

## CHAPTER 10 TROPOSPHERIC MODEL

### SATELLITE LASER RANGING

The formulation of Marini and Murray (1973) is commonly used in laser ranging. The formula has been tested by comparison with ray-tracing radiosonde profiles.

The correction to one-way range is

$$\Delta R = \frac{f(\lambda)}{f(\phi, H)} \cdot \frac{A+B}{\sin E + \frac{B/(A+B)}{\sin E + 0.01}}, \quad (1)$$

where

$$A = 0.002357P_0 + 0.000141e_0, \quad (2)$$

$$B = (1.084 \times 10^{-8})P_0 T_0 K + (4.734 \times 10^{-8}) \frac{P_0^2}{T_0} \frac{2}{(3-1/K)}, \quad (3)$$

$$K = 1.163 - 0.00968 \cos 2\phi - 0.00104 T_0 + 0.00001435P_0, \quad (4)$$

where

- $\Delta R$  = range correction (meters),
- $E$  = true elevation of satellite,
- $P_0$  = atmospheric pressure at the laser site (millibars),
- $T_0$  = atmospheric temperature at the laser site (degrees Kelvin),
- $e_0$  = water vapor pressure at the laser site (millibars),
- $f(\lambda)$  = laser frequency parameter ( $\lambda$  = wavelength in micrometers),
- $f(\phi, H)$  = laser site function,

Additional definitions of these parameters are available. The water vapor pressure,  $e_0$ , can be calculated from a relative humidity measurement,  $R_h(\%)$  by

$$e_0 = \frac{R_h}{100} \times 6.11 \times 10^{\frac{7.5(T_0 - 273.15)}{237.3 + (T_0 - 273.15)}}.$$

The laser frequency parameter,  $f(\lambda)$ , is

$$f(\lambda) \equiv 0.9650 + \frac{0.0164}{\lambda^2} + \frac{0.000228}{\lambda^4}.$$

$f(\lambda) = 1$  for a ruby laser, i. e.  $f(0.6943) = 1$ .

The laser site function is

$$f(\phi, H) = 1 - 0.0026 \cos 2\phi - 0.00031 H,$$

where  $\phi$  is the latitude and H is the geodetic height (km).

#### VERY LONG BASELINE INTERFEROMETRY

The most serious problem in practical atmospheric modelling is that of unmeasured atmospheric parameters. The differences between mathematical models are often less than the errors which would be introduced by the character and distribution of the wet component and breakdowns in azimuthal symmetry. For this reason, it is customary in the data reduction to determine the zenith atmospheric delay as a parameter and use models only for the mapping function which is the ratio of delay at a given zenith angle to the zenith delay. Accordingly, the IERS standard applies only to the mapping function which is the ratio of delay at a given zenith angle to the zenith delay.

Some standard models are available: CFA2.2 (Davis, et al., 1985), Chao (1974), Saastamoinen (1972), Black (1984), Marini (1972), Hopfield (1969), Yionoulis (1970), Goldfinger (1980), Matsakis, et al., (1986), Baby, et al. (1988), and Lanyi (1984). The reader should be aware of typographical errors in the published versions of the last three works cited. The models differ in their allowance for Earth curvature, atmospheric boundary structure, scale heights, and bending. Of these, the model which attempts to address all these aspects, particularly bending, in the most complete manner, is that of Lanyi. Some of the other models can be duplicated by dropping terms from the Lanyi model. Its abundance of adjustable parameters could prove useful for experimental applications. It is recommended that the lapse rate and the wet scale height parameter be adjusted for site dependence and seasonal variation (see Askne and Nordius, 1987). As pointed out by Davis, et al. (1985), the mapping function is considerably less sensitive than the zenith delay to the wet component.

There is some discrepancy in the reported literature concerning the numerical values of the refractivity coefficients for the wet delay. Measurements of the refractivity at radio wavelengths at different temperatures have been fit to a linear slope (in  $1/T$ ) by Boudouris (1963) and Birnbaum and Chatterjee (1952). Thayer (1974), using the same data, extrapolated values from the optical to derive slightly different values (Table 10.1) that were still within the measurement errors of the previous authors. The theoretical basis of this extrapolation was criticized by Hill, et al. (1982). The coefficients reported by Birnbaum and Chatterjee are actually a weighted average of their data and those of three other works, going back to 1935. Two works of these are based entirely upon data above  $100^\circ$  C; the coefficients of Boudouris are intermediate between the remaining

two measurements. Within the range of atmospheric temperature variations, all three sets of coefficients are consistent with the data (Table 10.1) and the choice has little effect on the mapping function.

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Table 10.1. Values of refractivity coefficients K2 and K3 for radio frequencies.

	K2	(error)	K3	(error)
Birnbaum and Chatterjee	71.40	(5.8)	$3.747 \times 10^5$	(.03)
Boudouris	72.00	(10.5)	$3.754 \times 10^5$	(.03)
Thayer	64.79	(.08)	$3.776 \times 10^5$	(.004)

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