# PATH LENGTH VARIATIONS DUE TO CHANGES IN TROPOSPHERIC REFRACTION

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Abstract

An experiment is described in which microwave Doppler is used to determine very small changes in path length to spacecraft tracked by the Deep Space Tracking Network (DSN). The experiment was carried out to test the detection capabilities of the DSN system to gravitational radiation of very low frequency ($10^{-2}$-$10^{-4}$ Hz). In this work spectral analysis of Doppler variations were performed for periods over 4 hours and more.

These results indicated that one of major sources of noise was due to rapid variations in tropospheric refraction. The results obtained a differential path length variation, $\Delta L/L$, of 1 part in $10^{14}$ for periods between 100 and 1 000 seconds.

Doppler spectra are shown and a general discussion of the experiment is given.

## 1. INTRODUCTION

In experiments first begun in 1969 attempts have been made to measure very low frequency gravitational radiation wave pulses and isotropic cosmic background using Doppler data from the Nasa Deep Space Tracking Network (Anderson, 1971, 1974, 1977). Because the system has certain unique response functions to gravitational radiation, it is possible to spectrally filter the data to improve the sensitivity of the measurement and uniquely determine the result. The two frequency X/S band systems presently envisioned allow for an elimination of space plasma effects, but do not allow for corrections of variations in tropospheric refraction. It therefore became essential to understand these tropospheric effects and to provide means of measuring and modelling them correctly.

Work has begun towards these goals. In a paper by Moran and Pen-



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field, 1976, an evaluation of the use of early water vapor radiometers to determine their capability to measure tropospheric path length propogation was made. Comparison with radiosonde profile measurements gave a rms of 2 - 5 cm absolute errors while those of the radiometers gave a rms of 1.5 cm in the correlation between measured brightness temperature and the calculated wet path length at zenith.

## 2. TROPOSPHERIC PATH LENGTH VARIATIONS

Variations of tropospheric path length propagation were studied by Hargrave and Shaw, 1978, using the 5 km baseline of the Cambridge Radio Telescope. Interpreting their data in terms of time variations indicated that path length differences amounting to 0.8 cm over periods of 5 000 seconds were typical (Callahan, 1978). It was also pointed out, however, that under favorable conditions, such as dense fog, and under other conditions where atmospheric convection is limited, measured path length variations were reduced by as much as 20 times this value. In other words, there is large variability in the tropospheric path length variation at different times under different conditions.

Figure 1 shows the type of data analysis used for the present study. Here is plotted the spectra of Doppler variations as received from Pioneer 9 under good conditions over an interval of 4.5 hours. Using the relationship for path length variation:

$$\Delta L/L = \frac{\lambda_{sb} \cdot A_s \cdot T_s}{4 \pi c R} \tag{1}$$

where:

$\lambda_{sb}$ = microwave Doppler wave length = 13 cm.

$A_s$ = amplitude of spectral value (Hz).

$T_s$ = period of spectral value (sec).

c = velocity of light (cm/sec).

R = light time to space craft (sec).

We obtain an estimate of total path length variation over any spectral period available from the analysis.

A flat spectrum is generally observed in the interval between 100-1 000 seconds, indicating that the path length error is proportional to T in this range. Beyond 1 000 seconds the spectrum rises, indicating

