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16.Sumário/Notas

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17.Observações

SATELLITE RANGE CORRECTION USING THE TROPOSPHERIC REFRACTIVITY DATA OVER BRAZILIAN STATIONS

by

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ABSTRACT

The tropospheric refraction affects the satellite signal received at a tracking station and the uncertainity in the determination of the range and range-rate of the satellite position over a station. The tropospheric refraction depends upon the meteorological conditions over the station. In a preliminary investigation, reported earlier, a quartic refractivity profile was found to explain the vertical refractivity distribution obtained from radio-sonde data over São José dos Campos, Brazil. In the present study the radio-sonde data of six stations of Brazil, are used to estimate the errors in the range and range-rate of the satellite elevation angle. The applicability of the results to satellite passages is examined for some of these stations.

1. INTRODUCTION

An electromagnetic signal travelling between an earth station and a satellite experiences a velocity change when passing through the atmosphere. The resulting error in measured range can be corrected by utilizing the meteorological parameters over the observed station. The present authors have used Hopfields models of dry and wet tropospheric refractivity in a preliminary study for São José dos Campos, Brazil (Mohana Rao et al., 1975). In this paper, such a study is extended to other Brazilian stations.

2. THE TROPOSPHERIC MODEL

The function used to model the troposphere is the two-quartic expression, discussed in detail by Hopfield (1969, 1971, 1972). Briefly, in terms of this model, the height distribution of the dry (d) and wet (w) components of refractivity, defined as 10^6 (N-1) where N is the refractive index, are given by the expression

$$N_{[d,w]}(h) = N_{[d,w]_s} \left\{ \left[(T_s/\alpha) - h \right] / (T_s/\alpha) \right\}^{\mu} \quad (1)$$

where $\mu = (g/R\alpha) - 1$ and subscript '<u>s</u>' refers to the surface.

In Equation (1), $N_{[d,w]_s}$ and T_s are the surface refractivity and temperature, respectively; α is the temperature lapse rate, g the acceleration due to gravity and R the universal gas constant for a unit mass of air. For a troposphere with a lapse rate of 7°C/km, μ is equal to 3.9 and it is shown taht N_d profile is well represented by a polynomial of fourth degree in height. In practice, the $N_{[d,w]}$ profile is written in the form

$$N_{(h)[d,w]} = \left[N_{[d,w]_s} / h^4_{[d,w]} \right] (h_{[d,w]} - h^4) \qquad (2)$$

$$h \leq h_{[d,w]}$$

The equivalent height above the geoid $h_{[d,w]}$ is selected to make theoretical zenith integrals of $N_{[d,w]}$ match the observed ones on a least-square basis. Expressions based on this matched N profile are then used to correct range error or doppler data, at different elevation angles, for a satellite pass.

3. DATA UTILIZATION

Balloon soundings made at São Paulo, Galeão (Rio de Janeiro), Salvador, Brasília, Natal e Trindade are utilized to evaluate the parameters discussed. The position of the stations are given in Table 1. Each balloon ascent provides data on pressure, temperature and water vapour content at different heights. The height for evaluation of the refractivity parameter is limited to the level of 100 mb to maintain uniformity of data for the stations, though for some stations the data is available at higher levels for some few days. For the stations mentioned above the daily radiosonde data for the months of January (summer) and July (winter) of 1972 are used in the present study.

4. DRY COMPONENT AND WET COMPONENT

The surface refractivity, as a function of time during

January and July 1972 at six stations of Brazil, is shown in Figs. 1A, 2A, 3A, 4A, 5A, 6A. The dry component of surface refractivity is about 260 for all stations, in January. Such a value is reported throughout the year for the tropical station Pago Pago, Samoa, by Hopfield (1972). In the case of Brazilian stations, there is a slight increase in the month of July (winter).

