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Modeling of GPS Tropospheric Delay Wet Neill Mapping Function (NMF)

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Abstract. The modeling of the GPS tropospheric delay mapping function should be revised by modifying or simplify its mathematical model. Some current mapping functions models are separated into hydrostatic and the wet part. The current tropospheric delay models use mapping functions in the form of continued fractions. This model is quite complex and need to be simplified. By using regression method, the wet mapping function models has been selected to be simplified. There are eleven operations for wet mapping function component of Neill Mapping Function (NMF), to be carried out before getting the mapping function scale factor. So, there is a need to simplify the mapping function models to allow faster calculation and also better understanding of the models.

INTRODUCTION

Nowadays, the established tropospheric delay models use mapping functions in the form of continued fractions. Most of the modern models have separated mapping functions for the hydrostatic and the wet component, in a form of continued fraction [1]. Saastamoinen model [2] does not use continued fractions to form a mapping function. The calculation for finding the mapping function scale factor, which is in a form of continued fractions are quite tedious. There are many mathematical operations to be carried out before getting the mapping function scale factor. To ensure faster calculation and also easier to understand, the mapping function is needed to be simplified. The Neill Mapping Function (NMF) models for hydrostatic and wet components are given in a form of continued fraction.

In this study, NMF for wet component is selected to be simplified. At 90 degree the mapping function should be normalized to unity, 1 [3]. As a coefficient of zenith hydrostatic delay and also zenith non hydrostatic delay, the mapping function scale factor values are very important for getting the total tropospheric delay value. The mapping function uses the elevation angles as its variables. The relation between mapping functions and tropospheric delay (TD) is given in equation (1) below [4]:

$$TD = ZHD.m_h(\varepsilon) + ZWD.m_w(\varepsilon) \tag{1}$$

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where ZHD is zenith hydrostatic delay (m), ZWD is zenith wet delay (m), $m_h(\varepsilon)$ is the hydrostatic mapping function (-) and $m_w(\varepsilon)$ is the wet mapping function (-).

NEILL MAPPING FUNCTION MODEL

In 1996, Arthur Neill had derived the mapping function and it is known to be the most accurate and easily-implemented functions [5]. This new mapping function (NMF) based on temporal changes and geographic location rather than on surface meteorological parameters. He claimed that all mapping functions have been limited in their accuracy by the dependence on surface temperature, which causes three dilemmas. Neill compared NMF and ray traces calculated from radiosonde data spanning about one year or more covering a wide range of latitude and various heights above sea level.

Such comparison was to ascertain the validity and applicability of the mapping function NMF. Through the least-square fit of four different latitude data sets, Niell showed that the temporal variation of the hydrostatic mapping function is sinusoidal within the scatter of the data.

Neill Mapping Function, NMF as given in equation (2) and (3) below state that;

For hydrostatic component;

$$m_h(\varepsilon) = \frac{1+\dfrac{a}{1+\dfrac{b}{1+c}}}{\sin\varepsilon + \dfrac{a}{\sin\varepsilon + \dfrac{b}{\sin\varepsilon + c}}} + \underbrace{\left[\frac{1}{\sin\varepsilon} - \left(\frac{1+\dfrac{a_{ht}}{1+\dfrac{b_{ht}}{1+c_{ht}}}}{\sin\varepsilon + \dfrac{a_{ht}}{\sin\varepsilon + \dfrac{b_{ht}}{\sin\varepsilon + c_{ht}}}}\right)\right] \mathrm{H}}_{\text{(height correction terms)}} \tag{2}$$

and for wet component:

$$m_w(\varepsilon) = \frac{1+\dfrac{a_{wet}}{1+\dfrac{b_{wet}}{1+c_{wet}}}}{\sin\varepsilon + \dfrac{a_{wet}}{\sin\varepsilon + \dfrac{b_{wet}}{\sin\varepsilon + c_{wet}}}} \tag{3}$$

where ε is elevation angle, m_h is hydrostatic mapping function, m_w is wet mapping function and H is station height above sea level (km).

For the hydrostatic NMF mapping function, the parameter *a* at tabular latitude ϕ_i at time t from January 0.0 (in UT days) is given as:

$$a(\phi,t) = a_{avg}(\phi) + a_{amp}(\phi)\cos\left(\frac{t-DOY}{365.25}2\pi\right) \tag{4}$$

where DOY (day of year) is the adopted phase, DOY = 28 for Northern hemisphere and DOY = 211 for Southern hemisphere. The linear interpolation between the nearest $a(\phi,t)$ is used to obtain the value of parameter $a(\phi,t)$ which is stated as parameter *a* in equation (2). For parameters *b* and *c*, the same procedure can be applied.

Height correction coefficients are given as a_{ht}, b_{ht} and c_{ht} were determined by a least-squares fit to the height correction at nine elevation angles. However, for the wet NMF mapping function coefficients which are stated as a_{wet}, b_{wet} and c_{wet}, no temporal dependence is included in the wet NMF mapping function. Therefore, only an interpolation in latitude for each parameter is required as described in [6].