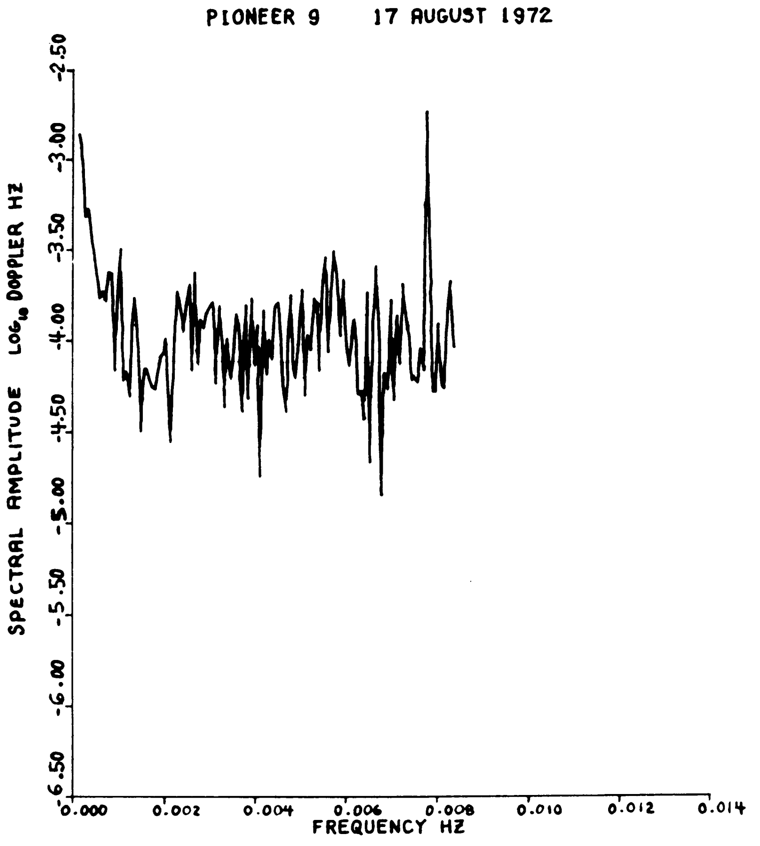


Figure 1. Amplitude Spectrum of Doppler variations from the Pioneer 9 spacecraft as tracked by DSN (Anderson, 1976).

that path error becomes proportional to $T^2$. The sharp peak in the Pioneer spectra at 129 seconds is a periodic offset of the spacecraft's antenna of 0.24 cm due to spacecraft rotation.

A comparison of results on measured tropospheric path length variation is given in Figure 2. The absolute variation $\Delta L$ (cm) is given for typical measured conditions and most favorable measured conditions. The measured results of Doppler variations from Pioneer 9 are included. The total effect on differential path length variation $\Delta L/L$ is given for a spacecraft at 10 AU. distance.