The wet component of the refractivity for all stations shows large variations and is between 100 and 120 in summer for Natal, Salvador, Galeão (coastal station) and Trindade (island station) and lesser values, 60 to 80, for Brasília and 80 to 95 for São Paulo. Brasília and São Paulo are inland stations. In July, the value is between 100 and 120 for Natal and Salvador and between 70 and 100 for Galeão and Trindade with much smaller values for Brasília and São Paulo.

In general, July values of surface refractivity of the dry component are slightly higher than those of January and the wet component is higher in January than in July. The wet component has larger day to day fluctuations and shows wide variability with season, with lower values in July, except for Natal.

5. HEIGHT INTEGRALS

Figs. 1B, 2B, 3B, 4B, 5B and 6B shows that the height integral of the dry component is 2.1 m in both seasons for the stations, except Salvador which has a value of 1.8 m in July and São Paulo with 1.8 m in January. The value 2.1 m is lower, by 0.2 m, as compared with the value of 2.3 m for Pago Pago, Samoa, and Washington, in spite of the climatic differences. A value of 2.1 m has been reported for São José dos Campos (Mohana Rao, 1975). The value 2.1 m seems reasonable if the relation given by Hopfield (1972) is used

$$\int N_d \, dh \equiv \Delta h_d = 2.275 \times 10^{-5} \times P_s$$

where P_s is the pressure in millibars. The height integral for the wet component is approximately one tenth of the dry component for all stations and fluctutates more than the dry component in both July and January. An exception is Natal, where the July values are consistently lower than the January values.

6. THEORETICAL QUARTIC FUNCTION AND OBSERVED DATA

Profiles of tropospheric refractivity (theoretical) are drawn for January and July, for all the stations, and compared with observations of one day in each month. These aspects are in Figs. 1C, 1D, 2C, 2D, 3C, 3D, 4C, 4D, 5C, 5D, 6C and 6D. It can be seen that the model provides a reasonable fit to the data even for instantaneous values. Average values show a still better agreement. There is a good agreement for Brasilia (theoretical and observed profiles) for January and July, as well. For Natal, there is a slight deviation in the wet component values (observed) from the profile (theoretical). For Salvador, the deviation is slightly more in the dry component beyond 9.0 km. São Paulo curves exhibit larger departures from the theoretical quartic profile. This is understandable in view of the fact that the station has the largest fluctuations in weather parameters compared with other stations. For an island station, such as Trindade, the July profile is in better agreement than the January one. Salvador and Galeão show reasonable agreement in January and slight deviation in July. Brasilia seems to be a better station for experimental work.

7. CONCLUDING REMARKS

The present work is an extension, of an earlier preliminary study made, for São José dos Campos, to more Brazilian stations, for which the data became avaialble recently. In the future, the authors intend to include still more stations, with different types of climate. Another aspect of primary consideration in future investigations will be to determine the refraction errors of the satellite signals for a wide range of elevation angles, for each of the observing stations.

REFERENCES

HOPFIELD, H. S., Two Quartic Tropospheric Refractivity Profile for Correcting Satellite Data. *J. Geophys. Res.*, 74: 4487, 1969.

HOPFIELD, H. S., Tropospheric Effect on Electromagnetically Measured Range: Prediction from surface weather data. *Radio Science*, 6: 357, 1971.

HOPFIELD, H. S., Tropospheric Refraction Effects on Satellite Range Measurements. *APL/JHU Techinical Digest*, 11: 11, 1972.

MOHANA RAO, N. J., G. S. S. NUNES and S. ANANTHAKRISHNAN, Satellite Range Measurements - Tropospheric Refraction Effects, *Space Research*, XV: 49, 1975.

