IPN Progress Report 42-165 May 15, 2006

Estimate of Interference from the Aeronautical Mobile Services of the Cities of Glendale and Pasadena to Goldstone Radio Astronomy Stations at 4.9 Gigahertz

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The Federal Communications Commission (FCC) recently allocated the 4.9-GHz band to public safety telecommunications services. Radio Astronomy Services (RAS) also has been using this frequency. NASA will primarily use Deep Space Station 28 (DSS 28) at Goldstone, California, for radio astronomy services that are sensitive to radio-frequency interference (RFI). This study is to determine the RFI potential of airborne transmission from two cities to radio astronomy sites in Goldstone. Propagation losses over the terrain between both cities and Goldstone are estimated using the Trans-Horizon Interference Propagation Loss (THIPL) software recently developed at JPL and high-resolution terrain data. The necessary coordination area for protecting the Goldstone radio astronomy station has been defined based on the minimum propagation loss required. Study results and suggestions for modification to the airborne areas proposed by both cities' police departments are presented.

I. Introduction

The Federal Communications Commission (FCC) recently allocated the 4.9-GHz band to public safety telecommunications services. This frequency is also allocated to Radio Astronomy Services (RAS). The cities of Glendale and Pasadena have both proposed to use this frequency band for police air mobile operation (helicopter to ground video). The helicopters for this use have a maximum flight altitude of 457 m (1500 ft) above the terrain. Direction of transmission will be steered by a Global Positioning System (GPS)-driven pointing solution to fixed mountain-top receiver sites.

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The research described in this publication was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

A ground and airborne operability demonstration at 4.9 GHz is planned for the near future, and this demonstration involves a receive test at Goldstone and an airborne test in the direction of susceptibility.[3]

This study evaluates the problem of potential radio-frequency interference (RFI) from the airborne transmitter impacting radio astronomy stations at Goldstone and the necessary coordination area. Also, it investigates a method that permits the air–ground activity in the vicinity of Goldstone while still protecting the RAS. In this article, we first introduce airborne transmission parameters in the two cities and the RFI threshold for RAS at Goldstone. Then we perform terrain profile analysis and the trans-horizon propagation loss calculation. Based on the minimum loss required for RAS, we establish an exclusion zone in the loss map. Finally, we generate suggestions for modifying airborne areas proposed by police departments in both cities.

II. Airborne Transmission in Two Cities

The cities of Glendale and Pasadena recently proposed airborne areas for their helicopter transmission. All parameters for transmitting systems and airborne areas are as described in the following.

Glendale is proposing to operate an air mobile broadcast (helicopter) over an 18.024-km (11.2-mile) radius around Verdugo Hill. The receiving radio tower has coordinates of $34°11'15''$N latitude and $118°15'20''$W longitude. The transmitter has a 1-W output, a 5-dBi omnidirectional antenna, and an 8.0-MHz bandwidth.[4]

In Pasadena, the airborne area has operating radii of 7.21 km (4 miles) from −50 deg to +80 deg relative to true north and 16.093 km (10 miles) in all other directions. The receiving center (called NAD83) has coordinates of $34°08'24.2''$N latitude and $118°02'42.45''$W longitude around Santa Anita Park. The transmitter has an output power of either 1 W or 5 W, a 5.5-dBi omnidirectional antenna, and an 8.0-MHz bandwidth. The effective isotropically radiated power (EIRP) of the transmitting system is either 5.5 dBW or 12.5 dBW. The resulting EIRP in dB(W/Hz) is −63.5 dBW/Hz and −56.5 dBW/Hz for transmitter power of 1 W and 5 W, respectively.[5]

Figures 1 and 2 are terrain elevation maps for airborne areas proposed by both cites and locations relative to the radio astronomy station (DSS 28) at Goldstone.

Both cities are on the southwest side of DSS 28 and behind the San Gabriel Mountains. The airborne center of Glendale is 178 km away from DSS 28, while the Pasadena center is 168 km from DSS 28. We expect that the San Gabriel Mountains can block significant amounts of interference signals. However, if a helicopter flies in the northern mountain areas, it is possible that there will be some line-of-sight links between the helicopter and the RAS station. A detailed terrain profile analysis needs to be performed.

III. Radio Astronomy Services at Goldstone

NASA will primarily use DSS 28 for radio astronomy services [1], but may also use other stations. Two radio astronomy stations at Goldstone (DSS 28 and DSS 27) with 34-m dish antennas are shown in Fig. 3.

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[3] R. Drummond, e-mail (personal communication), "4.9 GHz Regional Planning Meeting," September 30, 2005.

The research described in this publication was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

[4] H. Epstein, e-mail (personal communication), "Calculated Interference From Glendale, City of," November 24, 2004.

[5] H. Epstein, e-mail (personal communication), "Pasadena Police Department," October 25, 2004.

