55	86.58	0.01	99.28
GEO 150/150	48.10	34.93	90.19	0.02	100.00
DSN 5	44.56	21.88	84.10	0.00	97.82
DSN 10	44.33	21.71	83.59	0.00	97.23
DSN 15	42.96	21.31	80.92	0.00	94.06
DSN+GEO 10/0/30	44.55	22.03	84.08	0.00	97.77
DSN+GEO 10/30/30	44.69	22.29	84.36	0.00	98.04
DSN+GEO 10/90/30	45.86	25.67	86.44	0.01	99.40
DSN+GEO 10/150/30	46.94	28.05	88.45	0.02	99.98
DSN+GEO 10/90/90	46.58	30.45	87.51	0.01	99.95
DSN+GEO 10/150/150	48.18	35.02	90.35	0.02	100.00

TABLE B.6.3.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES
FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	2.01	0.89	3.79	0.00	4.32
GEO 30/30	3.52	1.79	6.60	0.00	7.55
GEO 90/30	11.59	6.17	21.93	0.00	25.35
GEO 150/30	11.38	6.79	21.51	0.01	24.05
GEO 90/90	6.06	5.87	11.23	0.00	12.74
GEO 150/150	0.93	4.56	1.40	0.01	0.05
DSN 5	9.47	5.51	18.05	0.00	20.95
DSN 10	11.01	6.04	20.88	0.00	24.26
DSN 15	11.86	6.40	22.43	0.00	26.00
DSN+GEO 10/0/30 -v1	9.48	5.38	18.03	0.00	20.97
DSN+GEO 10/0/30 -v2	6.09	2.45	11.63	0.00	13.54
DSN+GEO 10/30/30 -v1	8.23	4.65	15.67	0.00	18.23
DSN+GEO 10/30/30 -v2	5.39	1.98	10.30	0.00	11.93
DSN+GEO 10/90/30 -v1	2.09	2.44	3.88	0.00	4.40
DSN+GEO 10/90/30 -v2	2.56	1.68	4.79	0.00	5.13
DSN+GEO 10/150/30 -v1	0.18	1.51	0.25	0.00	0.05
DSN+GEO 10/150/30 -v2	0.88	1.89	1.57	0.01	0.80
DSN+GEO 10/90/90 -v1	0.19	0.89	0.33	0.00	0.23
DSN+GEO 10/90/90 -v2	2.37	3.13	4.25	0.00	4.53
DSN+GEO 10/150/150 -v1	0.02	0.08	0.06	0.00	0.00
DSN+GEO 10/150/150 -v2	0.77	3.68	1.18	0.01	0.02

B.6.4 Dynamic (2 hr).—Figures B.6.4.1 to B.6.4.3 show the system availability results for the 15 Earth-based constellations when the system is operating in two-way mode with terrain information (solving with 2-hr dynamic measurements). Table B.6.4.1 tabulates the weighted system availabilities from figures B.6.4.1 to B.6.4.3. Table B.6.4.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

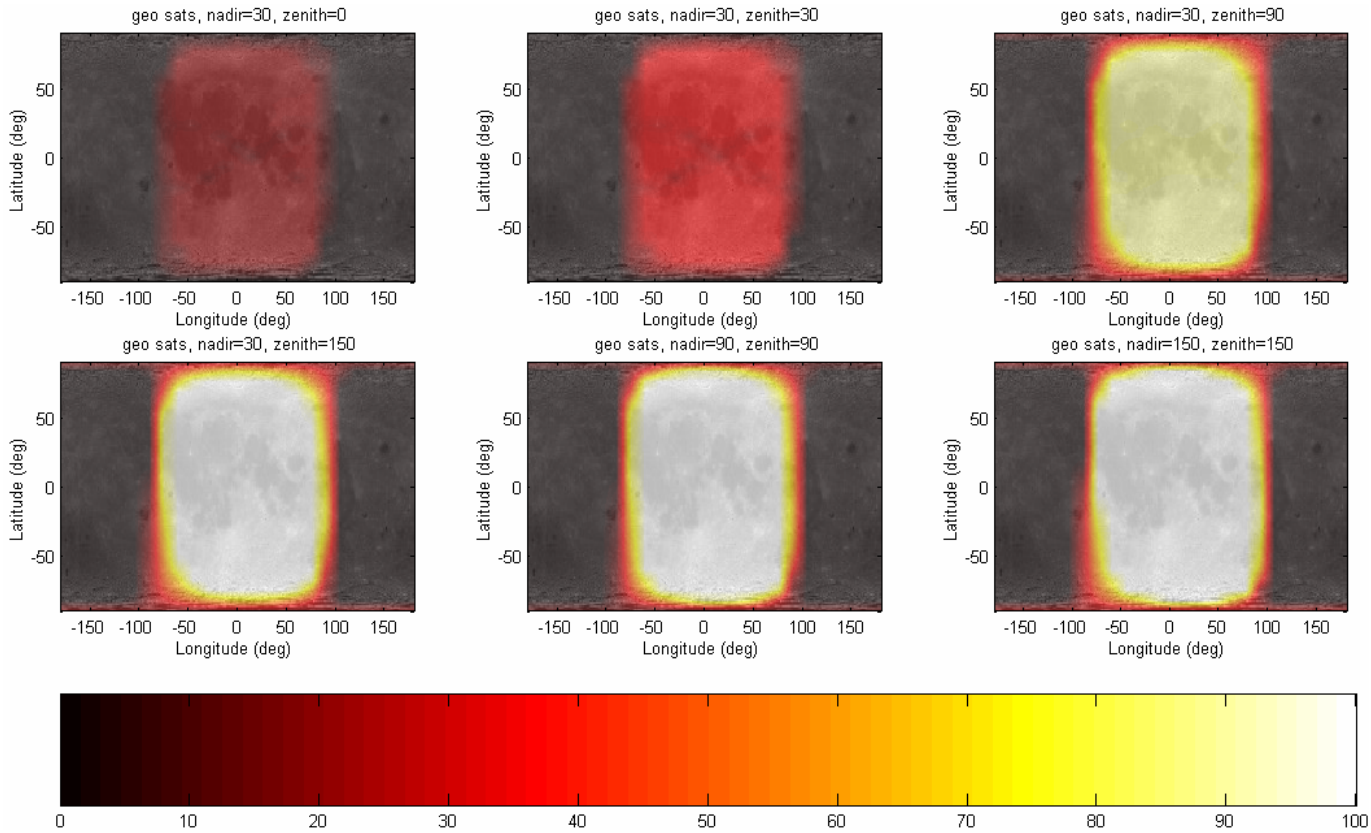

Figure B.6.4.1.—GEO system availability results.

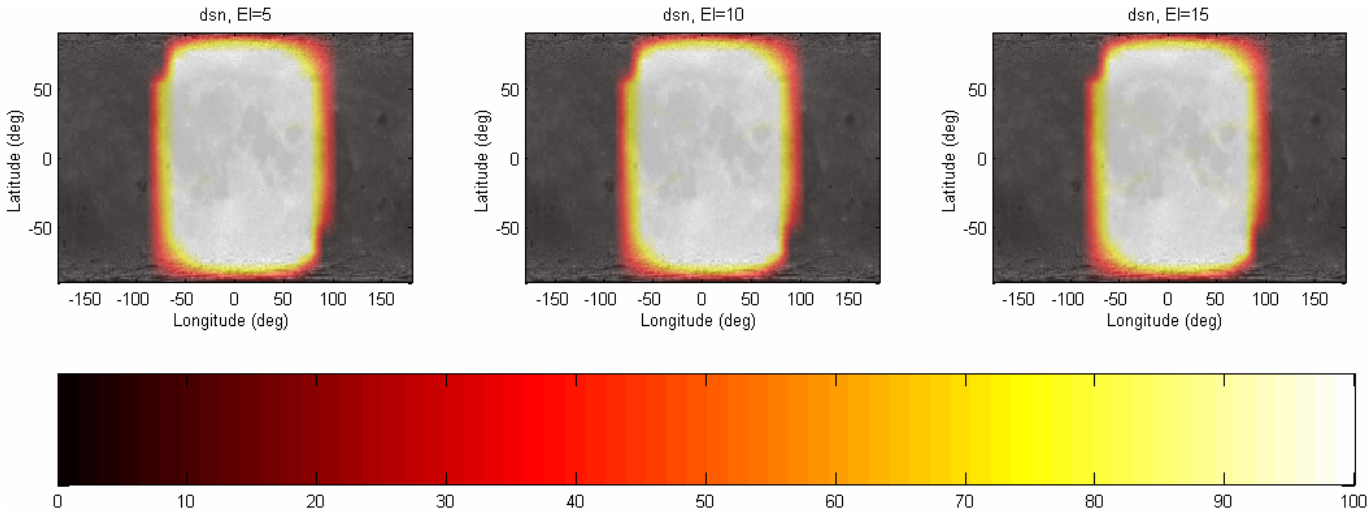

Figure B.6.4.2.—DSN system availability results.

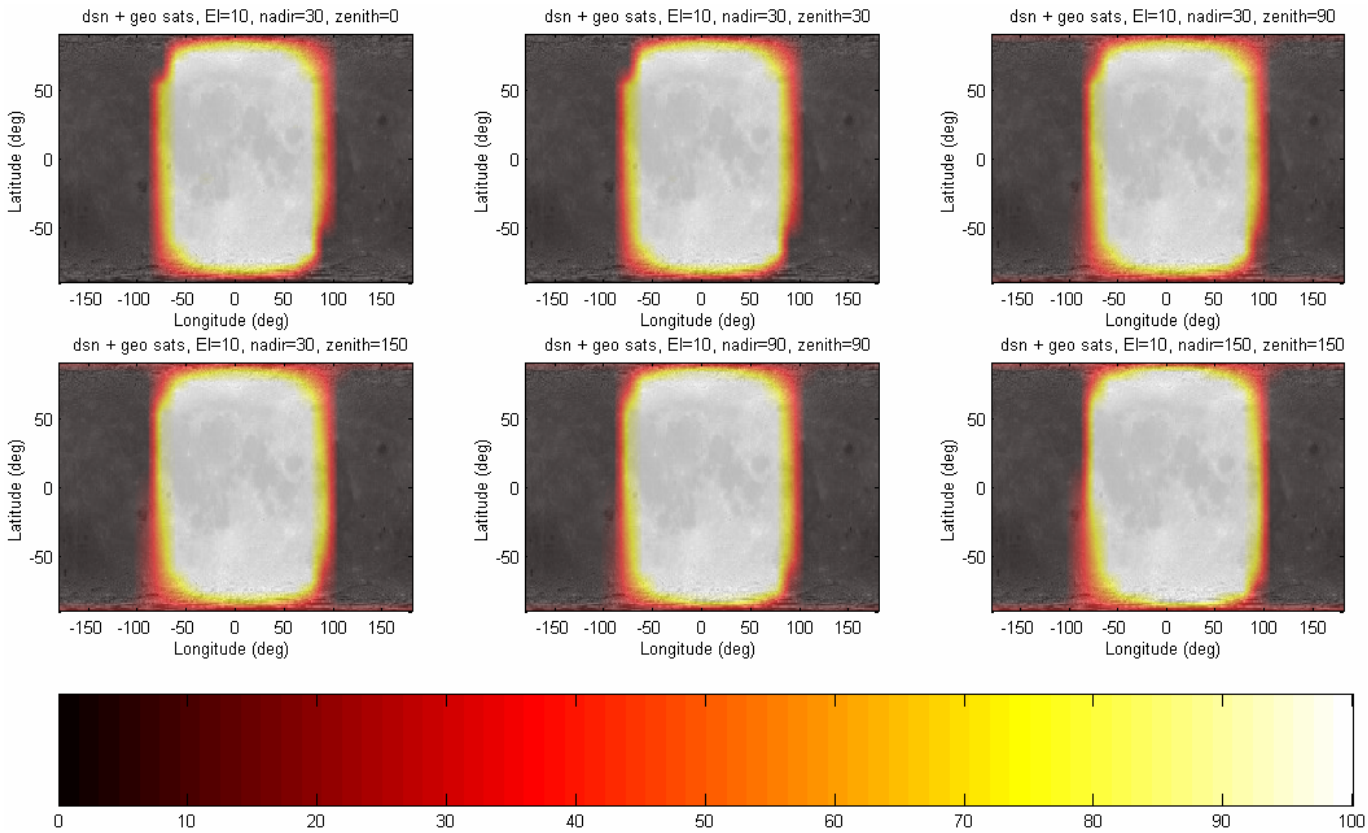

Figure B.6.4.3.—DSNGEO system availability results.