TABLE 1

LOCATION OF STATIONS USED IN THE PRESENT STUDY

STATION	SOUTH LATITUDE	WEST LONGITUDE	HEIGHT (aSL)
NATAL	$05^o55'$	$35^o15'$	49 m
SALVADOR	$13^o00'$	$38^o30'$	51 m
GALEÃO	$22^o50'$	$43^o14'$	42 m
BRASÍLIA	$15^o52'$	$47^o55'$	1061 m
SÃO PAULO	$23^o37'$	$46^o39'$	802 m
TRINDADE	$20^o30'$	$29^o19'$	21 m

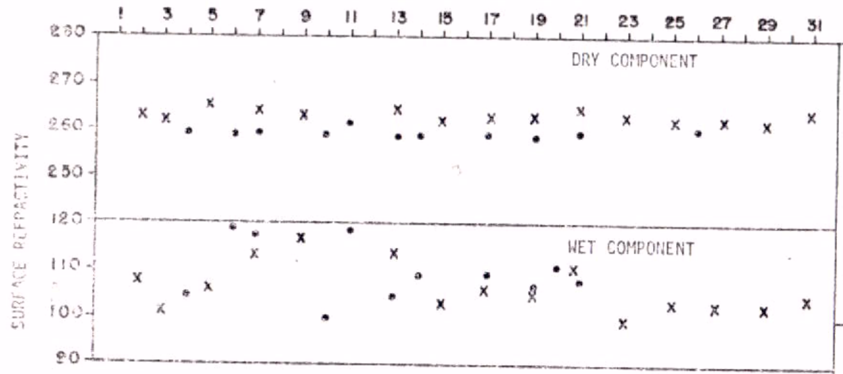

Fig. 1A - REFRACTIVITY AT THE SURFACE, NATAL, JAN. 72 (.) AND JUL. 72 (x).

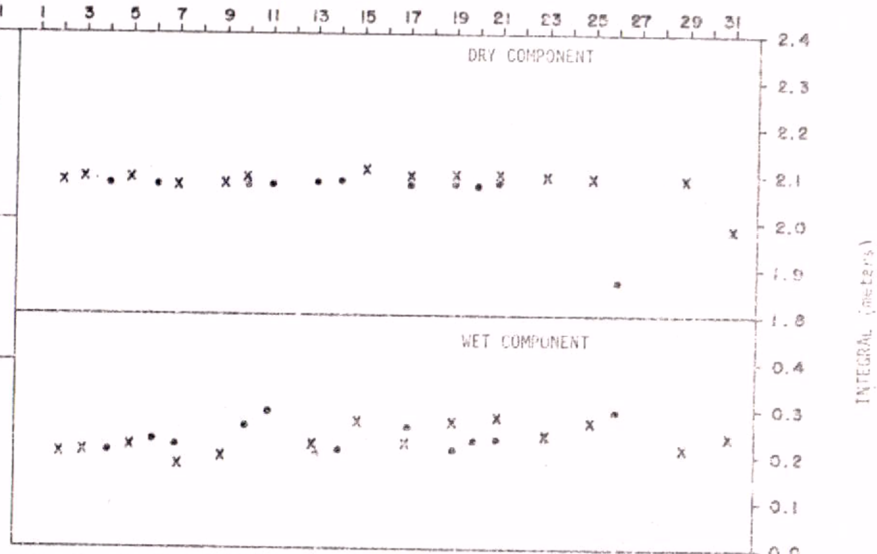

Fig. 1B - VERTICAL INTEGRALS OF REFRACTIVITY, NATAL, JAN.72 (.) AND JUL.72 (x).