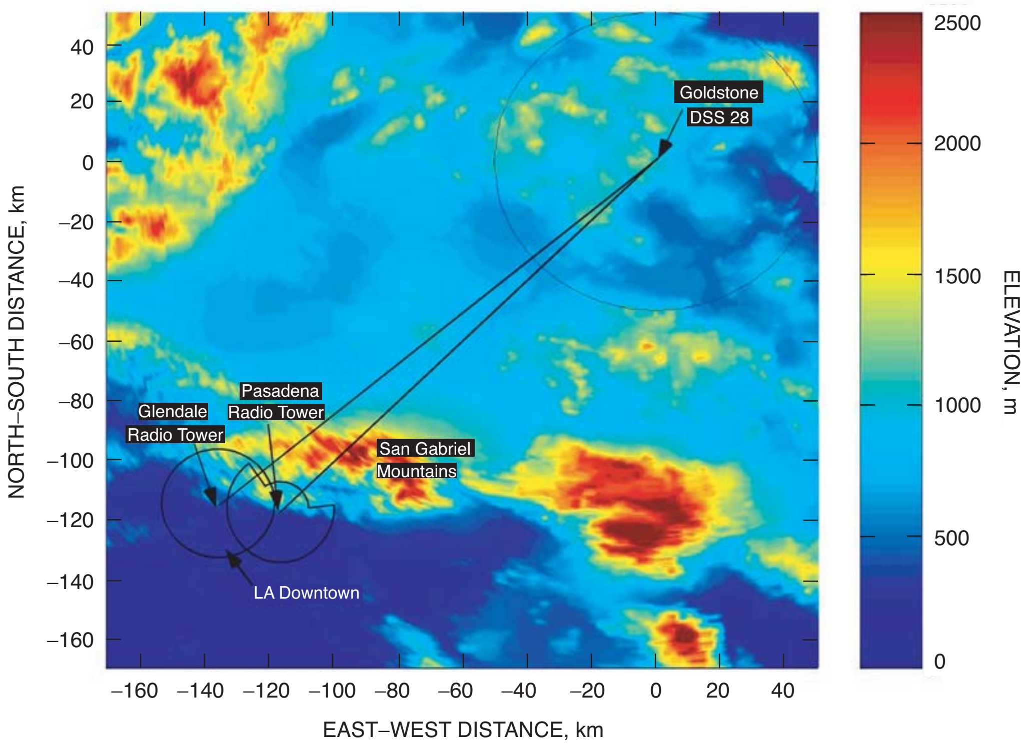

Fig. 1. Locations of the two airborne areas relative to DSS 28 (RAS) at Goldstone. Relative distances to DSS 28 are shown in the map. The color bar shows elevations with a range from 0 to 2500 m.

The radio astronomy station at DSS 28 is very sensitive to interference signals at the frequency of interest. An interfering signal is considered detrimental (harmful) if the level of unwanted emissions causes an increase of 10 percent in the measurement errors, relative to the errors due to the system noise alone [2].

The station tracks sources all over the sky, from as low as a 10-deg elevation angle to the zenith. The interference threshold level detrimental to radio astronomy continuum observations at 4995 GHz is $S_H = -241$ dBW/(m^{2}Hz) in spectral power flux density, assuming the RFI signal bandwidth is 10 MHz [2]. The maximum tolerable time during which interference may exceed the threshold of RAS is 5 percent from all interference sources, and 2 percent from a single source [3]. Since the public safety aeronautical mobile service will operate only during emergencies, we use 5 percent of time in this study to determine the coordination distance and propagation loss.

The model for RAS antenna gain, G, is given by

$$
\begin{aligned}
&G = (32 - 25\log\varphi)\ \text{dBi}, \quad && 1^\circ < \varphi < 47.8^\circ \\
&G = -10\ \text{dBi}, && 47.8^\circ < \varphi < 180^\circ
\end{aligned}
\qquad (1)
$$

The effect of an interfering signal clearly depends upon the angle of incidence relative to the main-beam axis (the boresight) of the antenna since the side-lobe gain, as represented by the model, varies from +32 to −10 dB as a function of this angle. However, it is useful to calculate threshold levels of detrimental interference for a particular side-lobe level, and for this it is suggested one use 0 dBi [2]. For the side-lobe model in Eq. (1), a value of 0 dBi, i.e., a gain equal to that of an isotropic radiator, occurs at 19.1 deg

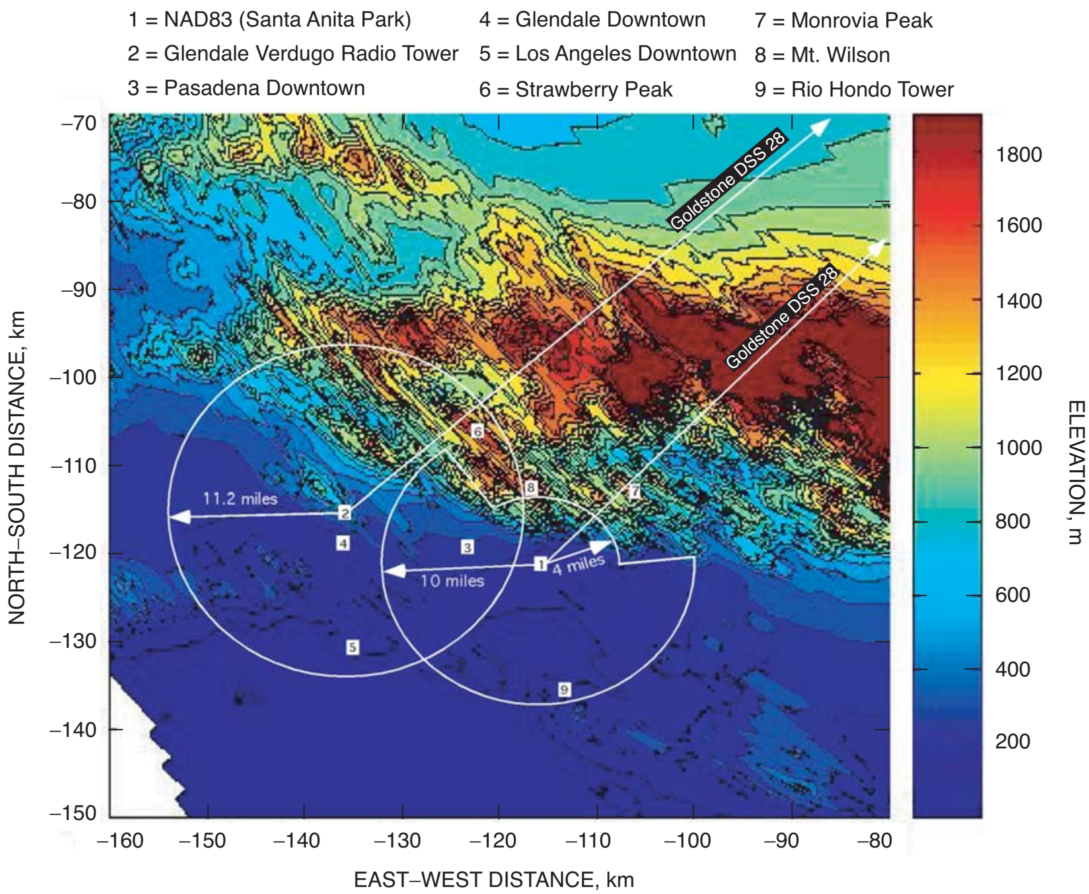

Fig. 2. Detailed airborne areas proposed by both city police departments. Glendale has a circular area with an 18.024-km (11.2-mile) radius, while the area proposed by Pasadena has radii of 7.21 km (4 miles) between –50 deg and +80 deg relative to true north and 16.093 km (10 miles) in the other direction from its receiving center.

from the main beam. In this study, we have assumed that there is a 0-dBi receiving antenna gain for the RAS station and that the airborne transmitter antenna points to the victim station [2].