TABLE B.6.4.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	8.95	4.43	16.83	0.00	19.40
GEO 30/30	15.36	8.01	28.90	0.00	33.32
GEO 90/30	41.00	22.29	77.46	0.01	88.94
GEO 150/30	47.05	27.23	88.83	0.02	100.00
GEO 90/90	46.81	31.39	87.86	0.01	99.98
GEO 150/150	48.70	36.44	91.26	0.02	100.00
DSN 5	45.28	22.21	85.75	0.00	99.64
DSN 10	45.21	22.05	85.63	0.00	99.56
DSN 15	44.95	21.85	85.09	0.00	98.96
DSN+GEO 10/0/30	45.36	22.52	85.91	0.00	99.79
DSN+GEO 10/30/30	45.45	22.89	86.06	0.00	99.87
DSN+GEO 10/90/30	46.39	26.81	87.45	0.01	99.98
DSN+GEO 10/150/30	47.38	29.17	89.21	0.02	100.00
DSN+GEO 10/90/90	46.99	32.29	88.14	0.01	99.99
DSN+GEO 10/150/150	48.71	36.44	91.28	0.02	100.00

TABLE B.6.4.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	2.85	1.41	5.35	0.00	6.17
GEO 30/30	4.97	2.56	9.35	0.00	10.78
GEO 90/30	11.31	6.38	21.40	0.00	24.63
GEO 150/30	9.79	6.35	18.45	0.01	20.03
GEO 90/90	3.07	5.55	5.43	0.00	5.73
GEO 150/150	0.90	4.11	1.41	0.01	0.00
DSN 5	7.79	5.02	14.86	0.00	17.16
DSN 10	9.47	5.57	18.03	0.00	20.91
DSN 15	11.14	6.10	21.17	0.00	24.59
DSN+GEO 10/0/30 -v1	7.74	4.82	14.76	0.00	17.10
DSN+GEO 10/0/30 -v2	4.27	1.78	8.12	0.00	9.33
DSN+GEO 10/30/30 -v1	6.34	3.93	12.11	0.00	13.98
DSN+GEO 10/30/30 -v2	3.53	1.32	6.71	0.00	7.65
DSN+GEO 10/90/30 -v1	1.04	1.90	1.90	0.00	2.02
DSN+GEO 10/90/30 -v2	1.54	1.68	2.76	0.00	2.57
DSN+GEO 10/150/30 -v1	0.10	1.35	0.12	0.00	0.00
DSN+GEO 10/150/30 -v2	0.73	1.98	1.18	0.01	0.08
DSN+GEO 10/90/90 -v1	0.06	0.40	0.10	0.00	0.00
DSN+GEO 10/90/90 -v2	1.50	3.36	2.55	0.00	2.48
DSN+GEO 10/150/150 -v1	0.01	0.00	0.01	0.00	0.00
DSN+GEO 10/150/150 -v2	0.82	3.65	1.30	0.01	0.00

B.6.5 Dynamic (4 hr).—Figures B.6.5.1 to B.6.5.3 show the system availability results for the 15 Earth-based constellations when the system is operating in two-way mode with terrain information (solving with 4-hr dynamic measurements). Table B.6.5.1 tabulates the weighted system availabilities from figures B.6.5.1 to B.6.5.3. Table B.6.5.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

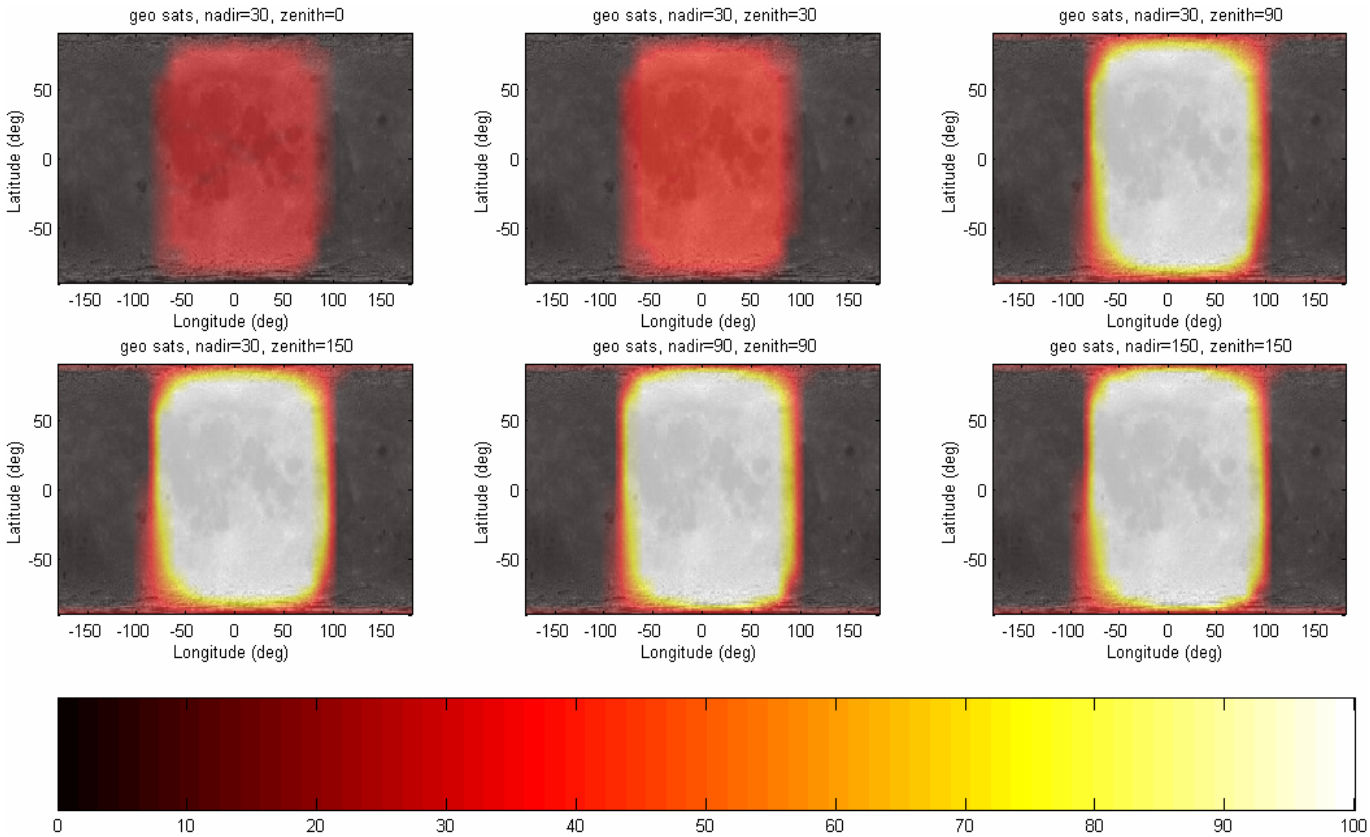

Figure B.6.5.1.—GEO system availability results.

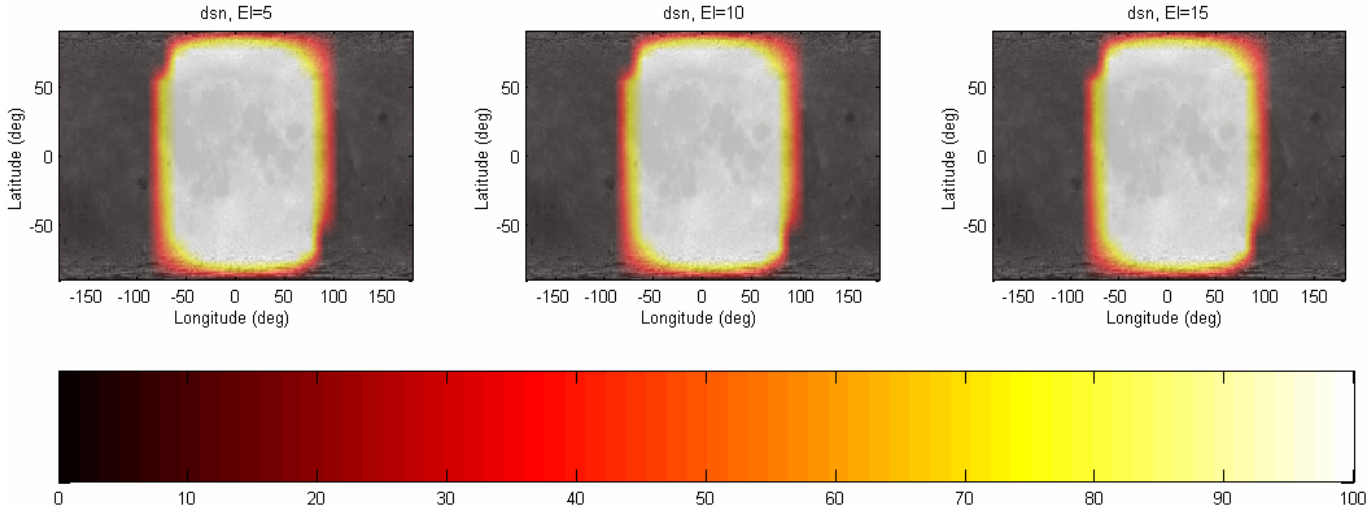

Figure B.6.5.2.—DSN system availability results.

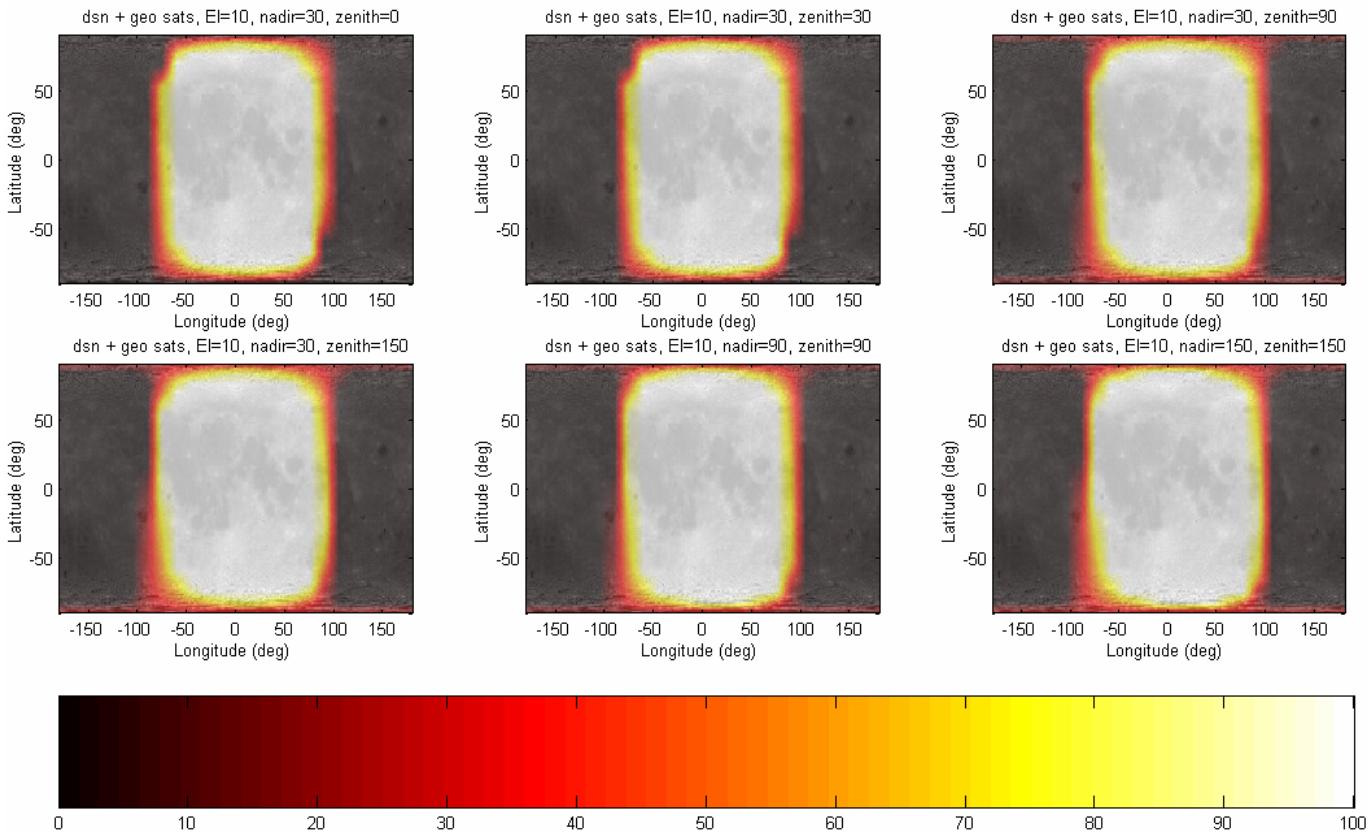

Figure B.6.5.3.—DSNGEO system availability results.