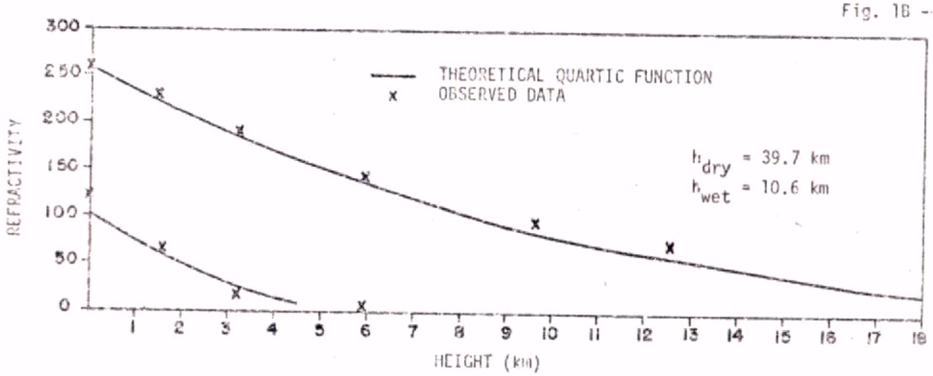

Fig. 1C - PROFILE OF TROPOSPHERIC REFRACTIVITY, NATAL (JAN.72)

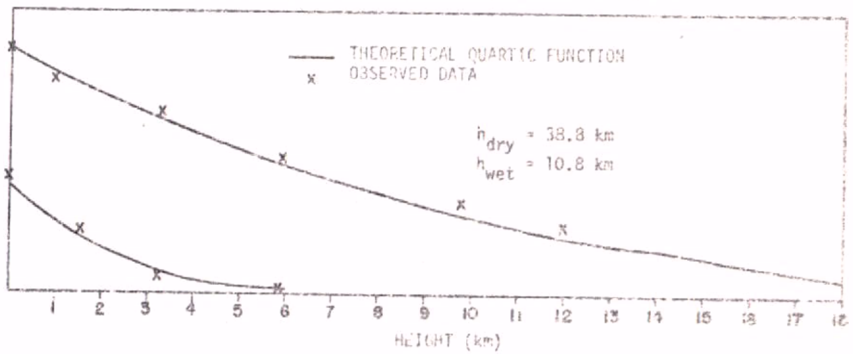

Fig. 1D - PROFILE OF TROPOSPHERIC REFRACTIVITY, NATAL (JUL.72).

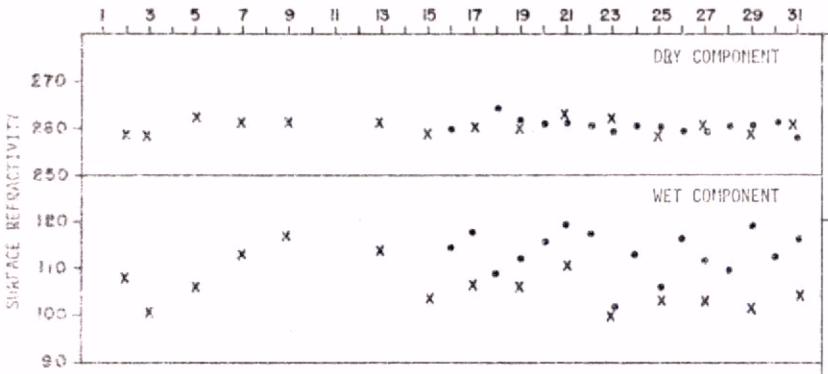

Fig. 2A - REFRACTIVITY AT THE SURFACE, SALVADOR, JAN. 72 (.) AND JUL. 72 (x)

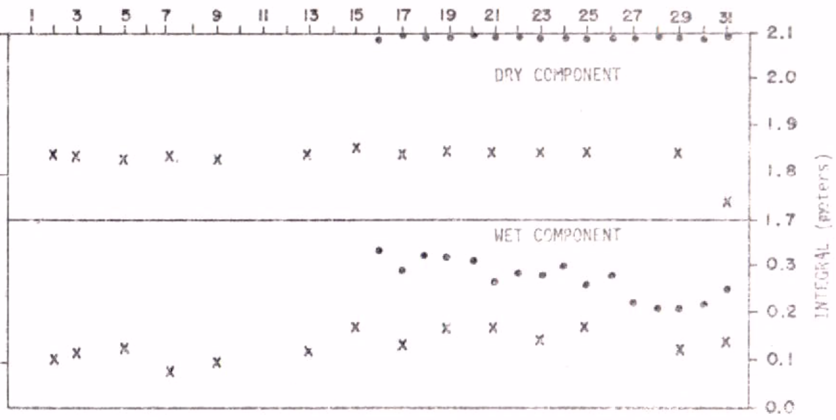

Fig. 2B - VERTICAL INTEGRALS OF REFRACTIVITY, SALVADOR, JAN. 72 (.) AND JUL. 72 (x).