Table 1 shows coordinates of DSS 28 and the receiving centers for both Glendale and Pasadena, azimuth angles relative to local north of DSS 28, and distances from DSS 28.

IV. Terrain Profile Analysis for Interference Paths

The key in this study is to find how large the propagation loss incurred by terrain shielding is from the two cites to DSS 28 in order to keep DSS 28 interference free. All trans-horizon propagation greatly depends on terrain features along the paths. Given two locations having the same interfering station and the same distance from the victim station, it is obvious that the interference propagation from the location isolated by a mountain will experience a higher propagation loss and will contribute lower interference than the area without terrain shielding.

The terrain profile analysis will help us identify whether a terrain profile along a great circle is a trans-horizon path or a line-of-sight path [4]. A line-of-sight path can be either with or without sub-path diffraction (i.e., with or without full first Fresnel zone clearance). Elevation angles of surrounding

Fig. 3. Two radio astronomy observation stations with 34-m dish antennas at Goldstone.

Table 1. Coordinates for RAS and receiving centers of Glendale and Pasadena.

Site	Latitude	Longitude	Azimuth angle, deg	Distance, km
DSS 28	35°14′17.8″N	116°46′44″W	—	—
Glendale Receiving Center (Verdugo Tower)	34°11′15″N	118°15′20″W	230	178
Pasadena Receiving Center (NAD83)	34°08′24.2″N	118°02′42.45″W	224	168

mountains relative to the transmitter and receiver are important parameters in controlling the interference propagation. We calculate the propagation loss by assuming that transmitters are located above any of these physical terrain points with an antenna height of the helicopter's flying elevation.

We assume that the helicopter flies at an elevation of 457 m (1500 ft) above the terrain surface, even though in the mountainous areas the helicopter may not fly as high above the terrain as it does above the flat areas. This assumption is equivalent to having a transmitter antenna height of 457 m (1500 ft) above the terrain.

In order to accurately determine whether a propagation path is line of sight or trans-horizon, we need to consider the surface atmospheric bending effect. Because the near-Earth space is filled with air, radio waves for a normal ray path will be refracted when they propagate through atmospheric gases that decrease in density with altitude. The nearly horizontally propagated waves, therefore, can reach locations beyond the line of sight. The severity of the bending is determined by the gradient of the refractive index near the Earth's surface. For radio waves with frequencies above 2 GHz, the atmospheric bending effects usually cannot be neglected. Thus, the propagating path that is a curved line above the Earth's surface needs to be modified into a straight line at a new coordinate system.

Using the effective Earth radius (4/3 Earth radius), we can modify the elevation of the terrain profile by shifting it to a relatively higher location so that the "stretched" trans-horizon propagation path can reach further. Due to use of the larger effective Earth radius, the modified Earth surface becomes less curved. Examples of modified terrain profiles between Goldstone DSS 28 and the receiving centers of both cities are shown in Figs. 4 and 5. The two receiving centers are also marked in the figures.

We can see that helicopter flights mainly occur on the left side of the mountains. There are several mountain peaks existing between the receiving centers and DSS 28. There is no direct line of sight from a helicopter operating in the Glendale or Pasadena area of operation to DSS 28, unless the helicopter flies to the top of the mountains, which is outside the airborne areas proposed by both cities.

V. Propagation Losses for Line-of-Sight and Trans-Horizon Paths

The interference propagation modes we investigated in this study include the line-of-sight mode and several trans-horizon propagation modes [5,6].

A fundamental parameter required for any realistic interference analysis of the interference between a transmitter and the victim receiver is the propagation loss from the transmitter to the receiver. The loss, L, is defined as [6]

$$L = P_t + G_t + G_r - P_r = \mathrm{EIRP} + G_r - P_r \text{ dB} \tag{2}$$

where P_r is the power received (or an acceptable RFI level for RAS), P_t is the power transmitted, G_t is the transmitter antenna gain, G_r is the receiver antenna gain, and EIRP is effective isotropically radiated power for the transmitter. For the line of sight, the propagation loss is dependent on the distance, while for the trans-horizon propagation, the loss mainly comes from the mountain shielding. Thus, the location with terrain shielding (i.e., larger loss) may sustain a higher transmitter power or a higher antenna gain toward the direction of propagation toward the Earth station without exceeding the protection criteria of the Earth station.

A. Line of Sight

The loss for a line-of-sight path is the basic transmission loss not exceeded for time percentage p percent:

$$L = 92.45 + 20 \log f + 20 \log d + E_s(p) + A_g \text{ dB} \tag{3}$$

where frequency, f, is in gigahertz; distance, d, is in kilometers; $E_s(p)$ is a correction term for multipath and focusing effects; and A_g is the gaseous absorption loss, as defined in International Telecommunication Union (ITU) Recommendation 452 [6].

Due to terrain shielding, only very limited areas have a direct line-of-sight view of the Deep Space Network (DSN) station. Most areas are blocked by mountains, and the interference signals can propagate only through a trans-horizon path along the great circle into the victim station.

B. Trans-Horizon

In addition to possible line-of-sight links, there are also non-line-of sight links due to several anomalous propagation modes that can propagate trans-horizontally for a very small percentage of the time [6].

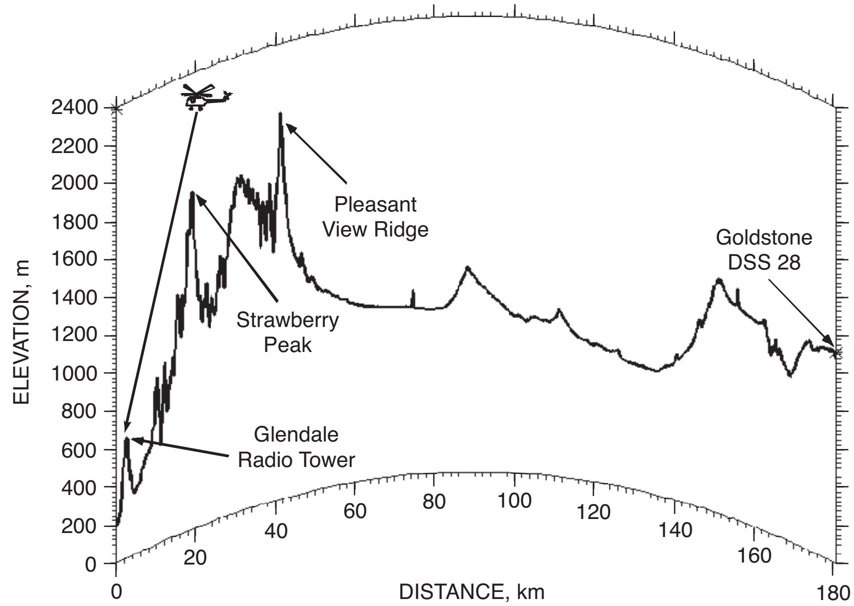

Fig. 4. Modified terrain profile between the Glendale receiving center (Verdugo radio tower) and DSS 28 (RAS) at Goldstone.