Reference [7] analyzed the large number of mapping functions by comparing against radiosonde profiles from 50 stations distributed worldwide (32,467 benchmark values). The models that meet the high standards of modern space geodetic data analysis are Ifadis, Lanyi, MTT, and NMF. He found that for elevation angle above 15 degrees, the models Lanyi, MTT, and NMF yield identical mean biases and the best total error performance. At lower elevation angles, Ifadis and NMF are superior.

Simplification of wet Neill mapping function, NMF(w)

In this paper, NMF(w) mapping function model will be focused on. Guo [3] states that in comparison with other mapping function, NMF (w) mapping function was given in a form of hyperbolic graph. However, the hyperbolic graph can also be obtained by using other form of equation which is simpler than the established equations. Here, the NMF is named as Z, while the simplified models have been named as Z1, Z2 and Z3. As the original model, Z has the shape of hiperbolic graph, while the other simplified models, also have the similar shape with slight difference between them. By using regression method, the simplified models (Z1, Z2 and Z3) have been generated as given below:

$$Z1 = AX^{B} \tag{5}$$

where $Z1$ is simplified NMF(w), A *and* B are constants and X is elevation angle (independent variable).

From equation (5) above, the simplified model looks like much simpler than the original NMF(w) mapping function. By comparing the number of operation of the model, the computation time can be reduced based on the number of model operation, to only 2 operations from 11 operations (original). Model Z1 has been generated from regression method, whereby model Z2 and Z3 have been produced from Z1 model. By fixing the value of constant B and changing the value of constant A, model Z2 is formed. For Z3 model, the value of constant B is changed and the value of constant A is fixed. However all models will give unity values at when X is 90 degree.

The value of Sum of Error For NMF wet component

The calculation of sum of error can show how far the simplified models deviate from the original model. When the deviation is small, it means that the simplified model is much more similar to the original model.

TABLE 1. Sum of error for NMF(w), Z and other models (Z1,Z2, Z3)

X	Z = NMF(w)	Z1 = 38.079X^ (-0.8452)	Z2 = 38.079X^ (-0.8088)	Z3 = 44.846X^ (-0.8452)	(Z -Z1)^2	(Z - Z2)^2	(Z - Z3)^2
2	21.854	21.196	21.738	24.963	0.433	0.014	9.663
5	10.751	9.770	10.360	11.507	0.961	0.153	0.571
10	5.657	5.439	5.914	6.405	0.048	0.066	0.559
15	3.833	3.861	4.261	4.547	0.001	0.182	0.509
20	2.911	3.027	3.376	3.565	0.013	0.216	0.428
25	2.360	2.507	2.819	2.952	0.022	0.210	0.351
30	1.997	2.149	2.432	2.531	0.023	0.190	0.285
35	1.741	1.886	2.147	2.222	0.021	0.165	0.231
40	1.554	1.685	1.927	1.985	0.017	0.139	0.185
45	1.413	1.525	1.752	1.797	0.013	0.115	0.147
50	1.305	1.395	1.609	1.643	0.008	0.092	0.115
55	1.220	1.287	1.490	1.516	0.004	0.072	0.087
60	1.154	1.196	1.388	1.409	0.002	0.055	0.065
65	1.103	1.118	1.301	1.317	0.000	0.039	0.046
70	1.064	1.050	1.226	1.237	0.000	0.026	0.030
75	1.035	0.991	1.159	1.167	0.002	0.015	0.017
80	1.015	0.938	1.100	1.105	0.006	0.007	0.008
85	1.004	0.891	1.048	1.049	0.013	0.002	0.002
90	1.000	0.849	1.000	1.000	0.023	0.000	0.000
		Sum of error			**1.610**	**1.759**	**13.299**

DISCUSSION

From Table 1 above, the Z1 model does not meet the constraint requirement, 1 which it gives 0.849, where the mapping function scale factor should be unity at 90 degree. For Z3 model it gives big value for sum of error (13.299), which mean some of the points are scattered away from the original NMF(w) model.

However, model Z2 = $38.079X^{(-0.8088)}$ gives the smallest sum of error (1.759) compared to the others and also at 90 degree elevation angle it's mapping function gives unity. So, Z2 model is selected as the simpler mapping function model for NMF(w).

As given in equation (1) and (2), the original Neill mapping function (NMF) are in a form of continued fraction. The NMF for wet component can be simplified to a simpler form as given in equation (5), which has only 2 operations.

CONCLUSION

In this study, by using regression method the model of wet component for NMF can give a reduction of number of operations. The reduction percentage of the model is 81.8% when the simpler model uses only 2 operations rather than 11 operations for the original model.

The operation reduction can reduce the computing time and also can give better understanding of the models.

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