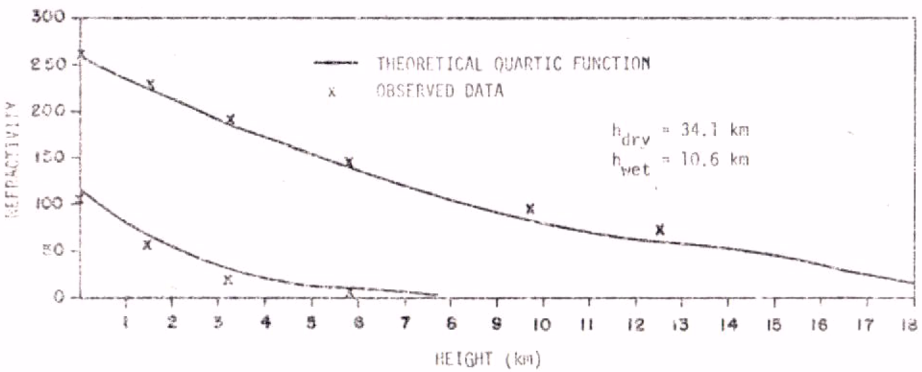

Fig. 2C - PROFILE OF TROPOSPHERIC REFRACTIVITY, SALVADOR (JAN.72)

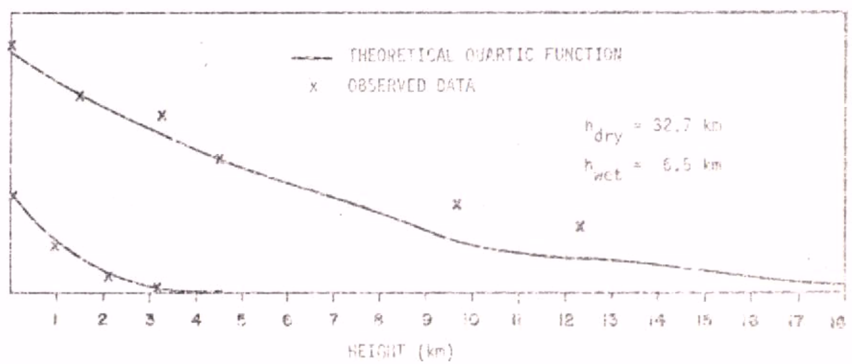

Fig. 2D - PROFILE OF TROPOSPHERIC REFRACTIVITY, SALVADOR (JUL.72)

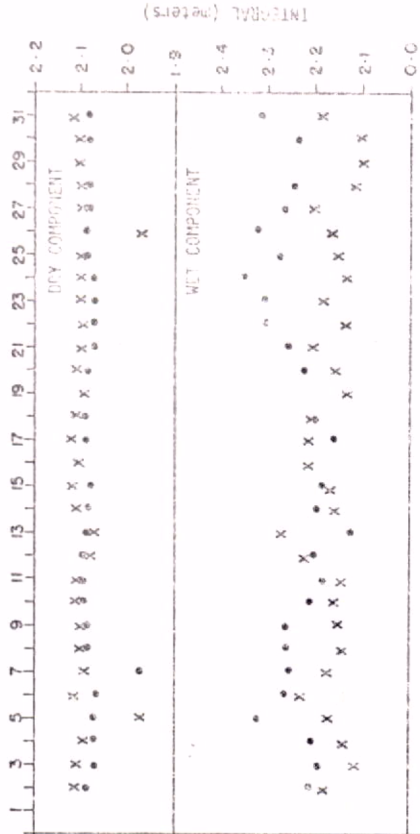

Fig. 3B - VERTICAL INTEGRALS OF REFRACTIVITY, GALEAO, JAN. 72 (.) AND JUL. 72 (x).