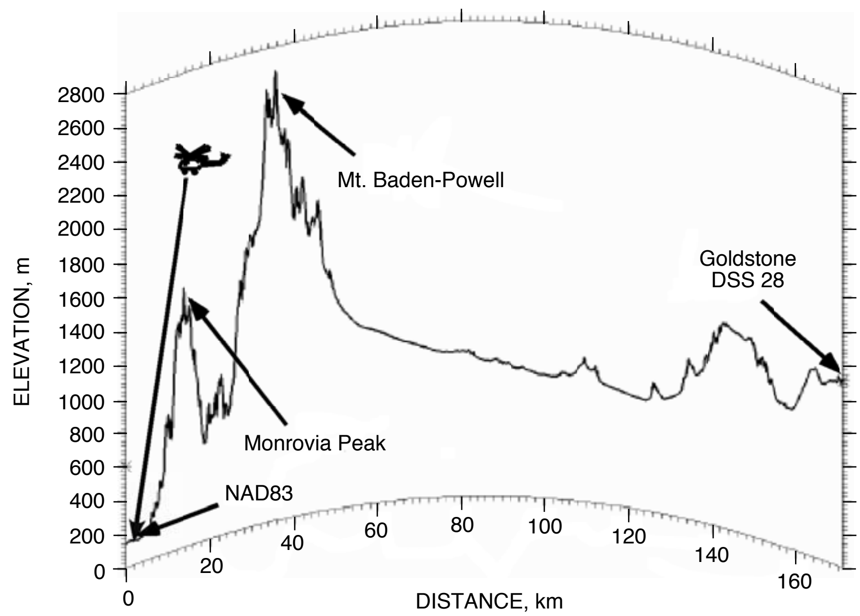

Fig. 5. Modified terrain profile between the Pasadena receiving center (NAD83, Santa Anita Park) and DSS 28 (RAS) at Goldstone.

Interference through these modes at a very small percent of the time can be significant. Anomalous mode propagation mechanisms depend on climate, signal frequency, time percentage of interest, distance, antenna height, terrain shape, and elevation angles. At any one time, a single mechanism (or more than one) may be present. Basically there are three types of anomalous modes of interest for this study. These modes are classified in ITU Recommendation P.452 as mode (1)—a clear air propagation mode along the great circle, as discussed in the following [6].

1. Terrain Diffraction. Interference signals can be diffracted by hilltops or rounded obstacles and propagate beyond the line of sight. Diffraction effects generally dominate a surrounding area (with a radius <100 km) and define the long-term signal levels. Diffraction losses increase with increasing signal frequency and obstacle sharpness, but have a weak dependence on the percentage of time. Diffraction loss over a hill can be calculated using a knife-edge model. The excess loss, $J(\nu)$, over a single knife edge is defined as [7]

$$J(\nu) = 6.9 + 20 \log \left(\sqrt{(\nu - 0.1)^2 + 1} + \nu - 0.1 \right) \text{ dB}, \quad (\nu > -0.78) \tag{4}$$

where ν is a geometry-related parameter as defined in ITU Recommendation 526 [7]. Total diffraction loss is the sum of the line-of-sight loss and excess diffraction loss.

2. Tropospheric Scatter. Interference signals can be scattered by the tropospheric particles or turbulence to propagate forward into a large distance beyond the line of sight. This mechanism defines the "background" interference level for longer paths (e.g., more than 100 to 150 km), where the diffraction field becomes very weak. For an Earth station as sensitive as the RAS station, interference via troposcatter can be significant. The loss from atmospheric scattering is defined as

$$L_{bs}(p) = 190 + L_f + 20 \log d + 0.573\theta - 0.15N_0 + L_c + A_g - 10.1\left[-\log(p/50)\right]^{0.7} \text{ dB} \tag{5}$$

The definitions for all parameters in the above equation can be found in ITU Recommendation 452 [6].

3. Ducting (Surface and Elevated). Due to surface heating and radiative cooling, inversion temperature layers often are generated on the ocean or flat coastal surface without large mountains. Interference signals can be trapped within this reflection layer at heights up to a few hundred meters and can propagate over a long distance (>500 km over the sea). Such signals can even exceed the equivalent "free space" level occasionally. The loss from ducting is defined as

$$L_{ba}(p) = A_f + A_d(p) + A_g \text{ dB} \tag{6}$$

Generally, for short transmission paths extending only slightly beyond the horizon, terrain diffraction is the dominant mechanism in most cases. Conversely, for longer paths (more than 100 km), scattering and ducting mechanisms need to be taken into account if there are no large mountains in between.

C. Propagation Loss Calculation

We have used the Trans-Horizon Interference Propagation Loss (TRIPL) software [5],[6] developed recently at JPL based on ITU-R P-452 [6] and high-resolution (30-m) terrain data, for this calculation. The parameters used in this calculation are given in Table 2. The smallest loss is selected from losses calculated for three modes along all azimuth profiles. Then the three-dimensional (3-D) propagation loss maps are constructed relative to DSS 28.

Figure 6 shows propagation loss profiles along a 230-deg azimuth angle cutting through the Verdugo receiving tower. The terrain elevation profile from DSS 28 to the Glendale receiving center also is shown using the left vertical axis. We can see there is dependence of the loss magnitude on the elevation of the helicopter (transmitter). Transmission from a lower elevation has a larger propagation loss, while

[6] C. Ho, K. Angkasa, P. Kinman, and T. Peng, *A Computer Software in Generating Trans-Horizon Interference Propagation Loss (THIPL) Maps around DSN Stations*, JPL D-31787 (internal document), Jet Propulsion Laboratory, Pasadena, California, April 5, 2005.

