Assessment of Weather Effects on DSN Antenna Tracking at Ka-band

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***Abstract*— This paper presents the findings of weather statistics at the three sites of the NASA Deep Space Network (DSN) and the effect of weather on antenna tracking performance at Ka-band frequency, based on operational data. Both aspects of weather effects are examined: the distribution statistics of wind patterns and the antenna pointing performance (and hence received signal level) in the presence of high winds. Due to smaller beamwidth inherent in the large aperture of DSN antennas (34-m diameter for Ka-band reception), a small offset in antenna pointing caused by winds could significantly reduce the received signal power and potentially result in a data outage. Some past models indicated a strong wind impact. Winds, even at a moderately low speed of 16 km/hr (10 mph), can distort the antenna's main reflector and cause signal degradation by as much as 2.9 dB at Ka-band frequency. Establishing the actual performance that is based on operational data is very important for mission operation planning, especially for missions that are power-constrained and thus need to conserve the link margin. Finding an optimal link margin setting that is neither wasteful nor insufficient would enable maximum data return for missions. The findings presented in this paper show that there are significant differences in the weather among the three DSN sites; thus, one possible strategy to maximize data return is to allocate more tracking at sites with low winds. Another surprising finding is that the wind effect is not as large as previously thought. Only small signal degradation (0.8 dB) was observed for wind speeds up to 50 km/hr.**

Keywords- Deep Space Network, Ka-band tracking, weather effect, antenna pointing, performance analysis.

I. INTRODUCTION

The communications between NASA mission operations team and their respective spacecraft venturing into deep space is supported by the NASA Deep Space Network (DSN). Over time, the S- and X-band spectrum allocated for deep space communications has become more and more crowded. By going to a higher operating frequency at Ka-band (32 GHz), missions would be less exposed to potential radio frequency interference (RFI). At the same time, they can realize a better performance with higher antenna gain [1].

One potential drawback however is the higher sensitivity to weather. Winds can affect antenna pointing, pushing it away from the maximum gain position. At Ka-band, the antenna beamwidth is about four times smaller than that at X-band. A small antenna pointing error at Ka-band could significantly reduce the received signal power and potentially result in more data outages. Some past models indicated a strong wind impact on the DSN 34-m antennas. They predicted that even at moderately low winds of 16 km/hr (10 mph), the signal degradation could be as much as 2.9 dB due to antenna main reflector distortion [2]. This posed a great concern to mission operations planning, especially for missions that have limited link margin; thus, prompted the interest to validate such model with actual operational data. Knowing the true operational performance would allow missions to set an appropriate link margin that is neither unnecessarily large nor insufficient. This in turn enables maximum data return.

The following sections describe the way data are processed and present the results of analysis. Section II discusses the data used for the analysis. Section III shows the statistics of wind measurements at the three main DSN tracking sites. Section IV presents the wind effect on received signal, followed by the effect on antenna pointing error in Section V. The final section provides a summary on the findings.

II. DATA PROCESSING

Data collected and used for this analysis are taken from the DSN performance dashboards, as reported in [3]. The dashboards capture performance monitor data for every spacecraft tracking pass conducted by the DSN antennas. Specific monitor data used in this analysis include wind speeds, antenna pointing errors, and received signal to noise ratio (SNR). Data collected from the tracking of Kepler spacecraft, which employs Ka-band for its downlink telemetry, are used to correlate the SNR fluctuation with antenna pointing error and wind speed. Observed wind speed data collected over a period of January - June 2011 are used to compute the exceedance probability distribution function at each of the three DSN sites.

III. WEATHER STATISTICS

Figure 1 presents a plot of the average wind speed observed for each tracking pass from January to June, 2011. From this data set, the exceedance probability distribution of wind speed are derived and presented in Figure 2. One can see distinctively different statistics for Goldstone compared to those at Canberra and Madrid. Goldstone is significantly windier than the other two sites. The median wind speed at Goldstone is 15 km/hr, more than twice the median wind

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speed of 7 km/hr at Canberra and Madrid. Five percent of the time, the wind speed at Goldstone is greater than 40 km/hr, but at Canberra and Madrid it exceeds only 15-18 km/hr for the same percentage of time.