TABLE B.6.5.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	13.76	6.86	25.91	0.00	29.99
GEO 30/30	18.19	9.86	34.31	0.00	40.02
GEO 90/30	46.60	26.60	87.91	0.02	99.97
GEO 150/30	48.04	29.44	90.52	0.03	100.00
GEO 90/90	47.68	35.12	89.16	0.02	100.00
GEO 150/150	48.99	37.44	91.76	0.03	100.00
DSN 5	45.51	22.83	86.18	0.00	99.94
DSN 10	45.48	22.67	86.14	0.00	99.93
DSN 15	45.43	22.47	86.07	0.00	99.92
DSN+GEO 10/0/30	45.59	23.32	86.30	0.00	99.97
DSN+GEO 10/30/30	45.67	23.87	86.40	0.00	99.98
DSN+GEO 10/90/30	46.98	28.88	88.35	0.02	100.00
DSN+GEO 10/150/30	48.14	30.81	90.55	0.03	100.00
DSN+GEO 10/90/90	47.70	35.19	89.20	0.02	100.00
DSN+GEO 10/150/150	48.99	37.44	91.76	0.03	100.00

TABLE B.6.5.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	4.38	2.21	8.25	0.00	9.55
GEO 30/30	4.01	2.30	7.59	0.00	9.01
GEO 90/30	10.52	6.59	19.83	0.01	22.36
GEO 150/30	6.49	5.11	12.15	0.01	11.99
GEO 90/90	0.63	4.98	0.67	0.01	0.01
GEO 150/150	0.69	3.14	1.09	0.01	0.00
DSN 5	4.57	4.27	8.70	0.00	9.87
DSN 10	6.01	4.60	11.43	0.00	13.12
DSN 15	7.79	5.11	14.84	0.00	17.13
DSN+GEO 10/0/30 -v1	4.22	3.63	8.06	0.00	9.19
DSN+GEO 10/0/30 -v2	0.80	0.45	1.50	0.00	1.51
DSN+GEO 10/30/30 -v1	3.76	3.02	7.17	0.00	8.08
DSN+GEO 10/30/30 -v2	0.67	0.46	1.20	0.00	1.18
DSN+GEO 10/90/30 -v1	20.08	1.50	0.09	0.00	0.00
DSN+GEO 10/90/30 -v2	0.53	1.80	0.76	0.01	0.01
DSN+GEO 10/150/30 -v1	0.04	1.09	0.02	0.00	0.00
DSN+GEO 10/150/30 -v2	0.87	1.95	1.45	0.01	0.00
DSN+GEO 10/90/90 -v1	0.01	0.07	0.02	0.00	0.00
DSN+GEO 10/90/90 -v2	0.45	3.44	0.50	0.01	0.00
DSN+GEO 10/150/150 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/150/150 -v2	0.67	2.94	1.08	0.01	0.00

B.6.6 Dynamic (8 hr).—Figures B.6.6.1 to B.6.6.3 show the system availability results for the 15 Earth-based constellations when the system is operating in two-way mode with terrain information (solving with 8-hr dynamic measurements). Table B.6.6.1 tabulates the weighted system availabilities from figures B.6.6.1 to B.6.6.3. Table B.6.6.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

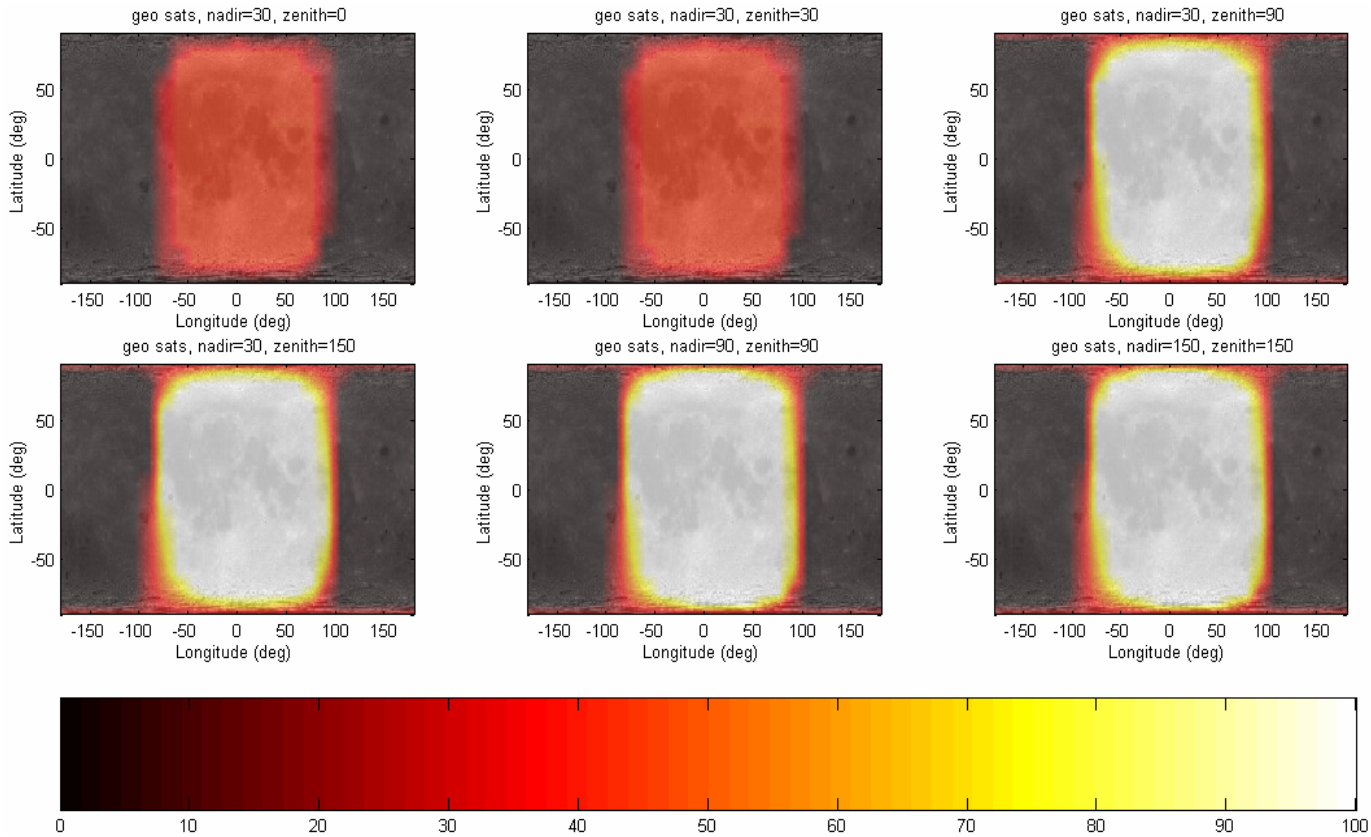

Figure B.6.6.1.—GEO system availability results.

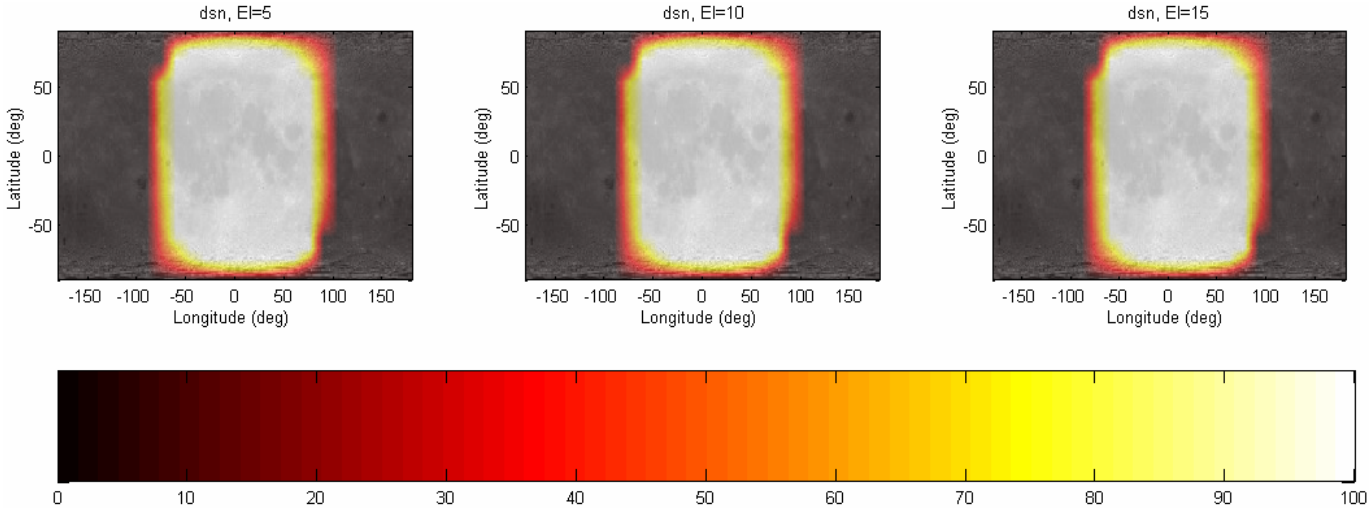

Figure B.6.6.2.—DSN system availability results.

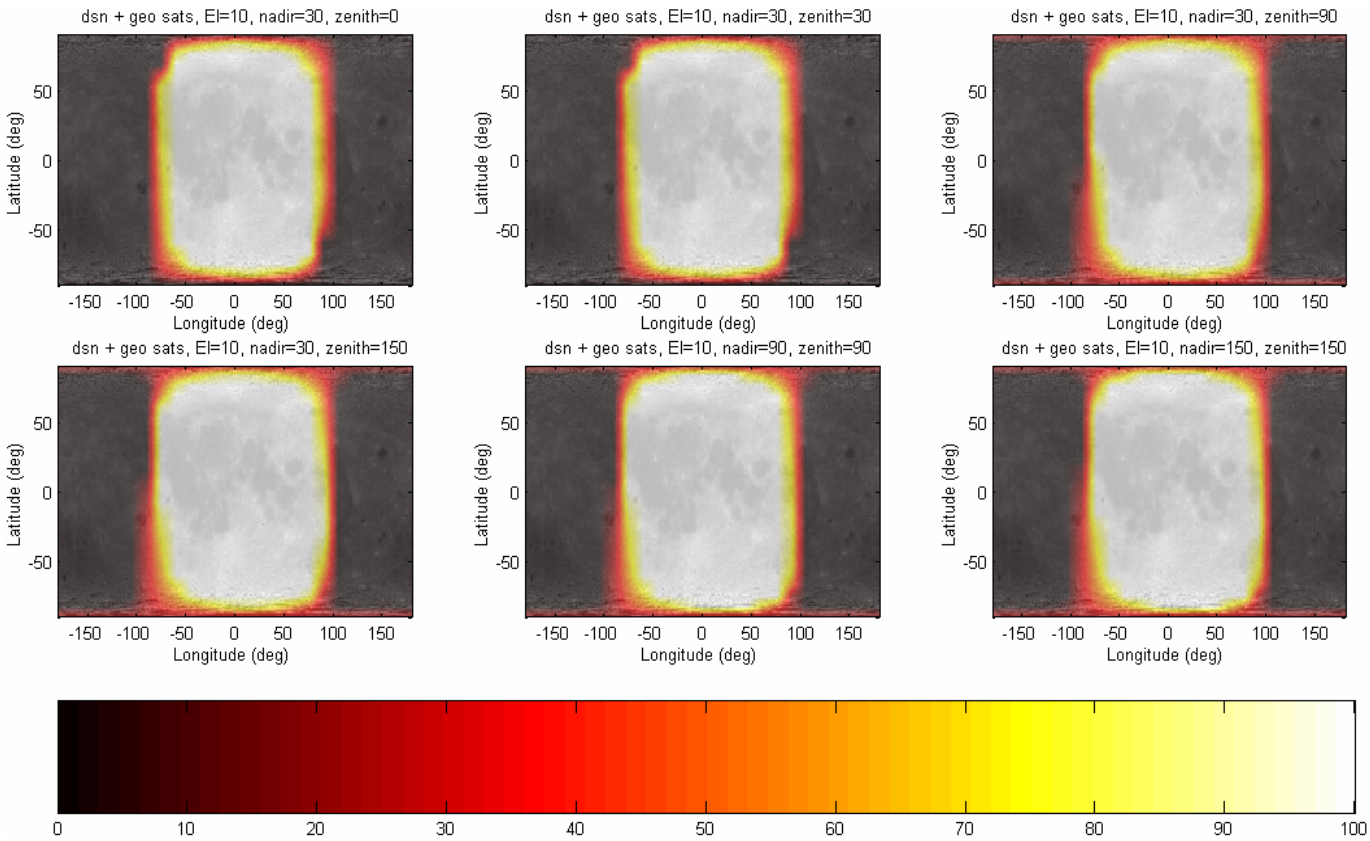

Figure B.6.6.3.—DSNGEO system availability results.

TABLE B.6.6.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	19.79	9.93	37.37	0.00	43.58
GEO 30/30	19.95	11.54	37.54	0.00	43.72
GEO 90/30	47.56	28.42	89.55	0.03	100.00
GEO 150/30	48.71	31.00	91.72	0.03	100.00
GEO 90/90	48.42	37.03	90.42	0.03	100.00
GEO 150/150	49.15	37.87	92.06	0.03	100.00
DSN 5	45.66	23.81	86.38	0.00	100.00
DSN 10	45.64	23.68	86.36	0.00	100.00
DSN 15	45.61	23.48	86.33	0.00	100.00
DSN+GEO 10/0/30	45.79	24.57	86.56	0.00	100.00
DSN+GEO 10/30/30	45.89	25.27	86.66	0.00	100.00
DSN+GEO 10/90/30	47.68	30.55	89.56	0.03	100.00
DSN+GEO 10/150/30	48.76	32.15	91.72	0.03	100.00
DSN+GEO 10/90/90	48.42	37.03	90.42	0.03	100.00
DSN+GEO 10/150/150	49.15	37.87	92.06	0.03	100.00

TABLE B.6.6.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	5.22	2.76	9.88	0.00	11.61
GEO 30/30	1.26	1.31	2.31	0.00	2.72
GEO 90/30	4.65	3.73	8.67	0.01	8.80
GEO 150/30	0.94	1.91	1.68	0.00	0.00
GEO 90/90	0.38	2.81	0.43	0.01	0.00
GEO 150/150	0.28	1.20	0.47	0.00	0.00
DSN 5	0.67	4.06	1.18	0.00	1.10
DSN 10	1.36	4.06	2.52	0.00	2.67
DSN 15	2.31	4.03	4.38	0.00	4.80
DSN+GEO 10/0/30 -v1	1.19	3.35	2.20	0.00	2.34
DSN+GEO 10/0/30 -v2	0.16	0.46	0.20	0.00	0.01
DSN+GEO 10/30/30 -v1	1.18	2.72	2.20	0.00	2.32
DSN+GEO 10/30/30 -v2	0.14	0.42	0.15	0.00	0.00
DSN+GEO 10/90/30 -v1	0.04	1.40	0.00	0.00	0.00
DSN+GEO 10/90/30 -v2	0.55	1.49	0.87	0.01	0.00
DSN+GEO 10/150/30 -v1	0.02	1.09	0.00	0.00	0.00
DSN+GEO 10/150/30 -v2	0.70	1.31	1.26	0.00	0.00
DSN+GEO 10/90/90 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/90/90 -v2	0.35	2.15	0.43	0.01	0.00
DSN+GEO 10/150/150 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/150/150 -v2	0.28	1.20	0.47	0.00	0.00

B.6.7 Dynamic (12 hr).—Figures B.6.7.1 to B.6.7.3 show the system availability results for the 15 Earth-based constellations when the system is operating in two-way mode with terrain information (solving with 12-hr dynamic measurements). Table B.6.7.1 tabulates the weighted system availabilities from figures B.6.7.1 to B.6.7.3. Table B.6.7.2 tabulates the losses in system availability that occurred as a result of losing a single asset (derived from the failure system availability analysis).