Table 2. Parameters used for trans-horizon propagation loss calculation.

Parameter	Value
Frequency	4.99 GHz
Percentage of time	1.0%/5.0%
Transmitter height	152 m/305 m/457 m (500 ft/1000 ft/1500 ft) above the terrain
Transmitter antenna gain	5.5 dBi
Transmitter power	5 W
Transmitter bandwidth	8 MHz
Receiver height	20 m
Receiver antenna (RAS) gain	0 dBi
Refractivity	330 (N units)
Refractivity gradient	45 (N units/km)

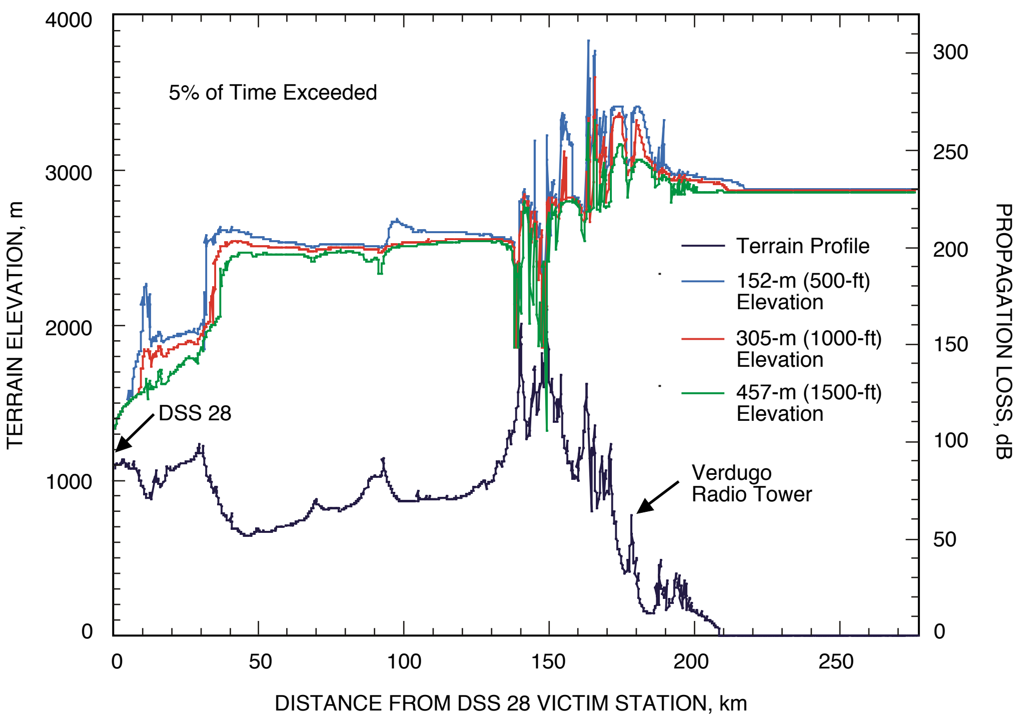

Fig. 6. Propagation loss profiles as a function of distance between DSS 28 (RAS) and the transmitter (airborne helicopter with various elevations) for a profile (azimuth 230 deg) through the Glendale Radio Tower.

transmission from a higher elevation has a smaller loss because of less mountain shielding. Figure 7 shows the propagation loss dependence on the percentage of time for a fixed flying elevation (305 m [1000 ft] above the terrain). A smaller percentage of time corresponds to a smaller propagation loss because an anomalous mode can generate smaller attenuation at a very small percentage of the time. For a percentage of time that is large, this loss can become huge.

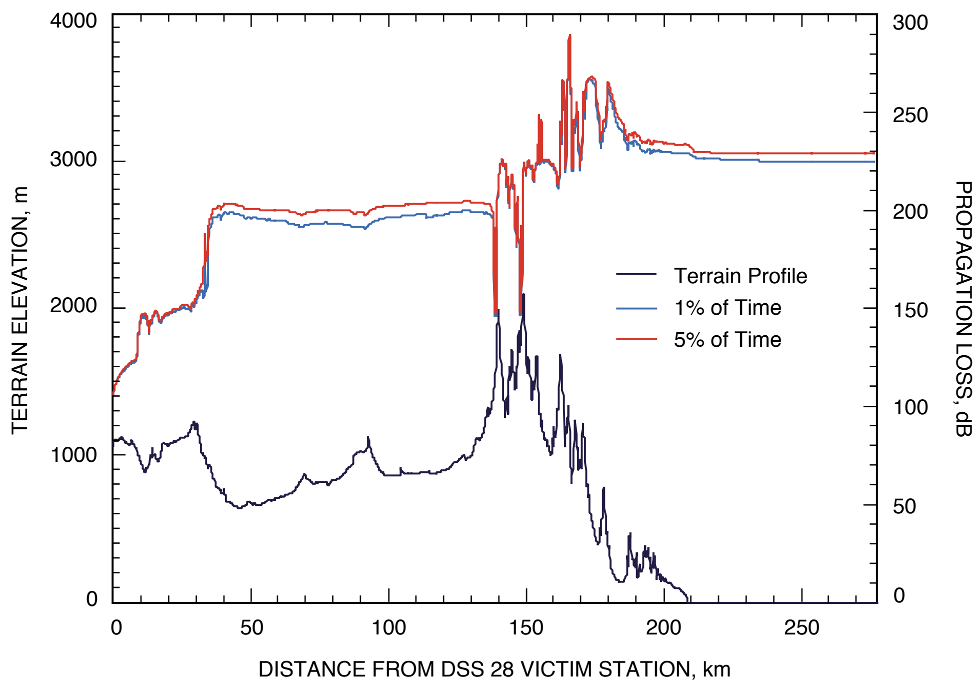

Fig. 7. Propagation loss profiles as a function of distance between DSS 28 (RAS) and the transmitter (airborne helicopter with 305-m (1000-ft) elevations for various percentages of time) for a profile (azimuth 230 deg) through the Glendale Radio Tower.