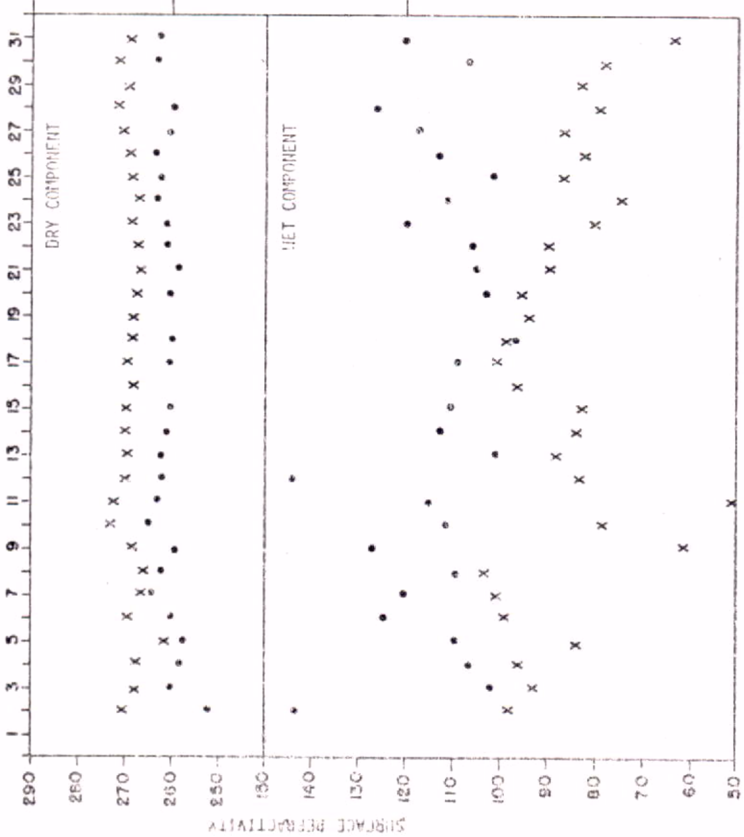

Fig. 3A - REFRACTIVITY AT THE SURFACE, GALEAO, JAN. 72 (.) AND JULY (x)

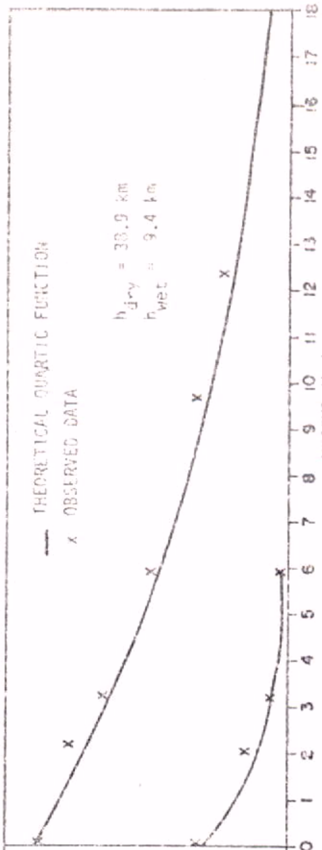

Fig. 3D - PROFILE OF TROPOSPHERIC REFRACTIVITY, GALEAO (JUL.72)