Given this highly unbalanced distribution, one possible strategy in optimizing the mission data return would be to schedule most of the tracking passes over Canberra and Madrid complexes, if the view periods at all sites are equal. However, the weather (clouds and rain) at Canberra and Madrid is significantly worse than at Goldstone [4], so that somewhat offsets the benefits of having lower wind speeds.

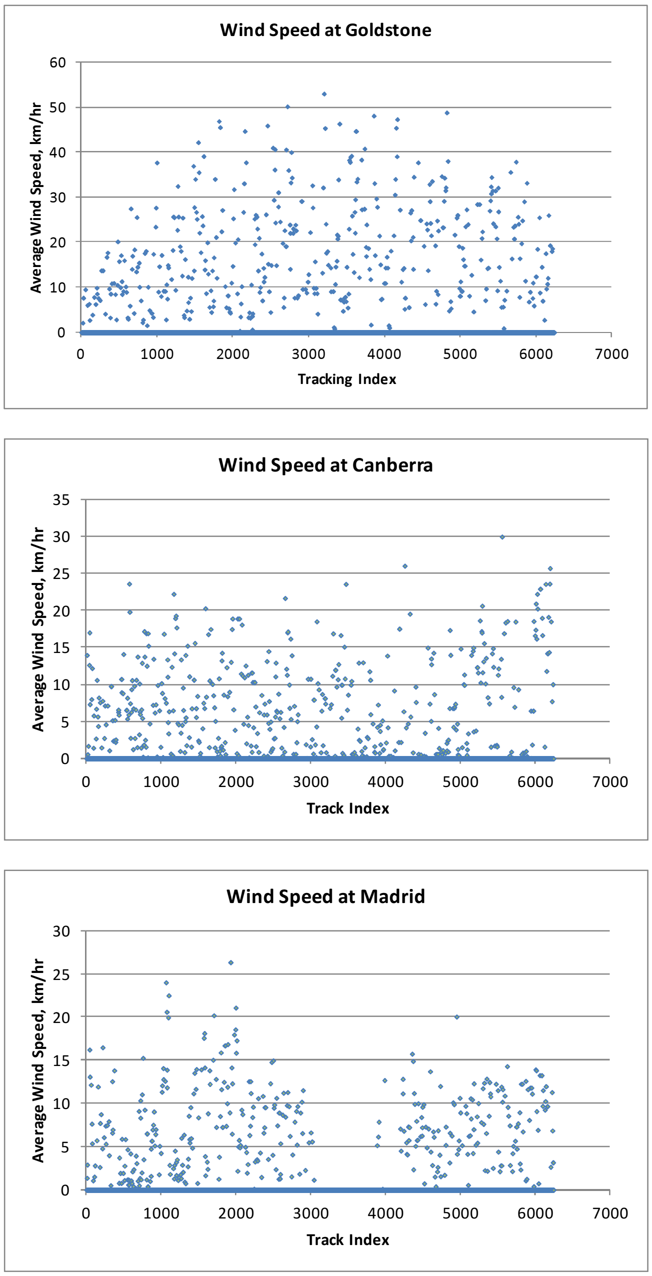

Figure 1. Wind speed distribution at three tracking complexes – Goldstone, Canberra, and Madrid.

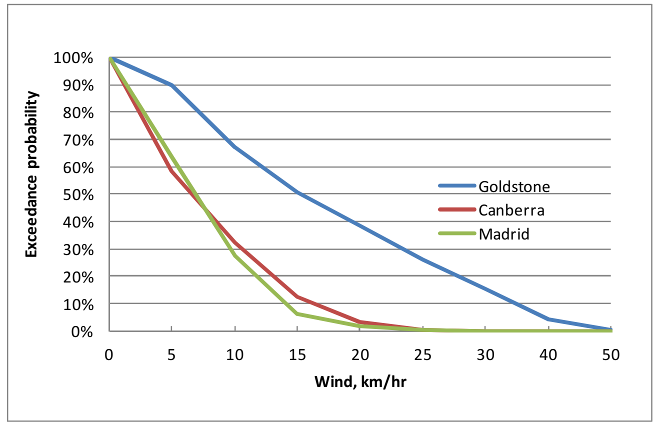

Figure 2. Exceedance probability distribution of wind speed at three tracking complexes.