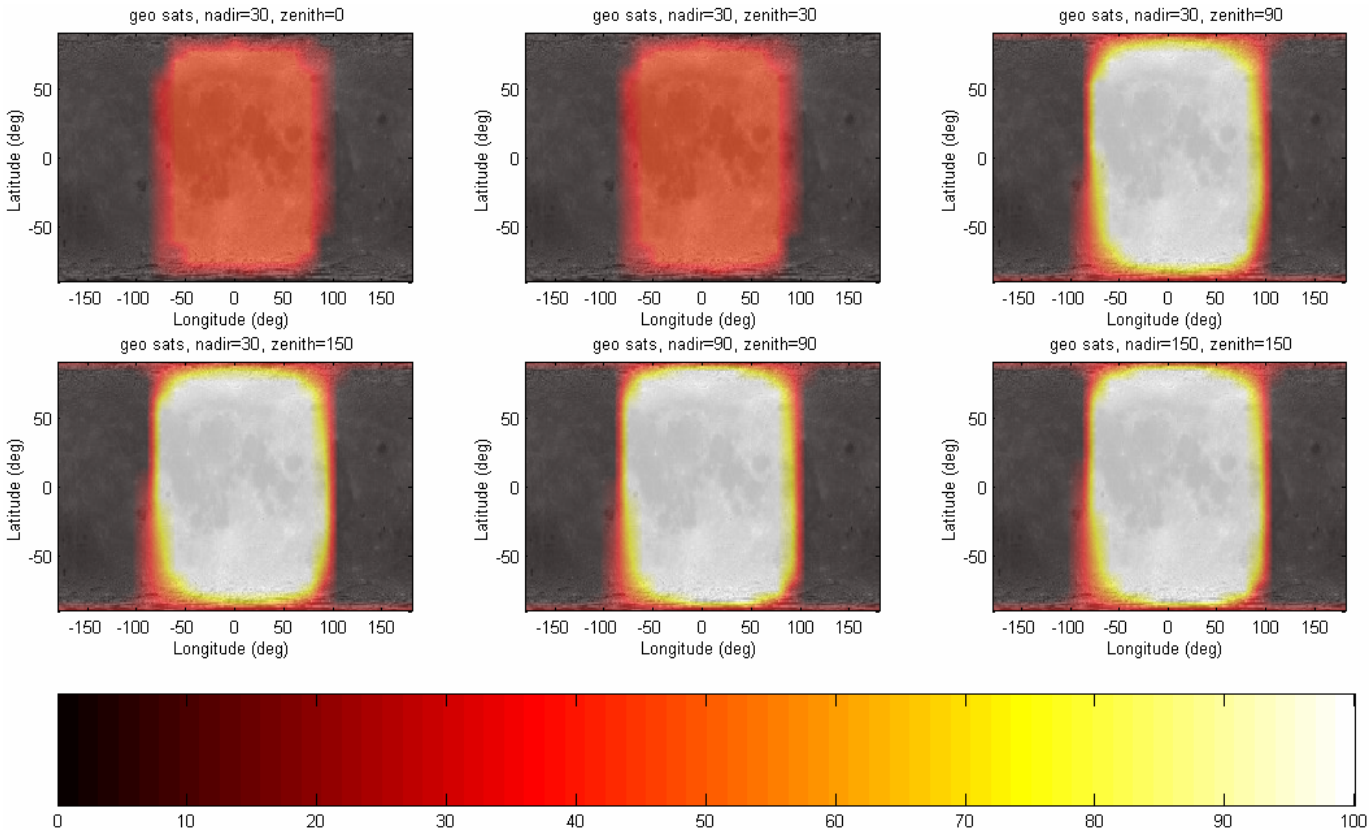

Figure B.6.7.1.—GEO system availability results.

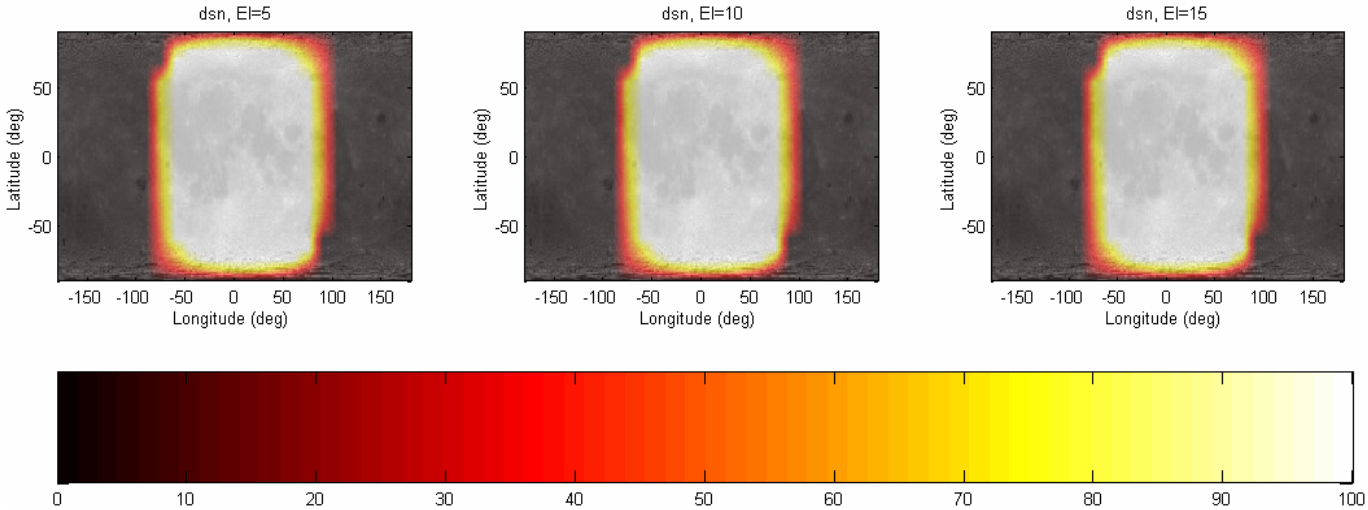

Figure B.6.7.2.—DSN system availability results.

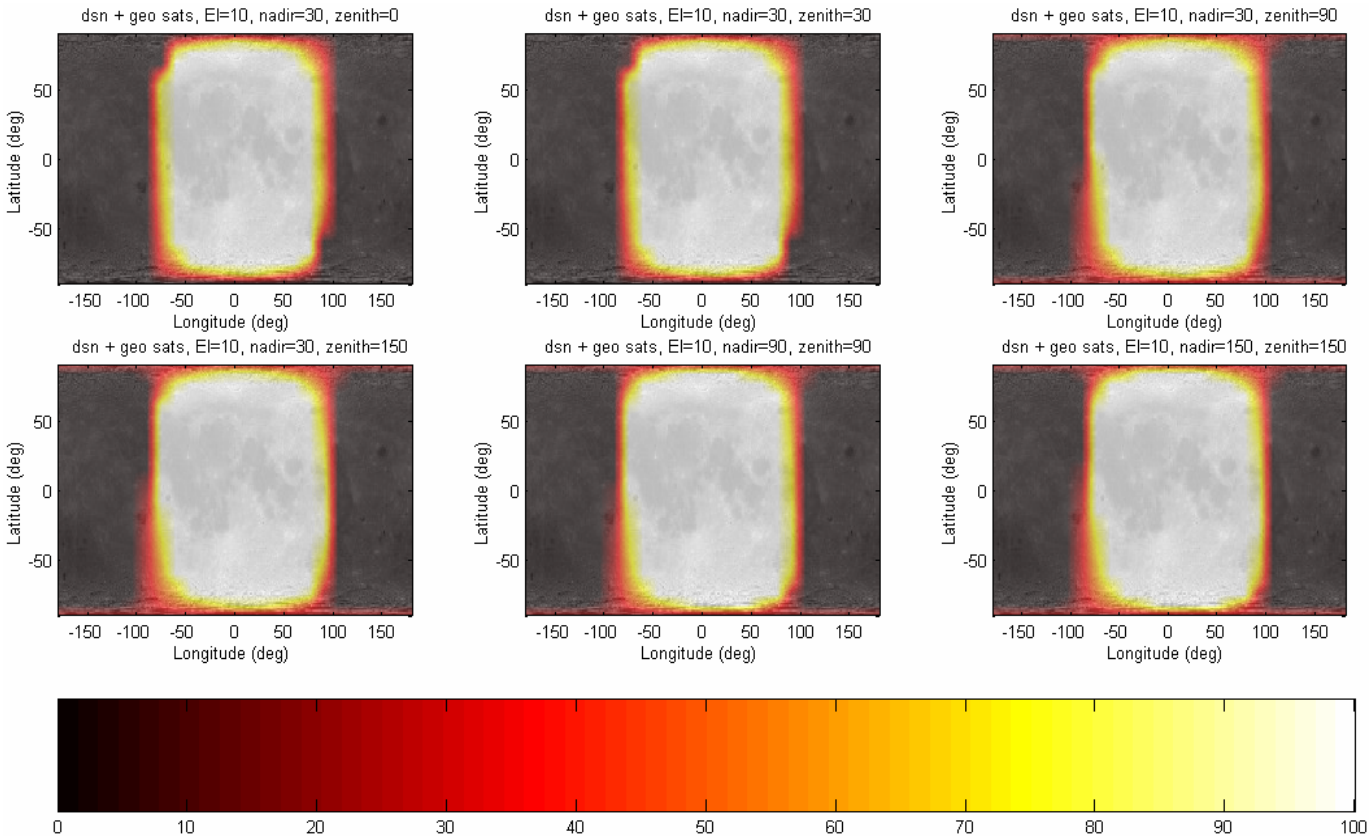

Figure B.6.7.3.—DSNGEO system availability results.

TABLE B.6.7.1.—WEIGHTED SYSTEM AVAILABILITY RESULTS

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	20.24	10.04	38.23	0.00	44.55
GEO 30/30	20.40	11.79	38.37	0.00	44.61
GEO 90/30	47.63	28.62	89.67	0.03	100.00
GEO 150/30	48.77	31.20	91.81	0.03	100.00
GEO 90/90	48.48	37.19	90.53	0.03	100.00
GEO 150/150	49.21	38.00	92.14	0.03	100.00
DSN 5	45.76	24.63	86.50	0.00	100.00
DSN 10	45.75	24.53	86.49	0.00	100.00
DSN 15	45.73	24.31	86.46	0.00	100.00
DSN+GEO 10/0/30	45.90	25.32	86.71	0.00	100.00
DSN+GEO 10/30/30	45.99	25.88	86.80	0.00	100.00
DSN+GEO 10/90/30	47.77	30.97	89.68	0.03	100.00
DSN+GEO 10/150/30	48.82	32.49	91.81	0.03	100.00
DSN+GEO 10/90/90	48.48	37.19	90.53	0.03	100.00
DSN+GEO 10/150/150	49.21	38.00	92.14	0.03	100.00

TABLE B.6.7.2.—WEIGHTED SYSTEM AVAILABILITY LOSSES FROM FAILURE MODE SYSTEM AVAILABILITY

Constellation	Regions on face of the Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	2.19	1.24	4.16	0.00	4.92
GEO 30/30	0.42	0.63	0.74	0.00	0.82
GEO 90/30	0.45	0.94	0.77	0.00	0.21
GEO 150/30	0.29	0.77	0.51	0.00	0.00
GEO 90/90	0.18	0.75	0.27	0.00	0.00
GEO 150/150	0.10	0.39	0.16	0.00	0.00
DSN 5	0.22	4.66	0.22	0.00	0.01
DSN 10	0.22	4.58	0.23	0.00	0.01
DSN 15	0.25	4.37	0.29	0.00	0.07
DSN+GEO 10/0/30 -v1	0.18	3.77	0.19	0.00	0.00
DSN+GEO 10/0/30 -v2	0.11	0.25	0.14	0.00	0.00
DSN+GEO 10/30/30 -v1	0.15	2.93	0.18	0.00	0.00
DSN+GEO 10/30/30 -v2	0.10	0.30	0.11	0.00	0.00
DSN+GEO 10/90/30 -v1	0.05	1.56	0.01	0.00	0.00
DSN+GEO 10/90/30 -v2	0.27	0.42	0.43	0.00	0.00
DSN+GEO 10/150/30 -v1	0.02	1.23	0.00	0.00	0.00
DSN+GEO 10/150/30 -v2	0.26	0.56	0.48	0.00	0.00
DSN+GEO 10/90/90 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/90/90 -v2	0.18	0.74	0.27	0.00	0.00
DSN+GEO 10/150/150 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/150/150 -v2	0.10	0.39	0.16	0.00	0.00

Appendix C—System Latency/Failure System Latency Results

C.1 No Terrain, One-Way Latency

Figures C.1.1 to C.1.3 show the system latency results for the 15 Earth-based constellations when the system is operating in one-way mode without terrain information. For figures C.1.1 to C.1.3, regions in black represent 1440 min of latency. Table C.1.1 tabulates the weighted system latency from figures C.1.1 to C.1.3. Table C.1.2 tabulates the increases in system latency that occurred as a result of losing a single asset (derived from the failure system latency analysis).

