OT TECHNICAL MEMORANDUM 77-235

A CALIBRATED TEST RANGE FOR EVALUATION OF REFRACTION CORRECTION METHODS

DEPARTMENT OF COMMERCE · UNITED STATES OF AMERICA

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U.S. DEPARTMENT OF COMMERCE Office of Telecommunications

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UNITED STATES DEPARTMENT OF COMMERCE
OFFICE OF TELECOMMUNICATIONS
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In carrying out this mission, the Office

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- Assists other government agencies in the use of telecommunications
- Conducts research, engineering, and analysis in the general field of telecommunication science to meet government needs
- Acquires, analyzes, synthesizes, and disseminates information for the efficient use of the nation's telecommunication resources.
- Performs analysis, engineering, and related administrative functions responsive to the needs of the Director of the Office of Telecommunications Policy, Executive Office of the President, in the performance of his responsibilities for the management of the radio spectrum
- Conducts research needed in the evaluation and development of telecommunication policy as required by the Office of Telecommunications Policy, pursuant to Executive Order 11556

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A CALIBRATED TEST RANGE FOR EVALUATION OF REFRACTION CORRECTION METHODS

M. C. Thompson, L. E. Wood, and K. C. Allen*

A 64 km path between the islands of Hawaii and Maui was measured using a Geodimeter with refractive index correction based on airborne measurements of temperature along the line. The standard deviation of the slant range is estimated as about 0.9 ppm (0.06 m).

1. INTRODUCTION

To approach the potential instrumental accuracy of microwave ranging systems, the measurements must be adjusted for the signal velocity over the path being measured. This velocity, v, is commonly considered in terms of the refractive index, n, or the refractivity, N, of the medium through which the signal is propagated. In the earth's atmosphere for systems using radio frequencies up to 40 GHz, these quantities are essentially determined by the state and composition of the air as expressed in the following:

$$n \equiv \frac{c}{v} \tag{1}$$

$$N \equiv (n - 1) \times 10^6 \tag{2}$$

$$N = \frac{77.6P}{T} + \frac{3.73 \times 10^5 e}{T^2} \tag{3}$$

where P and e are total pressure and water vapor pressure, respectively, in millibars, and T is temperature in degrees Kelvin.

In the atmosphere, all three of these quantities vary in space and time. Various techniques have been used to estimate the value of N appropriate for the correction in individual cases. These methods vary in the kinds of input data they

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require, the approximations involved, and the methods used in calculation of the correction factors and, consequently, in the degree to which they succeed in approximating the correct value of the required correction factor.

The test range described in the following was established to provide a means for evaluating the accuracy of various correction methods. It has been comparatively easy to determine the precision obtainable from these methods. However, only a few lines in the world have been measured with the accuracy required to evaluate the residual systematic errors within 1 to 2 parts per million. Furthermore, for most tracking and many geodetic applications, the evaluations should be made over a path from 10 to 100 km long, and along which the refractive index undergoes appreciable variations in space and time.

2. PATH GEOMETRY

Such a path has been established between Mt. Haleakala, Maui, Hawaii, and Upolu Point, near the northwestern extremity of the Island of Hawaii.

The 64-km path extends from about 3000 m to 30 m. mean sea level elevation with an elevation angle of about 2.5° as shown in Figures 1 and 2, and simulates aircraft-, missile-, or satellite-to-ground geometry.

3. MEASUREMENTS

The calibration was made using an AGA Model 8 geodimeter modified by the Coast and Geodetic Survey (currently National Ocean Survey) to use a 5 mW He-Ne laser in place of the normal 1 mW unit. The reflector consisted of 51 two-inch corner cubes at the 3000 m terminal (C&GS benchmark "KOLEKOLE 13"). Corrections for these measurements were obtained from temperature measurements taken by an instrumented aircraft which was flown along the line. Since a cloud-free path was required for the optical measurement, it was usually feasible to fly nearly directly between the terminals. Figure shows samples of the temperature recordings.

A total of 16 sets of data were taken during eight days of the period from August 17 to August 26, 1971, and these were fairly evenly distributed around the clock. In general, the visibility along the path was either "zero" or good; i.e., in the absence of clouds, the light levels were adequate to give stable readings. This is indicated more quantitatively by the relatively small differences between readings; e.g., 30 mm or 0.5 ppm in each set.

4. DATA REDUCTION AND ERROR ANALYSIS

The geodimeter data were reduced in accordance with the standard procedures to obtain the uncorrected length measurement, D, for each flight. A refractivity correction, $\overline{N}$, was determined for each flight by the procedure described in the following and used to obtain an adjusted length, D_R (see Table I). The mean of these values, $\overline{D}_R$, was then adjusted for the other instrumental corrections and path curvature to obtain the estimate of the slant path length, D_C .

Table II summarizes the correction terms as well as the estimate of their standard deviations.

4.1 Instrument Corrections

4.1.1. Instrument constant

The geodimeter (No. 80070) had an instrument constant of 20.3 cm.

4.1.2. Reflector constant

The retrodirective prisms introduce an additional path length of 3.0 cm with an assumed standard deviation of 0.3 cm.

4.1.3. Modulation frequency

The instrument calibration is based on a velocity of light in a vacuum of 299,792.5 km/s, atmospheric refractivity of 308.6 N, and a modulation frequency (F1) of 29.970 MHz (wavelength of 10 m). During the time observations were being made, 23 measurements of F1 were made with a standard deviation of 0.10 ppm. Since F1 was measured for only some of the observations sets, the sets were not individually corrected. Instead, the mean of the F1 measurements was used to correct for modulation frequency. The resulting correction was 0.68 ppm and, including the errors in the frequency counter, the standard deviation assumed for this correction is 0.5 ppm.

4.1.4. Instrument calibration

The geodimeter operating manual (AGA publication 571/2501) gives the following uncertainties in the calibration and use of the instrument:

Geodimeter constant: ± 2 mm.

Eccentricities of geodimeter and reflectors: ± 1 mm.

Phase determination: ± 3 mm.

In estimating the overall measurement precision, each of these numbers is taken as standard deviation, σ.

4.2 Average Path Refractivity

4.2.1. Temperature

For each set of geodimeter observations, there were two temperature profiles, one for the ascent of the aircraft along the path and one for the descent along the path. Figure 4 is a sample of such a pair of temperature profiles, together with the calculated refractivity profiles.

Several methods were used to correct for aerodynamic heating of the temperature probe due to the airspeed of the aircraft. (NBS Report, 1969, and Kelly and Brean 1967). The resultting correction was 1.6°C with an estimated σ of 0.4°C. The σ for the probe calibration was assumed to be 0.1°C (0.1 ppm).

4.2.2. Pressure

Pressure profiles were calculated approximating the NACA Standard Atmosphere (Smithionan Institute, 1965) by

$$P(\text{in.Hg}) = 29.92\,[1 - 6.879 \times 10^{-6} Z\,(\text{ft})]^{5.2553} \quad .$$

For each flight, the pressure at ground level (100 ft or 30 m) was recorded. The calculated (standard atmosphere) pressure for Z = 100 ft (30 m) was subtracted from the ground measurement and the difference was added to the standard pressure at the remaining height intervals. The standard deviation of the results is assumed as 1 mb.

4.2.3. Water vapor

Since its contribution to refractivity at this wavelength (6328Å) is small, the water vapor was not measured along the path. A value of 50% average relative humidity along the path