IV. WIND EFFECT ON SIGNAL RECEPTION

In the current mission set that the DSN supports, Kepler is the only mission that uses Ka-band (32 GHz) for telemetry downlink. The spacecraft, launched in March 2009, spends most of its time searching for exoplanets (planets orbiting other stars in our galaxy) and only downlinks the data to Earth roughly once a month. Thus, Ka-band telemetry tracks are rather limited, making the observed passes with high winds much less common. Figure 3 presents the measurement of received signal to noise ratio (SNR) for both carrier and symbol data, along with wind speeds during the track for about three hours on day-of-year (DOY) 241/2011. On this particular day, wind speed averaged 18 km/hr, with relatively large gusts of up to 50 km/hr. Note also that there were several step-like changes in the carrier SNR profile, but that phenomenon was not reflected in the symbol SNR. Unfortunately, the cause for such jumps is not well understood. Because of these jumps, the carrier SNR data were not used for correlation analysis.

Over the three hours of tracking, the antenna elevation changed from 40 to 70 degrees. This caused a change in the system noise temperature of about 10 kelvins and resulted in a nearly 1-dB increase in SNR from the beginning to the end of the track. The antenna gain also changed slightly over this elevation range. Both changes were removed in the correlation analysis so that their effects would not mask the impact of the wind.

Figure 4 shows the correlation of received symbol SNR relative to the wind speed. Within the inherent fluctuation of 0.8 dB standard deviation in the symbol SNR measurements, a linear fit of the data indicates the degradation caused by winds at 20 km/hr is about 0.3 dB. For winds up to 50 km/hr, the degradation is within 0.8 dB, much less than predicted in past models.

Combining this observation with the exceedance distribution function in Figure 2 where the 50 km/hr wind speed threshold is at the end of the distribution curves for all three sites, it seems that a very high percentage of tracking passes (~99%) should only experience at most 0.8 dB degradation from the winds, from all causes including main reflector distortion and pointing errors.

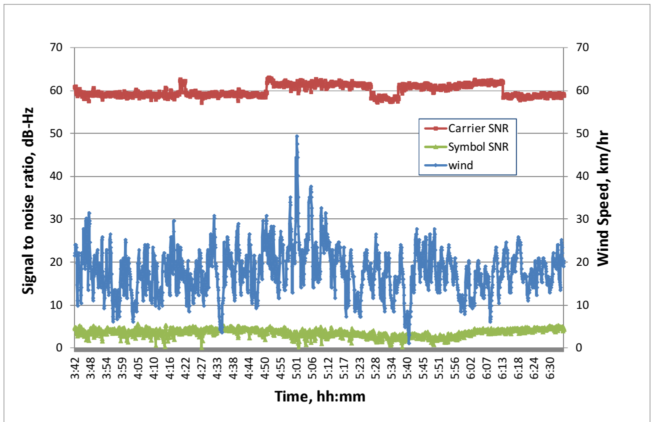

Figure 3. Signal SNR and wind speed measurements on DOY 241/2011 track with Kepler spacecraft at Ka-band.

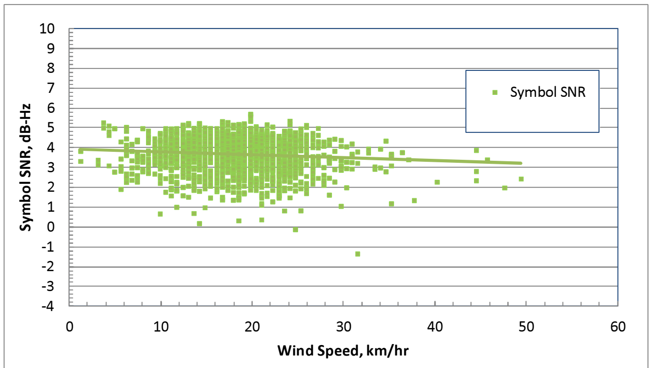

Figure 4. Correlation of symbol SNR against wind speed.