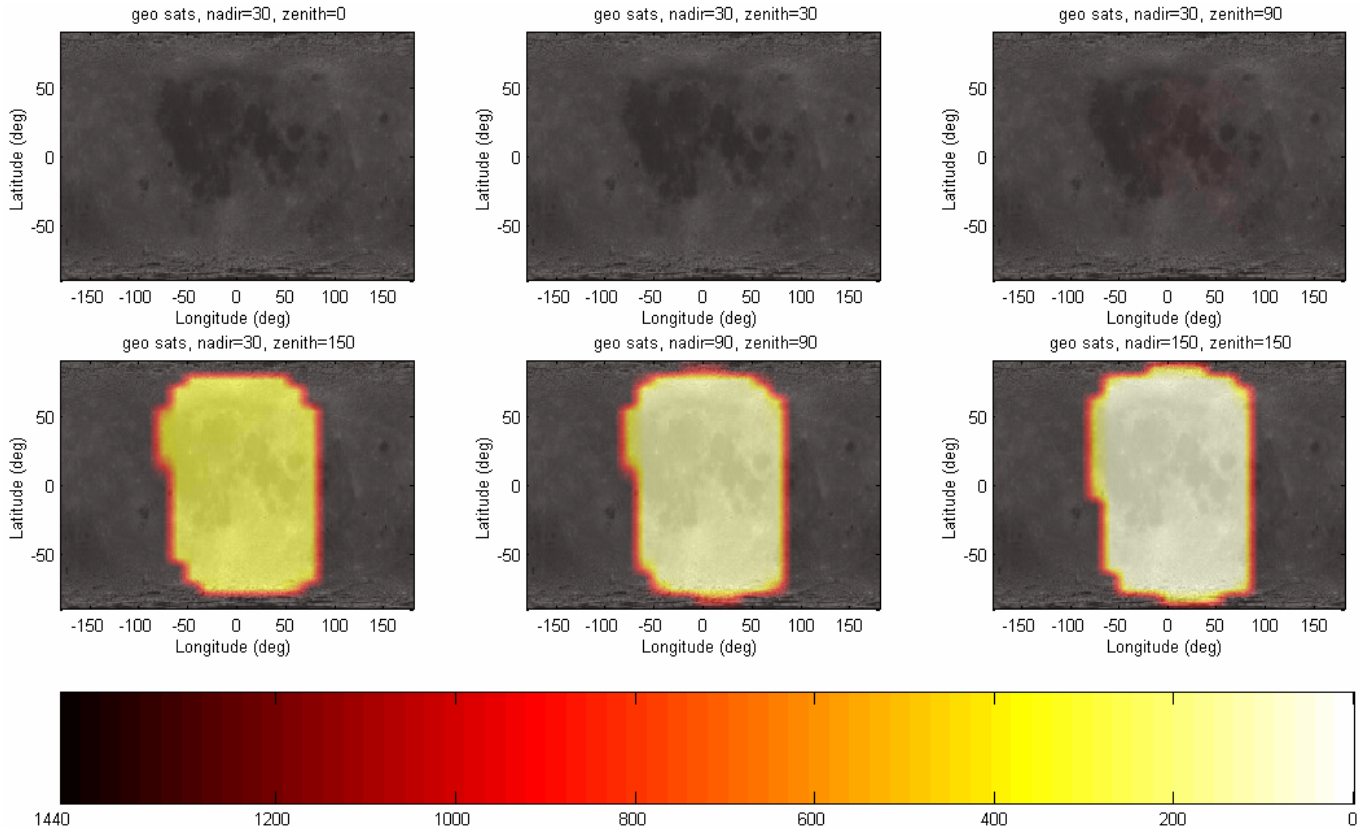

Figure C.1.1.—GEO system latency results.

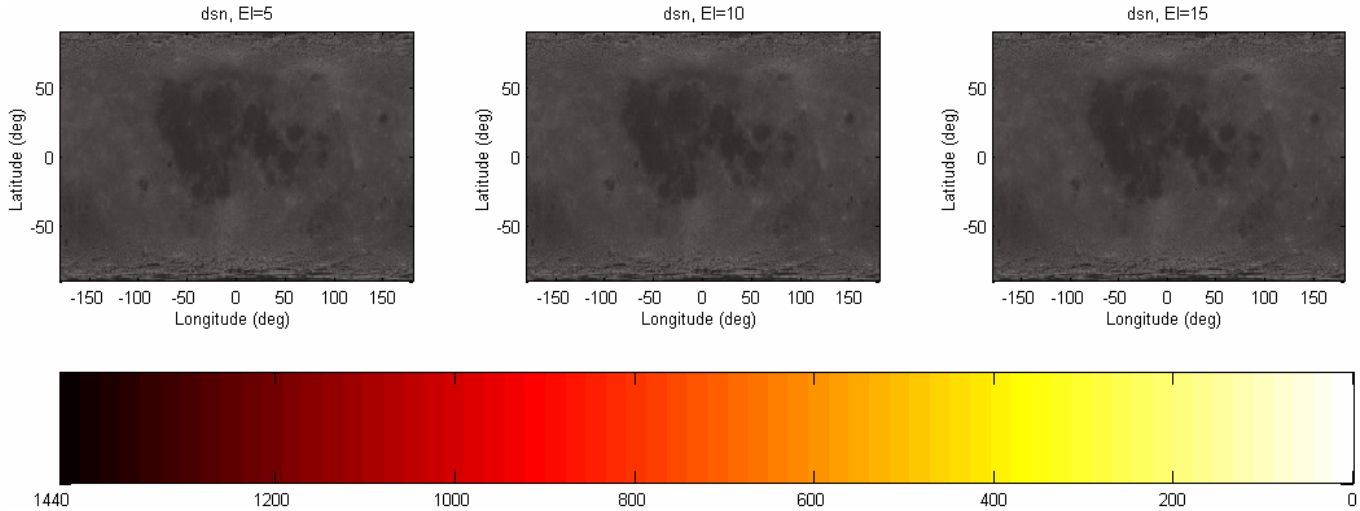

Figure C.1.2.—DSN system latency results.

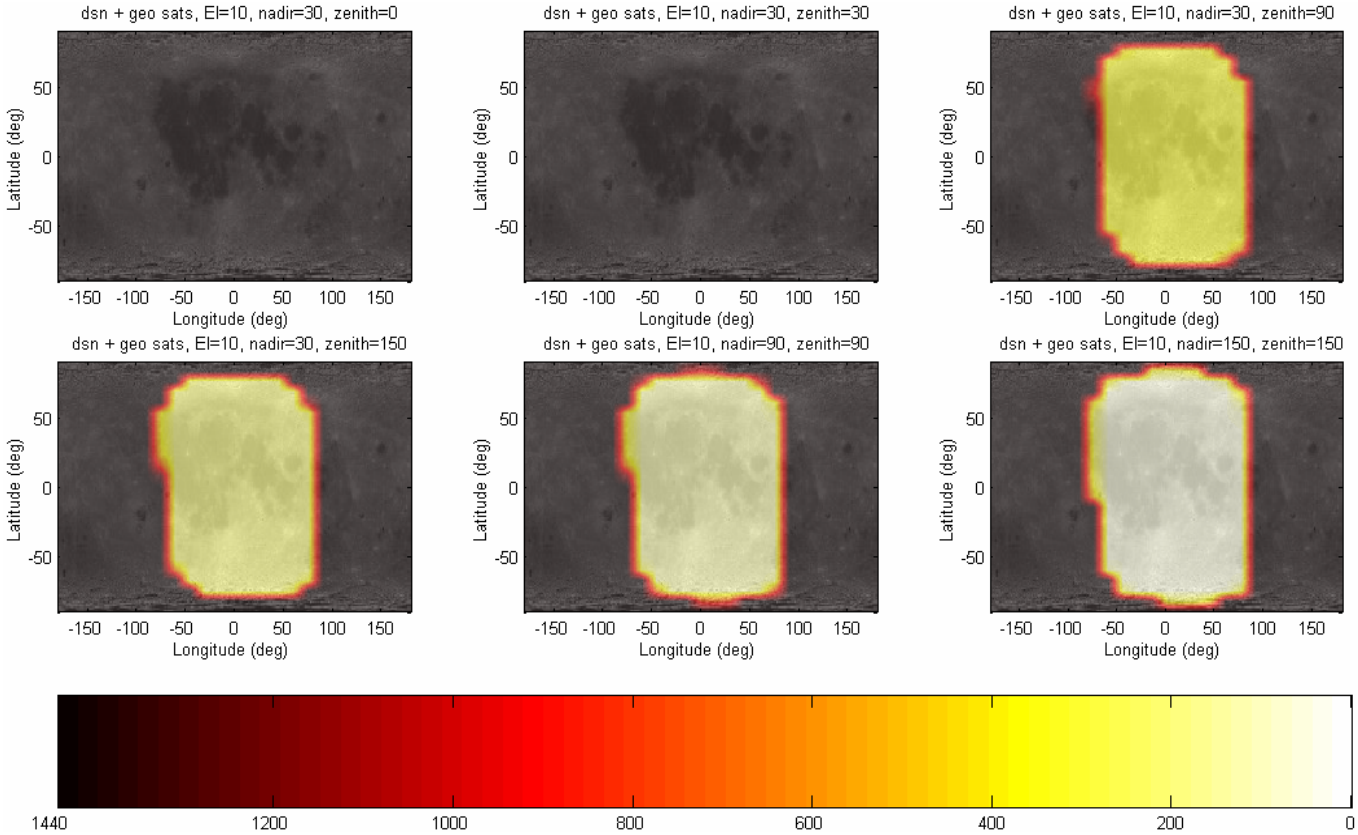

Figure C.1.3.—DSNGEO system latency results.

TABLE C.1.1.—WEIGHTED SYSTEM LATENCY RESULTS

Constellation	Regions on face of Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	1440.0	1440.0	1440.0	1440.0	1440.0
GEO 30/30	1440.0	1440.0	1440.0	1440.0	1440.0
GEO 90/30	1431.5	1440.0	1423.1	1440.0	1416.0
GEO 150/30	977.5	1440.0	547.3	1440.0	315.0
GEO 90/90	905.9	1357.5	419.7	1440.0	155.0
GEO 150/150	854.8	1248.5	331.6	1440.0	70.0
DSN 5	1440.0	1440.0	1440.0	1440.0	1440.0
DSN 10	1440.0	1440.0	1440.0	1440.0	1440.0
DSN 15	1440.0	1440.0	1440.0	1440.0	1440.0
DSN+GEO 10/0/30	1440.0	1440.0	1440.0	1440.0	1440.0
DSN+GEO 10/30/30	1440.0	1440.0	1440.0	1440.0	1440.0
DSN+GEO 10/90/30	983.9	1440.0	563.3	1440.0	305.0
DSN+GEO 10/150/30	923.1	1440.0	446.5	1440.0	185.0
DSN+GEO 10/90/90	892.8	1357.3	396.5	1440.0	125.0
DSN+GEO 10/150/150	852.6	1248.3	327.7	1440.0	65.0

TABLE C.1.2.—WEIGHTED SYSTEM LATENCY INCREASES FROM FAILURE MODE SYSTEM LATENCY

Constellation	Regions on face of Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	0.00	0.00	0.00	0.00	0.00
GEO 90/30	8.50	0.00	16.90	0.00	24.00
GEO 150/30	101.10	0.00	195.20	0.00	238.40
GEO 90/90	150.40	46.00	285.40	0.00	353.80
GEO 150/150	38.50	56.50	68.50	0.00	75.00
DSN 5	0.00	0.00	0.00	0.00	0.00
DSN 10	0.00	0.00	0.00	0.00	0.00
DSN 15	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/0/30 -v2	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/30/30 -v1	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/30/30 -v2	0.00	0.00	0.00	0.00	0.00
DSN+GEO 10/90/30 -v1	65.70	0.00	123.60	0.00	160.10
DSN+GEO 10/90/30 -v2	98.70	0.00	188.30	0.00	239.50
DSN+GEO 10/150/30 -v1	15.40	0.00	27.00	0.00	35.00
DSN+GEO 10/150/30 -v2	93.70	0.00	179.60	0.00	220.00
DSN+GEO 10/90/90 -v1	2.20	0.20	3.47	0.00	4.70
DSN+GEO 10/90/90 -v2	61.20	40.80	114.50	0.00	135.00
DSN+GEO 10/150/150 -v1	0.10	0.20	0.00	0.00	0.00
DSN+GEO 10/150/150 -v2	27.50	52.70	48.10	0.00	50.00

C.2 Good Terrain, One-Way Latency

Figures C.2.1 to C.2.3 show the system latency results for the 15 Earth-based constellations when the system is operating in one-way mode with terrain information. For figures C.2.1 to C.2.3, regions in black represent 1440 min of latency. Table C.2.1 tabulates the weighted system latency from figures C.2.1 to C.2.3. Table C.2.2 tabulates the increases in system latency that occurred as a result of losing a single asset (derived from the failure system latency analysis).