D. Minimum Required Propagation Loss

Using the interference threshold level defined in ITU Recommendation 769 [2] and the EIRP of airborne transmitting systems in both cities, we can determine the minimum propagation loss required in order to keep interference under the threshold of RAS. The acceptable RFI level for RAS at 4.9 GHz is $P_{sfd} = -241$ dB (W/m^{2}Hz) in power spectral flux density for DSS 28 [2]. The corresponding received power spectral density, P_{sd} dB (W/Hz), at DSS 28 should be

$$P_{sd} \text{ (W/Hz)} = A_{eff}(\text{m}^2) \times P_{sfd} \text{ (W/m}^2\text{Hz)} \tag{7}$$

where A_{eff} is the effective antenna area for DSS 28. Also, from Eq. (2), we have

$$P_{sd}(\text{W/Hz}) = \frac{\text{EIRP (W/Hz)} \times G_r}{L} = \frac{\text{EIRP (W/Hz)} \times 4\pi A_{eff}(\text{m}^2)}{\lambda^2(\text{m}^2)L} \tag{8}$$

because $G_r = 4\pi A_{eff}/\lambda^2$. Thus, from both Eqs. (7) and (8), we have

$$P_{sfd}\left(\text{W/m}^2\text{Hz}\right) = \text{EIRP (W/Hz)} - L + 10\log\left(\frac{4\pi}{\lambda^2(\text{m}^2)}\right) \tag{9}$$

Converting it into dB (using $\lambda = 0.06$ m at 4.9 GHz),

$$L \text{ (dB)} = \text{EIRP (dBW/Hz)} - P_{sfd} \text{ (dBW/m}^2\text{Hz)} + 35.4 \text{ (dBm}^{-2}\text{) dB} \tag{10}$$

In this study, for a transmitter with a 5-W output power over an 8-MHz bandwidth and a 5.5-dB antenna gain, we have

$$\text{EIRP} = 10\log(5)\ \text{(dBW)} - 10\log(8\times 10^6)\ \text{(dB-Hz)} + 5.5\ \text{(dB)} = -56.5\ \text{(dBW/Hz)} \tag{11}$$

Thus, the minimum required total loss is

$$L = -56.5\ \text{(dBW/Hz)} + 241\ (\text{dBm}^2\text{Hz/W}) + 35.4\ (\text{dBm}^{-2}) \approx 220\ \text{dB} \tag{12}$$

We use the minimum propagation loss to define the coordination area in the loss maps. The coordination area is an area in which the transmitted interference level exceeds the acceptable threshold of the victim receiver a certain percentage of time. In this study, it is an exclusion zone for the airborne transmission.

In Fig. 8, the propagation loss profile calculated along an azimuth angle of 224 deg is shown. Starting from DSS 28, this profile cuts through the Pasadena receiving center. Losses are calculated for two helicopter elevations: 305 m (1000 ft) and 457 m (1500 ft) above the terrain less than 5 percent of the time. Figure 8 also shows the terrain profile and the minimum required propagation loss. We can see that at mountain tops and mountain sides facing DSS 28 there are smaller losses. At mountain sides facing away from DSS 28 or inside valleys, there are larger propagation losses. Also, transmission from higher elevations has smaller losses.

Figure 9 shows loss profiles along a 229-deg azimuth angle relative to the local north of DSS 28. Two loss profiles cut through the west border of the airborne area. The airborne area proposed by the Pasadena Police Department is also marked out. We can see that within the airborne area the propagation loss from a hilltop is lower than the required value (220 dB).

Figure 10 is a map of the three-dimensional propagation loss around the airborne areas proposed by Glendale and Pasadena. The right-side color bar gives the loss range from 100 dB to 300 dB. Using the minimum propagation loss we calculated, an exclusion area is drawn in the map. We can see that the exclusion zone border cuts through a slight area for Pasadena, but a significant area for Glendale.

Based on the minimum propagation loss we calculated, an exclusion zone around Goldstone for the 4.9-GHz air mobile transmission was defined in the terrain map, as shown in Fig. 11. We used the key points listed in Table 3 to define the exact locations of the border line for the exclusion zone. This area should be restricted from access by helicopter transmission. Here we would like to emphasize that this result is obtained under the assumption of a 457-m (1500-ft) flight height and a 5 percent time of weather (see Table 3).

VI. Summary and Suggestions

This study evaluated potential RFI from the airborne transmitters in the cities of Glendale and Pasadena to the radio astronomy station at Goldstone at 4.9 GHz. It defined the necessary coordination area for protecting the Goldstone radio astronomy station. Propagation losses over the terrain between both cities and Goldstone have been calculated using the THIPL software recently developed at JPL and high-resolution terrain data. Study results and suggestions for a modification to the airborne areas proposed by both city police departments are summarized below.

The radio astronomy service station (DSS 28) at Goldstone has a very sensitive RFI threshold at 4.9 GHz. The Glendale airborne center is about 178 km away from the Goldstone DSS 28 (RAS) site, with an azimuth angle of 230 deg with respect to the local north of DSS 28, and the Pasadena airborne center is about 168 km away, with an azimuth angle of 224 deg.