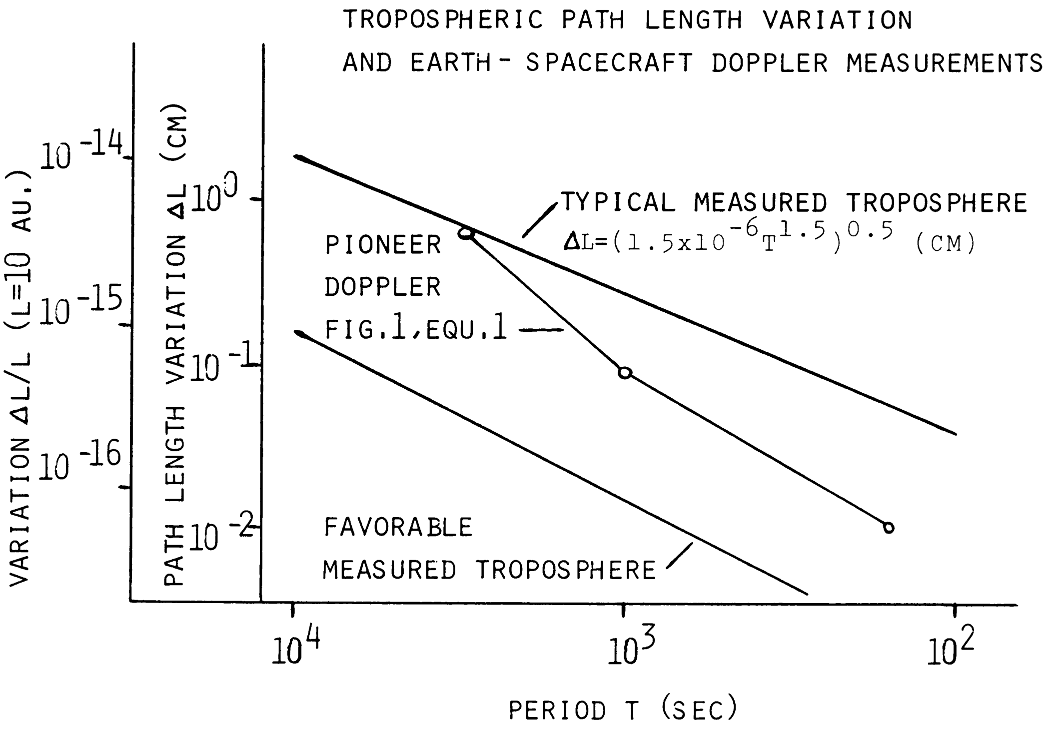


Figure 2. Tropospheric path length variability as measured by Thompson, et al, 1975, and Hargrave and Shaw, 1978 compared with Doppler path length variations.

## 3. CONCLUSIONS

The method of Doppler tracking of spacecraft provides a means of monitoring tropospheric path length variations. Under favorable tropospheric conditions and/or by monitoring these variations, measurements of the total path length variation, $\Delta L/L$, to less than 1 part in $10^{15}$ can be obtained when tracking spacecraft at a distance of 5 AU and beyond.

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REFERENCES

1. Anderson, A. J. (1971) Probability of long period gravitational radiation, Nature, 229, 547-548.

2. Anderson, A. J. (1974) A study of the anomalous effects in the spectra of Doppler from the DSN, JPL MEM, 391-560.

3. Anderson, A. J. (1977) Detection of gravitational waves by spacecraft Doppler data, in Experimental Gravitation, 235-246.

4. Callahan. P. S. (1978) A first look at errors from small scale tropospheric fluctuations. JPL IOM 315, 1-272.

5. Hargrave, P. L. and Shaw, L. J. (1978) Large-scale tropospheric irregularities and their effect on Radio Astronomy seeing. Mon. Not. Roy. Astr. Soc., 182, 233.

6. Moran, J. M. and H. Penfield (1976) Test and evaluation of water vaper radiometers and determination of their capability to measure tropospheric propagation path length. Final Report, Smithsonian Astrophysical Obs., Cambridge, Mass.

7. Thompson, M. C., Wood, L. E., Janes, H. B., and Smith, D. (1975) Phase and Amplitude Scintillations in the 10 to 40 GHz Band. IEEE Trans. on Ant. and Prop. 23, 190.

DISCUSSION

K. Poder: You are transmitting over a 500 second transmission line path, which must be a long one, and even a very small gradient will give a correction. Of course, if you are lucky that this gradient does not change within your measuring time, you are safe. Obviously, the direct refraction can more or less be connected by using the dispersion, but the other one is beyond correction by dispersion. The only thing you have to know is to get an idea of how the gradients of the refractive index is perpendicular to the propagation path. It is a second order effect, but it goes up with the third power of distance. For all geodetic measurements, it is really one of the most limiting factors.

A.J. Anderson: The estimates on the induced pathlength correction, that is, the total amplitude of the tropospheric corrections, the dry and the wet components, give upwards of 2.6 meters on the total pathlength, at an azimuth angle of, say, 60°. Then the ionospheric corrections give you another 2 to 3 meters. Finally you have to consider the total ion density value of the solar system path, which changes very much with the sunspot cycle, but totally you can get upwards of 10 meters of pathlength correction, due to the bending of the ray from the spacecraft to the point on the earth, so we are dealing with a total of 10 meters refractive value due to three different sources.

D.G. Currie: If the spacecraft are close enough in the sky, the refraction would be similar, going to the earth's atmosphere. If they would be ideally in the same direction, you would then be measuring the distance between them at high accuracy with no tropospheric (wet or dry component).

A.J. Anderson: Yes, that is possible. However, the constraints on the DSN-network have been, so far, that one has not been able to track simultaneously two spacecraft of this type. One has the hope to do that, however. We presently can track two spacecraft, being distant in the sky, which are tracked at separate sites. Let me give you an example: One can track two spacecraft simultaneously at two sites at Goldstone. Generally the angles have been very large between spacecraft and they have not been relevant for anything in which we would be interested in, however with some additional equipment there will be simultaneous tracking at Goldstone in the early 1980's of the two Voyager spacecraft and they will be very close to each other in the sky, and it is hoped to carry out that experiment you have mentioned.