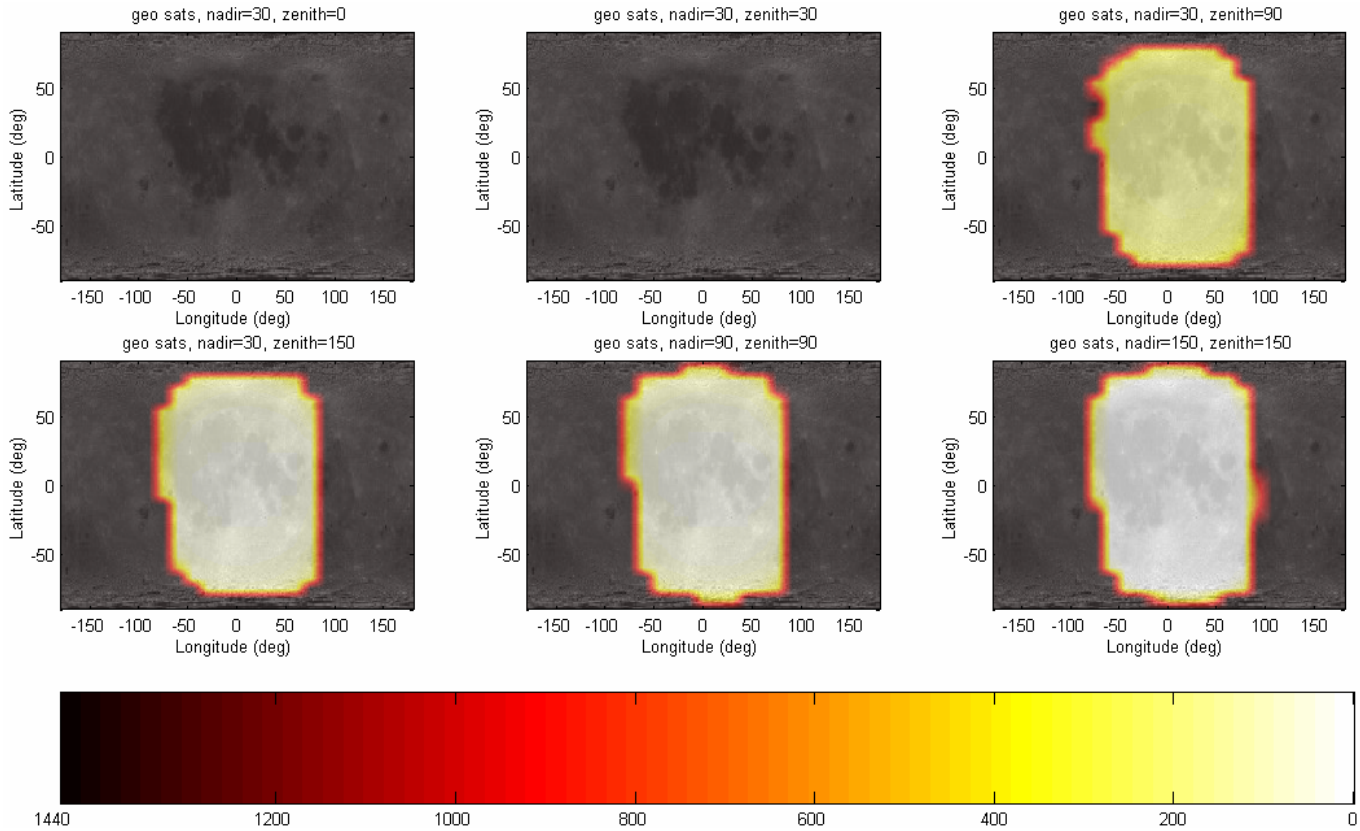

Figure C.2.1.—GEO system latency results.

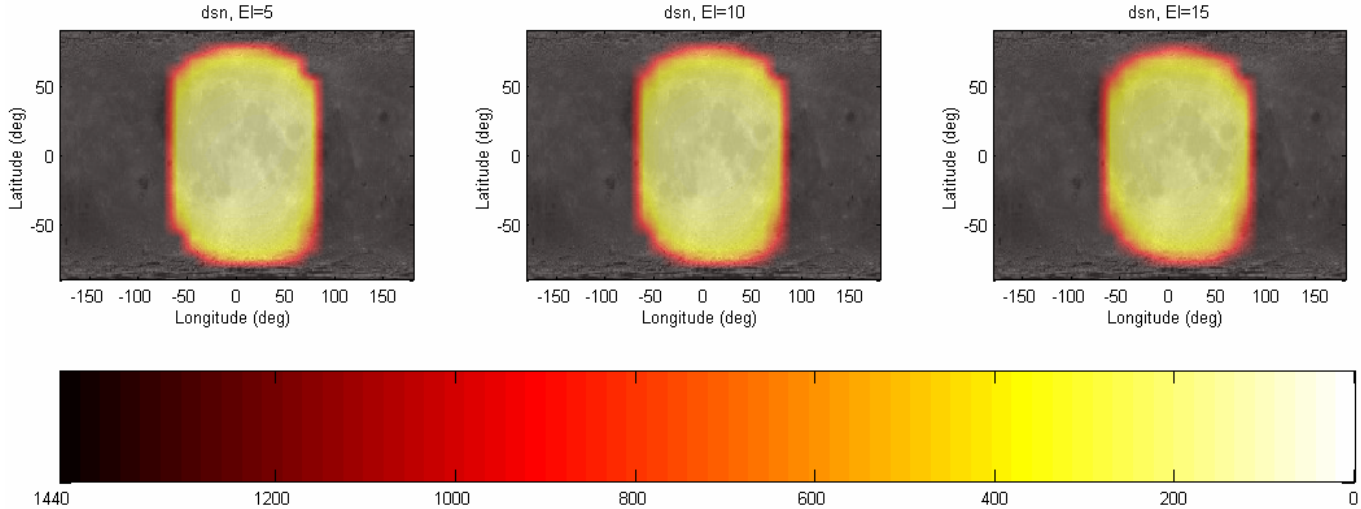

Figure C.2.2.—DSN system latency results.

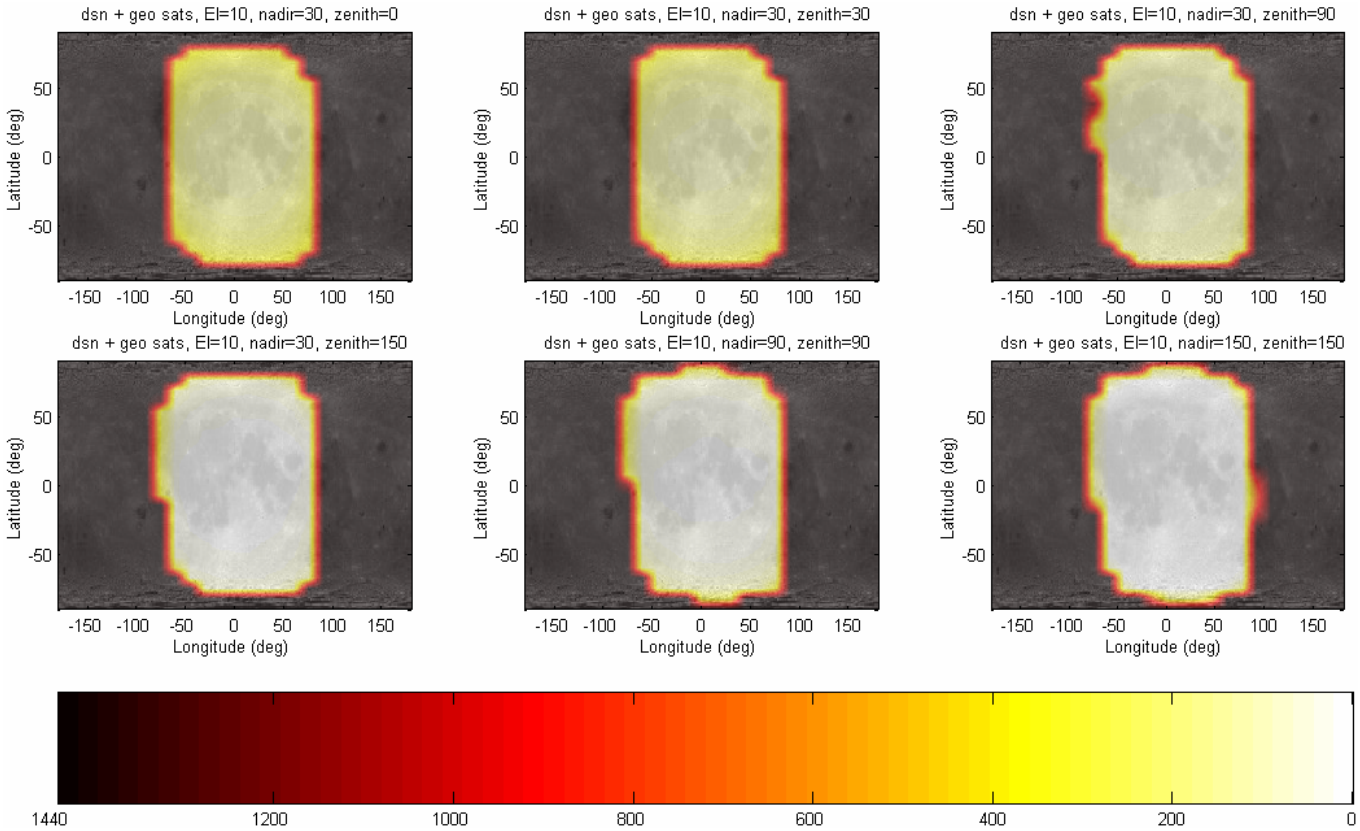

Figure C.2.3.—DSNGEO system latency results.

TABLE C.2.1.—WEIGHTED SYSTEM LATENCY RESULTS

Constellation	Regions on face of Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	1440.0	1440.0	1440.0	1440.0	1440.0
GEO 30/30	1440.0	1440.0	1440.0	1440.0	1440.0
GEO 90/30	930.8	1440.0	449.8	1440.0	172.4
GEO 150/30	859.2	1440.0	315.8	1440.0	42.5
GEO 90/90	856.4	1298.5	327.2	1440.0	40.1
GEO 150/150	813.8	1212.5	247.9	1440.0	0.0
DSN 5	963.8	1440.0	487.2	1440.0	156.3
DSN 10	976.2	1440.0	504.8	1440.0	172.4
DSN 15	993.9	1440.0	531.0	1440.0	199.8
DSN+GEO 10/0/30	933.1	1440.0	452.6	1440.0	126.5
DSN+GEO 10/30/30	923.6	1440.0	436.0	1440.0	110.7
DSN+GEO 10/90/30	890.2	1440.0	378.4	1440.0	85.0
DSN+GEO 10/150/30	845.0	1440.0	291.5	1440.0	13.0
DSN+GEO 10/90/90	847.0	1296.0	310.4	1440.0	20.5
DSN+GEO 10/150/150	813.3	1212.1	247.4	1440.0	0.0

TABLE C.2.2.—WEIGHTED SYSTEM LATENCY INCREASES FROM FAILURE MODE SYSTEM LATENCY

Constellation	Regions on face of Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	0.00	0.00	0.00	0.00	0.00
GEO 90/30	139.80	0.00	266.60	0.00	332.50
GEO 150/30	108.20	0.00	213.00	0.00	261.10
GEO 90/90	49.90	35.50	88.80	0.00	105.30
GEO 150/150	26.90	50.40	48.90	0.00	30.50
DSN 5	134.20	0.00	255.60	0.00	331.00
DSN 10	152.00	0.00	292.70	0.00	383.90
DSN 15	167.80	0.00	326.20	0.00	427.50
DSN+GEO 10/0/30 -v1	109.50	0.00	202.30	0.00	271.00
DSN+GEO 10/0/30 -v2	65.50	0.00	122.10	0.00	157.50
DSN+GEO 10/30/30 -v1	101.50	0.00	178.80	0.00	225.40
DSN+GEO 10/30/30 -v2	53.80	0.00	102.50	0.00	135.50
DSN+GEO 10/90/30 -v1	8.70	0.00	12.30	0.00	11.80
DSN+GEO 10/90/30 -v2	25.60	0.00	43.80	0.00	32.60
DSN+GEO 10/150/30 -v1	5.80	0.00	10.50	0.00	13.50
DSN+GEO 10/150/30 -v2	38.40	0.00	69.60	0.00	68.40
DSN+GEO 10/90/90 -v1	3.00	1.70	5.70	0.00	6.80
DSN+GEO 10/90/90 -v2	27.40	27.50	48.56	0.00	54.88
DSN+GEO 10/150/150 -v1	0.20	0.40	0.20	0.00	0.00
DSN+GEO 10/150/150 -v2	19.70	49.80	35.30	0.00	14.50

C.3 No Terrain, Two-Way Latency

Figures C.3.1 to C.3.3 show the system latency results for the 15 Earth-based constellations when the system is operating in two-way mode without terrain information. For figures C.3.1 to C.3.3, regions in black represent 1440 min of latency. Table C.3.1 tabulates the weighted system latency from figures C.3.1 to C.3.3. Table C.3.2 tabulates the increases in system latency that occurred as a result of losing a single asset (derived from the failure system latency analysis).