V. WIND EFFECT ON ANTENNA POINTING ERROR

To examine the wind effect on antenna pointing, we look at the correlation of wind speed and pointing error. The pointing error is derived from the conical scanning offset. Conical scanning, often referred to as conscan, is a method to keep the antenna on point by continuously circling the antenna around the predicted position. As the antenna traces this conscan circle, the received signal power varies as a function of the radial distance between the instantaneous antenna position and the spacecraft's true position. This variation in signal power allows for determination of pointing offset, and enables correction at the next scan cycle. The conscan offset measurements are used to infer the wind's effect on antenna pointing.

In the earlier data set on DOY241/2011 as discussed in Section IV, conscan was not enabled; thus, we could not analyze the correlation of pointing errors on that particular windy date. However, on the DOY 177/2011 pass, winds up to 20 km/hr were observed and conscan offset data were available for analysis, as shown in Figure 5.

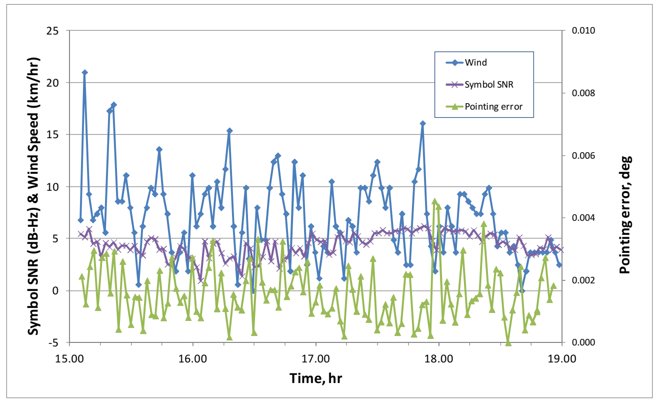

Figure 5. SNR, pointing error and wind speed on pass DOY 177/2011.

Figure 6 shows a correlation of antenna pointing error and received SNR versus wind speed. The linear fit for the pointing errors is almost a constant, indicating a weak correlation. The change in pointing error is less than 0.0002 deg for wind speed ranges from zero to 20 km/hr. This error would have translated to a very small additional pointing loss of only 0.05 dB around the operating point for the beamwidth of a 34-m antenna at Ka-band.

Note that the linear fit for the symbol SNR seems to be affected by the high noise level of symbol SNR measurements, and does not accurately reflect the expected behavior. It shows an increase in SNR for greater wind speeds and slightly increased pointing errors. As such, the indicated change of 0.6 dB from 0 to 20 km/hr wind does not appear to be real. One conclusion we can draw from the SNR data is that there seems to be no degradation observed.

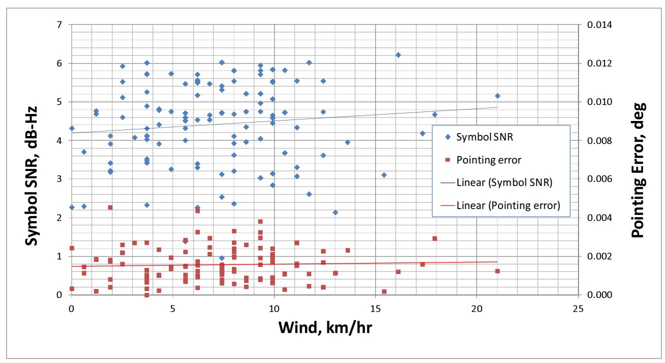

Figure 6. Correlation of received symbol signal to noise ratio and pointing error to wind speed.

VI. CONCLUSION

From the analysis of weather data collected at the three main DSN sites, it is established that tracking antennas at Goldstone are subject to significantly windier conditions than those at Canberra and Madrid. Missions, especially those that operate at low link margin, can optimize data return by having more tracking scheduled at Canberra and Madrid, assuming that the view period is equal at all three sites.

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Further analysis of the wind effect on symbol SNR and pointing error indicates a minimum effect. Only a small increase in pointing error, 0.0002 deg, was observed with wind speeds up to 20 km/hr. Symbol SNR was estimated to degrade by no more than 0.8 dB for winds up to 50 km/hr, and possibly not at all at wind speeds up to 20 km/hr. These estimates, however, are subject to a comparable SNR measurement uncertainty of 0.8 dB standard deviation.

The finding shows a much more robust Ka-band operation under windy condition than previously believed. This is a testament to the inherent mechanical stability and excellent tracking performance of the large NASA DSN antennas.

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