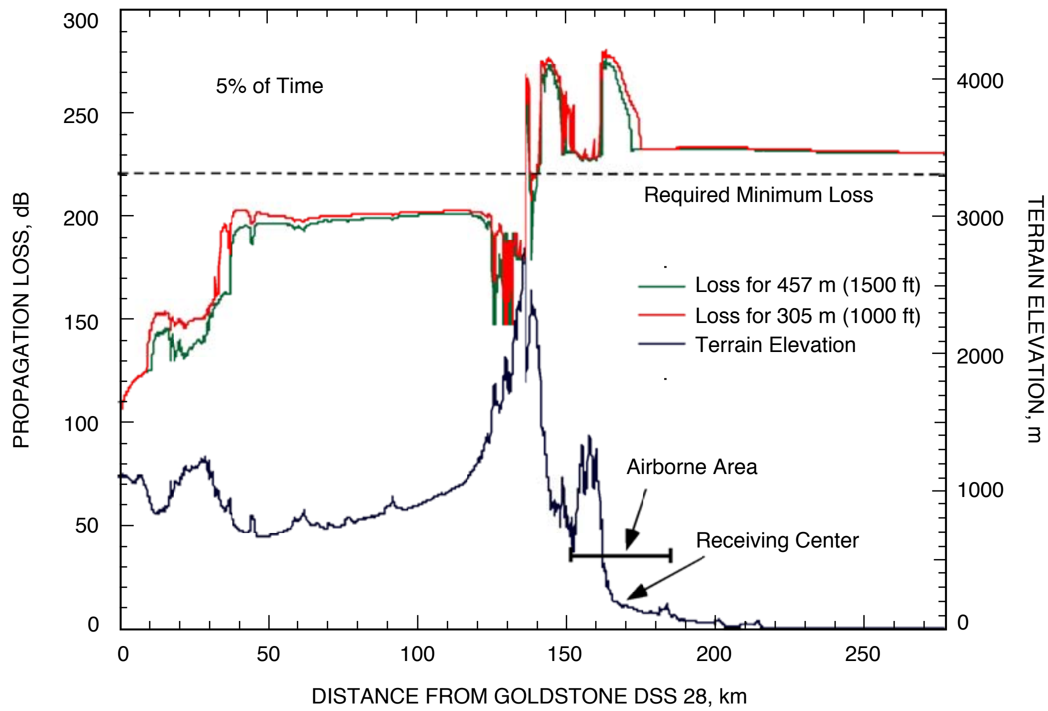

Fig. 8. Loss profile along azimuth 224 deg relative to the local north of DSS 28. The profile is through the central receiving tower of the airborne area proposed by the Pasadena Police Department (airborne helicopter with various elevations).

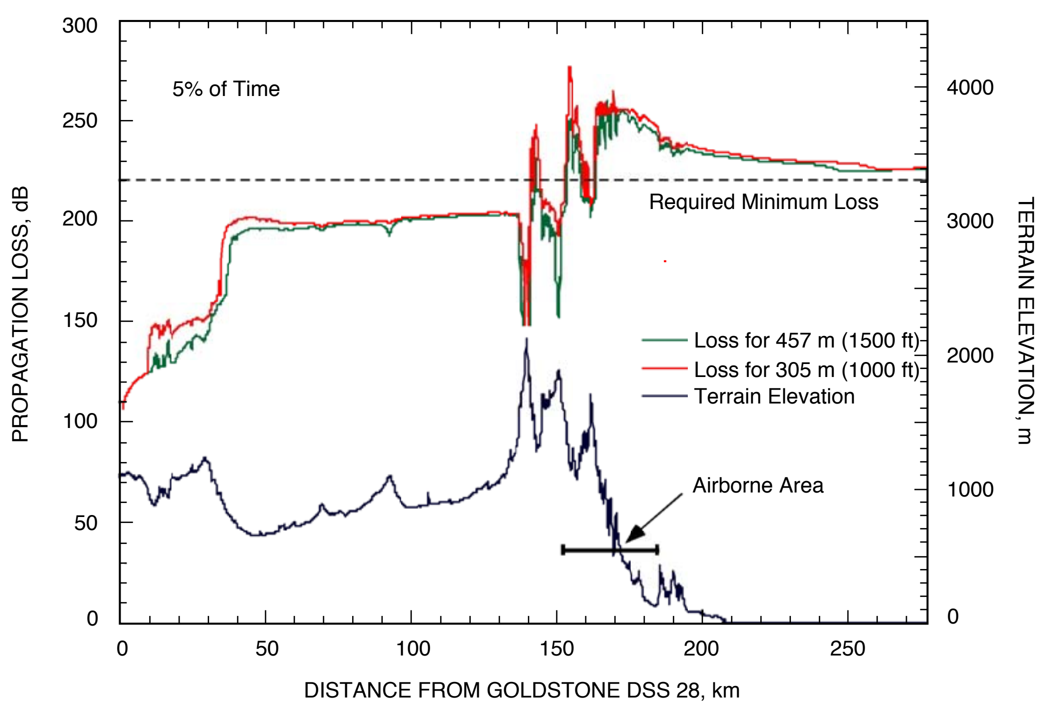

Fig. 9. Loss profile along azimuth 229 deg relative to the local north of DSS 28. The profile is through the west border of the airborne area proposed by the Pasadena Police Department (airborne helicopter with various elevations).

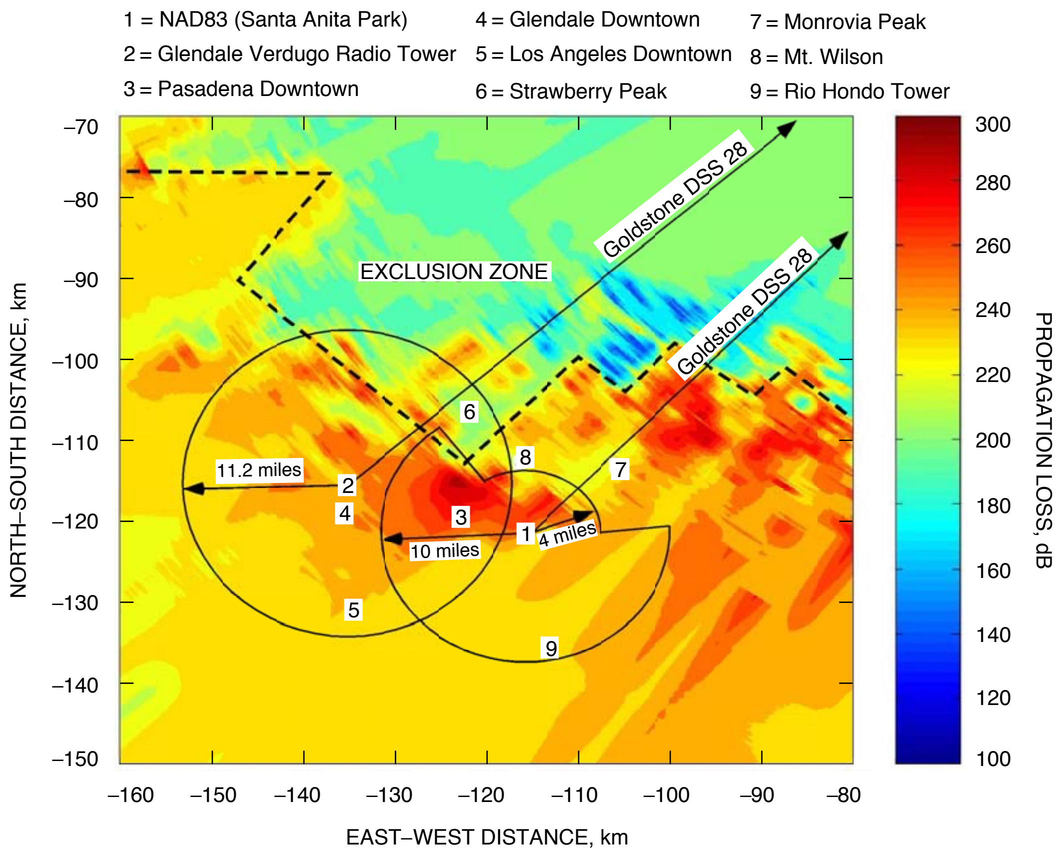

Fig. 10. Propagation loss map around airborne areas for both cities. An exclusion zone is drawn based on the 220-dB loss requirement. We can see that the airborne areas proposed by both cities have some overlap with the exclusion zone we calculated.