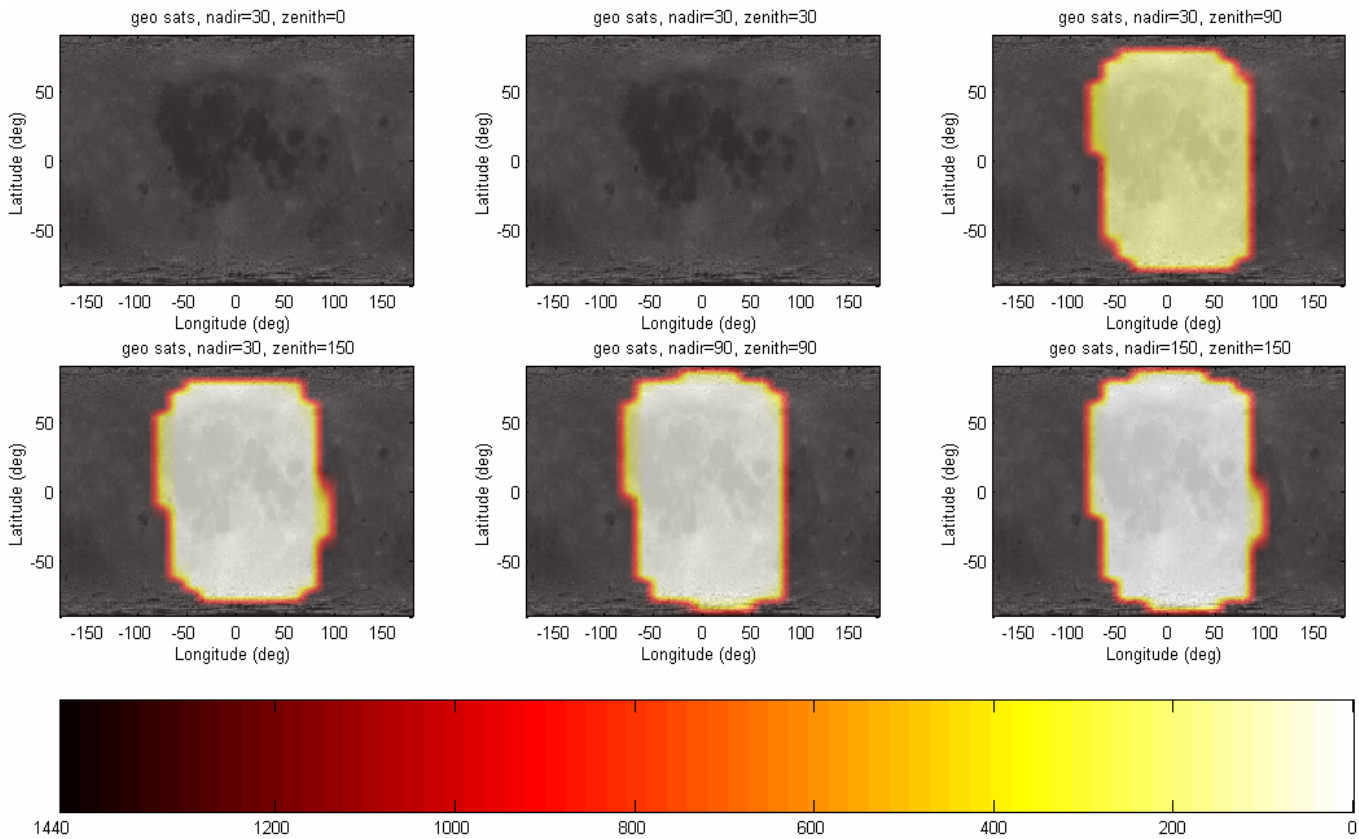

Figure C.3.1.—GEO system latency results.

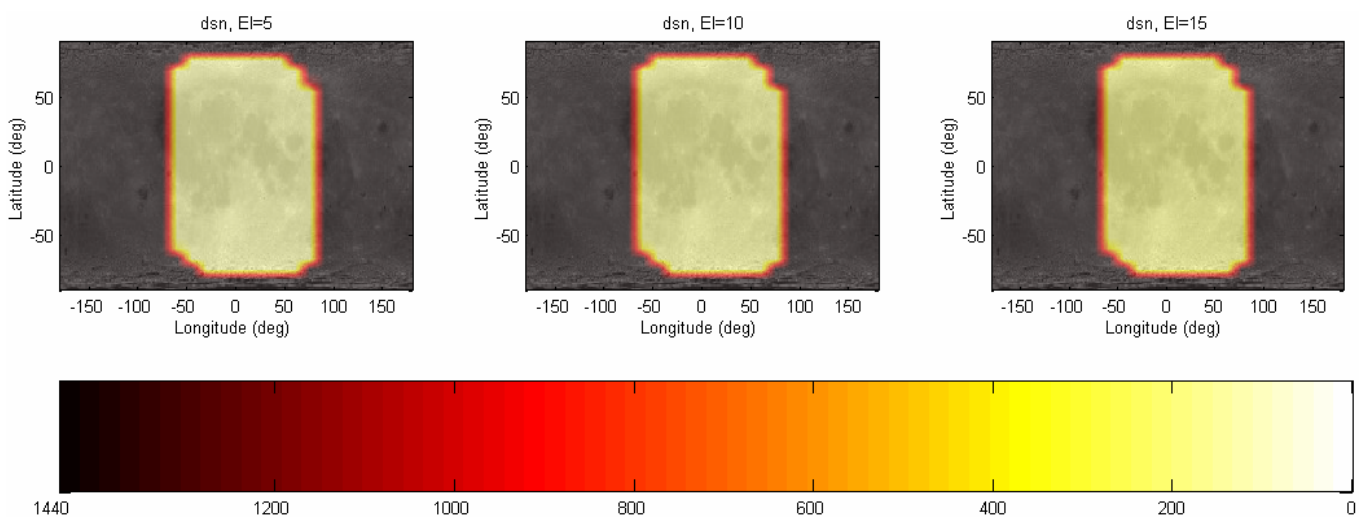

Figure C.3.2.—DSN system latency results.

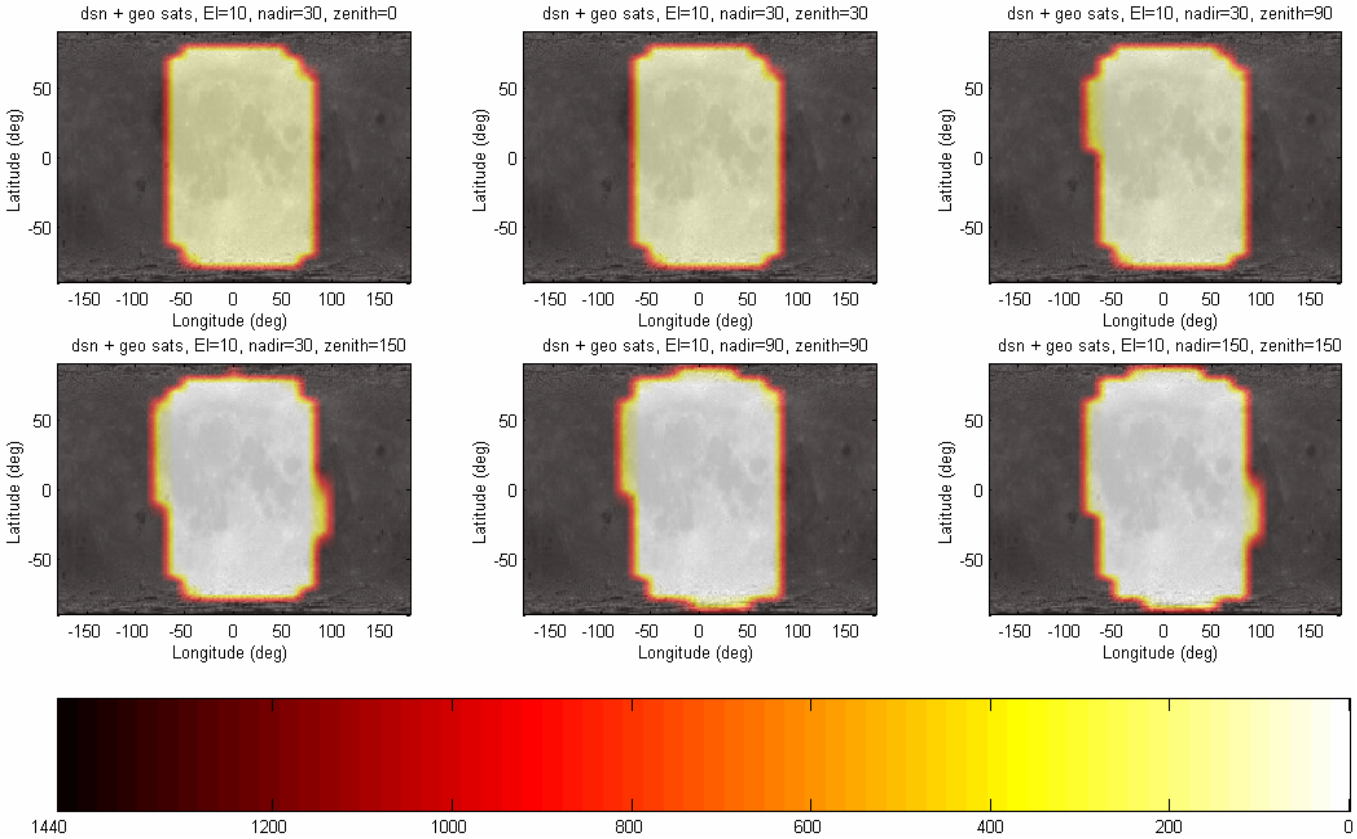

Figure C.3.3.—DSNGEO system latency results.

TABLE C.3.1.—WEIGHTED SYSTEM LATENCY RESULTS

Constellation	Regions on face of Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	1440.0	1440.0	1440.0	1440.0	1440.0
GEO 30/30	1440.0	1440.0	1440.0	1440.0	1440.0
GEO 90/30	913.0	1440.0	424.6	1440.0	169.9
GEO 150/30	834.2	1440.0	266.2	1440.0	40.0
GEO 90/90	841.2	1225.0	308.0	1440.0	35.0
GEO 150/150	798.6	1157.7	217.7	1440.0	0.0
DSN 5	917.8	1440.0	440.9	1440.0	141.3
DSN 10	925.9	1440.0	455.4	1440.0	160.0
DSN 15	936.7	1440.0	475.6	1440.0	185.4
DSN+GEO 10/0/30	906.4	1440.0	420.8	1440.0	115.0
DSN+GEO 10/30/30	900.2	1440.0	409.2	1440.0	100.0
DSN+GEO 10/90/30	873.3	1440.0	354.7	1440.0	80.0
DSN+GEO 10/150/30	818.9	1440.0	242.2	1440.0	10.0
DSN+GEO 10/90/90	832.6	1222.9	292.1	1440.0	15.0
DSN+GEO 10/150/150	798.3	1157.1	217.3	1440.0	0.0

TABLE C.3.2.—WEIGHTED SYSTEM LATENCY INCREASES FROM FAILURE MODE SYSTEM LATENCY

Constellation	Regions on face of Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	0.00	0.00	0.00	0.00	0.00
GEO 90/30	145.50	0.00	278.70	0.00	346.60
GEO 150/30	120.50	0.00	236.00	0.00	266.00
GEO 90/90	48.30	39.60	88.07	0.00	110.00
GEO 150/150	17.60	35.40	33.10	0.00	25.00
DSN 5	132.50	0.00	250.90	0.00	327.20
DSN 10	153.40	0.00	291.90	0.00	379.90
DSN 15	170.80	0.00	325.90	0.00	424.60
DSN+GEO 10/0/30 -v1	110.90	0.00	211.00	0.00	273.90
DSN+GEO 10/0/30 -v2	64.70	0.00	123.00	0.00	160.00
DSN+GEO 10/30/30 -v1	96.40	0.00	182.60	0.00	237.30
DSN+GEO 10/30/30 -v2	56.77	0.00	107.70	0.00	140.00
DSN+GEO 10/90/30 -v1	5.50	0.00	8.40	0.00	10.10
DSN+GEO 10/90/30 -v2	16.60	0.00	30.40	0.00	30.30
DSN+GEO 10/150/30 -v1	7.07	0.00	11.90	0.00	15.00
DSN+GEO 10/150/30 -v2	37.50	0.00	74.76	0.00	65.00
DSN+GEO 10/90/90 -v1	4.10	0.40	7.85	0.00	10.00
DSN+GEO 10/90/90 -v2	26.30	31.30	46.50	0.00	56.02
DSN+GEO 10/150/150 -v1	0.10	0.40	0.10	0.00	0.00
DSN+GEO 10/150/150 -v2	11.10	33.70	21.00	0.00	10.00

C.4 Good Terrain, Two-Way Latency

Figures C.4.1 to C.4.3 show the system latency results for the 15 Earth-based constellations when the system is operating in two-way mode with terrain information. For figures C.4.1 to C.4.3, regions in black represent 1440 min of latency. Table C.4.1 tabulates the weighted system latency from figures C.4.1 to C.4.3. Table C.4.2 tabulates the increases in system latency that occurred as a result of losing a single asset (derived from the failure system latency analysis).

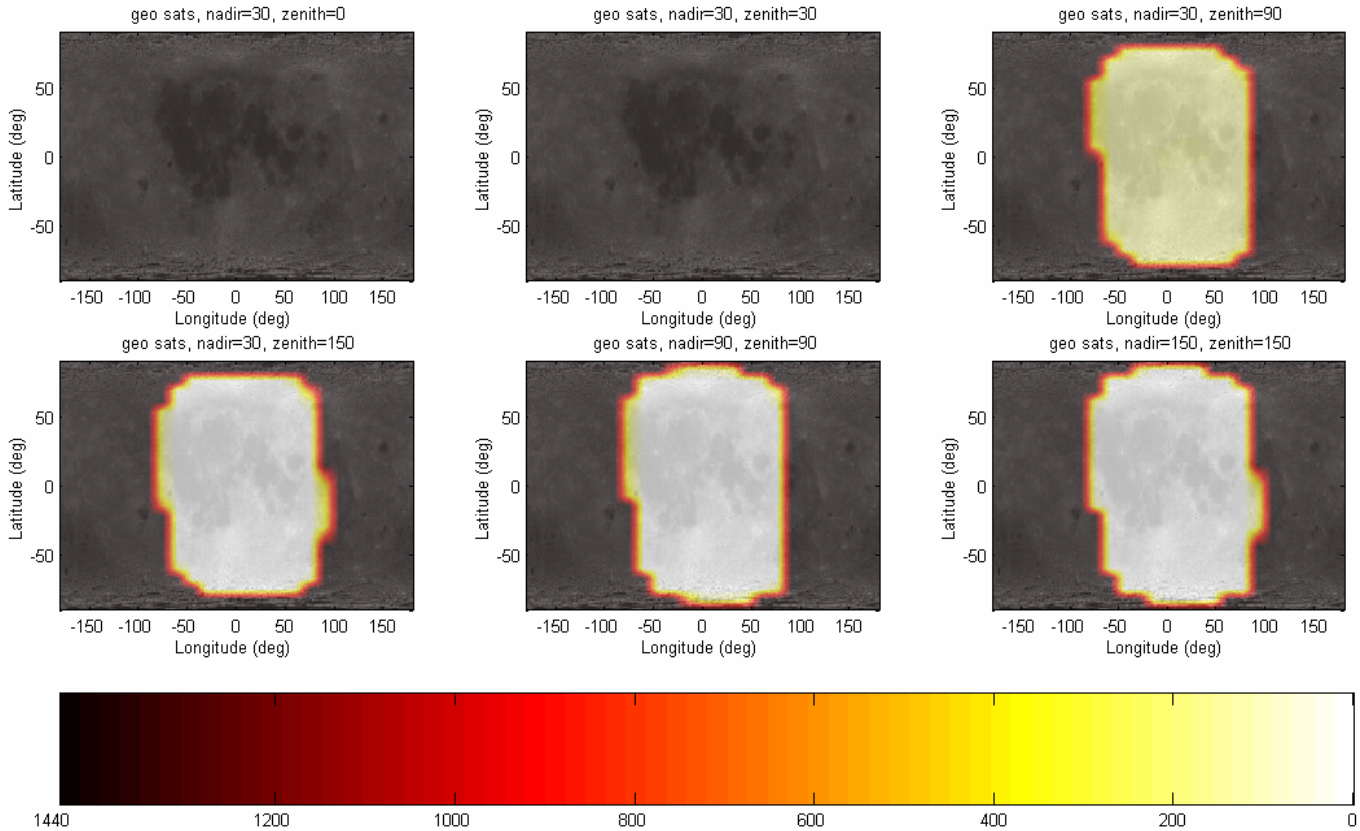

Figure C.4.1.—GEO system latency results.

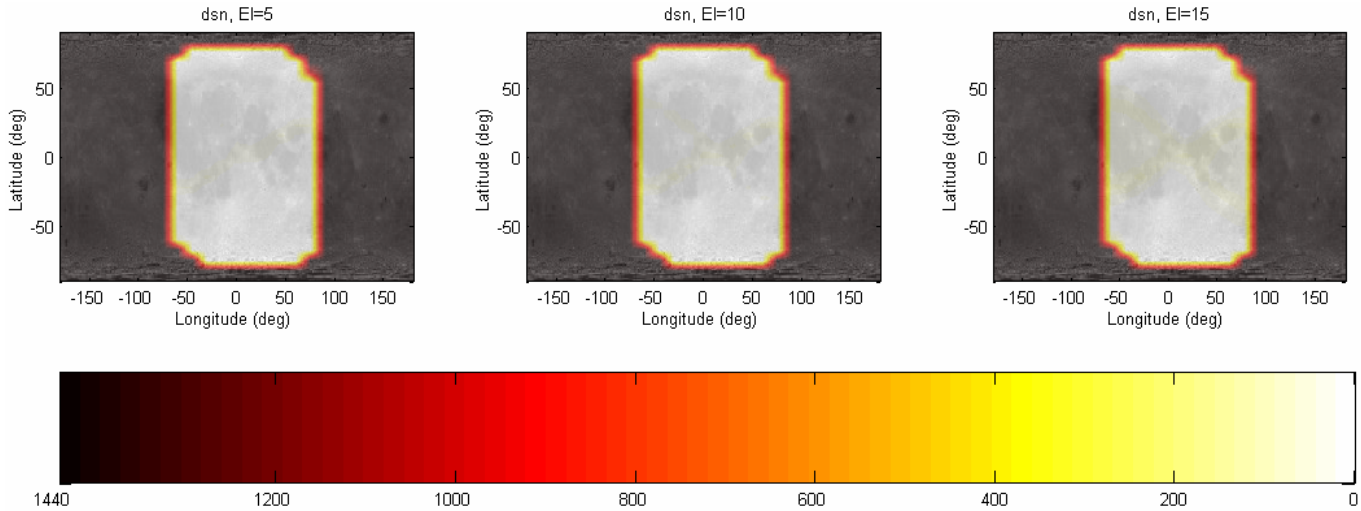

Figure C.4.2.—DSN system latency results.

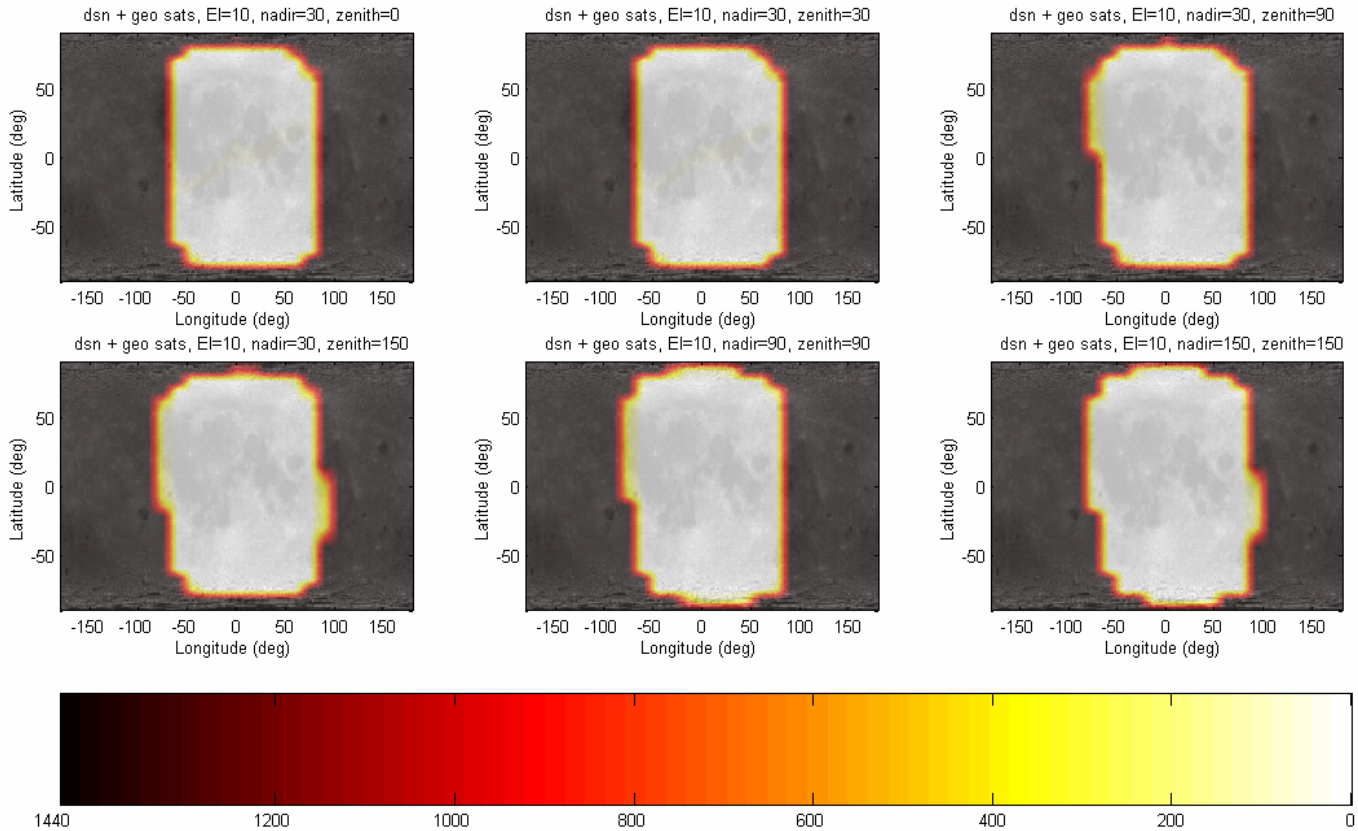

Figure C.4.3.—DSNGEO system latency results.

TABLE C.4.1.—WEIGHTED SYSTEM LATENCY RESULTS

Constellation	Regions on face of Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	1440.0	1440.0	1440.0	1440.0	1440.0
GEO 30/30	1440.0	1440.0	1440.0	1440.0	1440.0
GEO 90/30	893.7	1440.0	389.5	1440.0	132.5
GEO 150/30	812.3	1440.0	224.2	1440.0	5.9
GEO 90/90	824.1	1188.5	276.7	1440.0	6.3
GEO 150/150	794.2	1146.9	208.5	1440.0	0.0
DSN 5	864.1	1440.0	340.2	1440.0	12.5
DSN 10	865.7	1440.0	343.9	1440.0	17.6
DSN 15	871.7	1440.0	357.3	1440.0	34.2
DSN+GEO 10/0/30	863.2	1440.0	342.1	1440.0	15.1
DSN+GEO 10/30/30	862.7	1440.0	340.9	1440.0	13.7
DSN+GEO 10/90/30	837.9	1440.0	288.9	1440.0	3.4
DSN+GEO 10/150/30	807.4	1440.0	220.8	1440.0	0.0
DSN+GEO 10/90/90	822.5	1185.8	273.7	1440.0	0.7
DSN+GEO 10/150/150	793.8	1146.9	207.6	1440.0	0.0

TABLE C.4.2.—WEIGHTED SYSTEM LATENCY INCREASES FROM FAILURE MODE SYSTEM LATENCY

Constellation	Regions on face of Moon				
	Global	South pole	Front equatorial	Backside	Apollo
GEO 0/30	0.00	0.00	0.00	0.00	0.00
GEO 30/30	0.00	0.00	0.00	0.00	0.00
GEO 90/30	134.50	0.00	258.40	0.00	321.70
GEO 150/30	123.20	0.00	239.80	0.00	266.40
GEO 90/90	36.00	39.40	65.20	0.00	79.30
GEO 150/150	8.00	32.30	15.80	0.00	2.20
DSN 5	93.60	0.00	176.70	0.00	228.80
DSN 10	115.00	0.00	217.00	0.00	280.90
DSN 15	134.10	0.00	251.50	0.00	326.30
DSN+GEO 10/0/30 -v1	87.90	0.00	165.60	0.00	215.00
DSN+GEO 10/0/30 -v2	42.10	0.00	78.30	0.00	100.40
DSN+GEO 10/30/30 -v1	75.70	0.00	142.50	0.00	184.70
DSN+GEO 10/30/30 -v2	32.70	0.00	61.40	0.00	78.00
DSN+GEO 10/90/30 -v1	6.50	0.00	11.70	0.00	15.50
DSN+GEO 10/90/30 -v2	11.30	0.00	22.00	0.00	23.00
DSN+GEO 10/150/30 -v1	1.50	0.00	1.00	0.00	1.60
DSN+GEO 10/150/30 -v2	13.57	0.00	27.70	0.00	3.25
DSN+GEO 10/90/90 -v1	0.30	1.90	0.50	0.00	0.82
DSN+GEO 10/90/90 -v2	4.70	32.70	7.10	0.00	6.00
DSN+GEO 10/150/150 -v1	0.10	0.00	0.20	0.00	0.00
DSN+GEO 10/150/150 -v2	7.30	28.30	14.90	0.00	0.24

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13. ABSTRACT ***(Maximum 200 words)***
The NASA Vision for Space Exploration is focused on the return of astronauts to the Moon. Although navigation systems have already been proven in the Apollo missions to the Moon, the current exploration campaign will involve more extensive and extended missions requiring new concepts for lunar navigation. In contrast to Apollo missions, which were limited to the near-side equatorial region of the Moon, those under the Exploration Systems Initiative will require navigation on the Moon's limb and far side. These regions are known to have poor Earth visibility, but unknown is the extent to which a navigation system comprised solely of Earth-based tracking stations will provide adequate navigation solutions in these areas. This report presents a dilution-of-precision (DoP)-based analysis of the performance of a network of Earth-based assets. This analysis extends a previous analysis of a lunar network (LN) of navigation satellites by providing an assessment of the capability associated with a variety of assumptions. These assumptions pertain to the minimum provider elevation angle, nadir and zenith beam widths, and a total single failure in one of the Earth-based assets. The assessment is accomplished by making appropriately formed estimates of DoP. Different adaptations of DoP, such as geometrical DoP and positional DoP (GDoP and PDoP), are associated with a different set of assumptions regarding augmentations to the navigation receiver or transceiver.

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