For the worst case of transmitter power (5 W), a minimum propagation loss of 220 dB is required between DSS 28 and the helicopter in order to keep interference under the acceptable level. An exclusion zone has been defined in the maps. (If the helicopter operates in the exclusion zone, the resulting interference level will exceed the acceptable level.)

Even though there is no direct line-of-sight link between the transmitters within the proposed airborne areas and DSS 28 (RAS), interference signals still can propagate trans-horizontally by anomalous modes with less propagation loss for a small percent of time. Terrain profile analysis shows that the San Gabriel Mountains can block most of the interference signals. Although there are large propagation losses in shadow areas that correspond to valleys away from DSS 28, transmission from the tops of mountains or in ridges toward DSS 28 will suffer small losses.

Due to mountain shielding, helicopter transmissions within most of the airborne area proposed by both city police departments will in general not cause interference to the RAS stations, except for the following: a significant airborne area in the northeast mountain region proposed by Glendale and a small area in the northwest region of the airborne area proposed by Pasadena in which transmission will interfere with the RAS in Goldstone if the helicopter is flying about 457 m (1500 ft) above the terrain.

For Glendale, we suggest modification of the helicopter airborne area by having a 8.047-km (5-mile) radius between −10 deg and +90 deg relative to the local north of the receiving center, and an 18.024-km

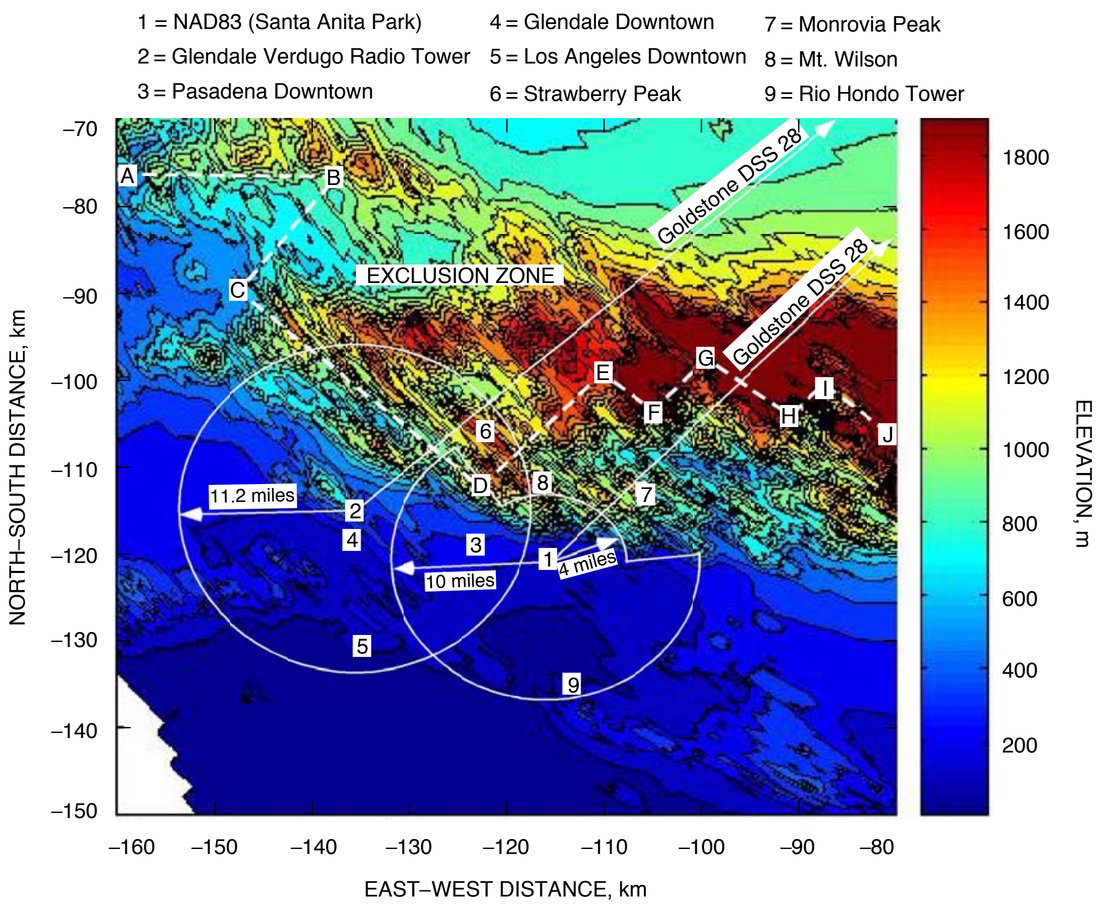

Fig. 11. Exclusion zone in the terrain map around both Glendale and Pasadena. Key points defining the exclusion zone border are marked. We can see that the airborne areas proposed by both cities have some overlap with the exclusion zone.

Table 3. Key points for defined exclusion zone.

Key point	Latitude (N)	Longitude (W)
A	34°29′	118°32′
B	34°29′	118°20′
C	34°21′	118°23′
D	34°12′	118°07′
E	34°19′	118°00′
F	34°18′	117°55′
G	34°20′	117°52′
H	34°18′	117°45′
I	34°19′	117°43′
J	34°17′	117°39′

(11.2-mile) radius for other directions. For Pasadena, we suggest having a modified airborne area with a 7.21-km (4-mile) radius between −55 deg and +80 deg, and a 16.093-km (10-mile) radius between the remaining azimuth angles.

Acknowledgments

The authors thank the following individuals for contributing information used in this study: Reid Drummond of the Goldstone Deep Space Communication Complex; Paul Robbins, Valery Altunin, and Tom Kuiper from JPL; and Howard Epstein from Consolidated Spectrum Services. The authors also thank Anil Kantak for reviewing this article.

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