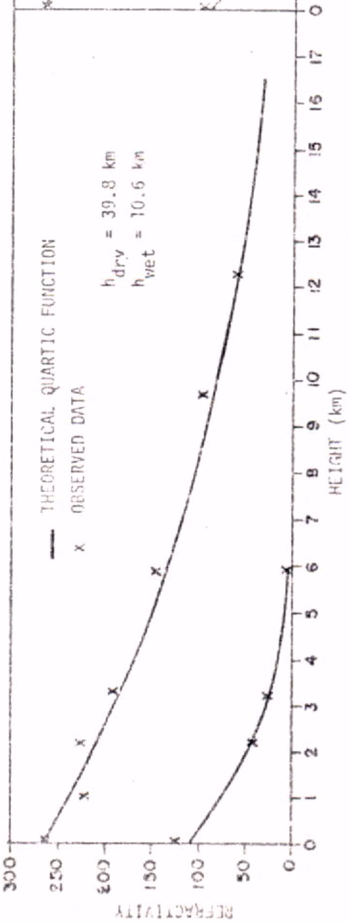

Fig. 3C - PROFILE OF TROPOSPHERIC REFRACTIVITY, GALEAO (JAN. 72)

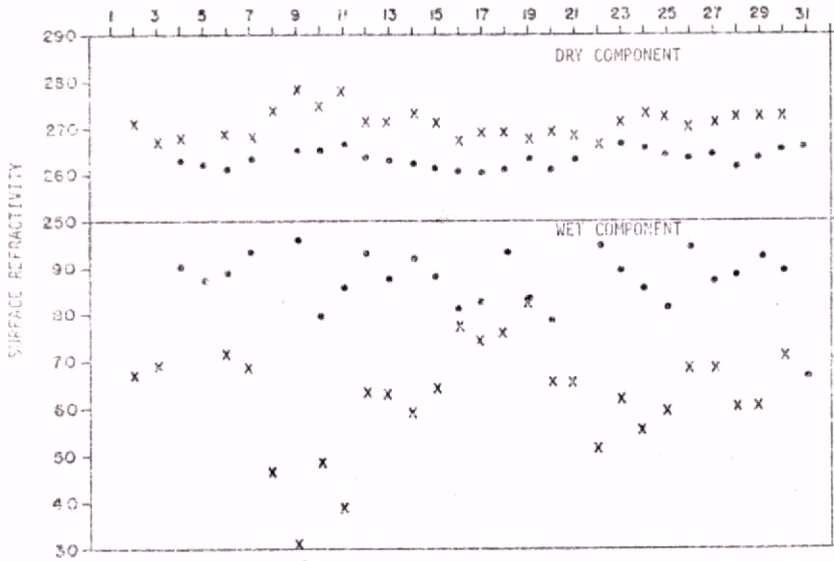

Fig. 4A - REFRACTIVITY AT THE SURFACE, SÃO PAULO, JAN. 72 (.), AND JUL. 72 (x).

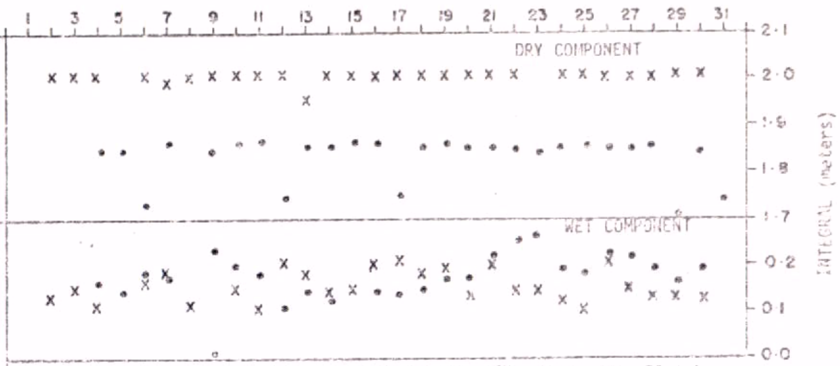

Fig. 4B - VERTICAL INTEGRALS OF REFRACTIVITY, SÃO PAULO, JAN. 72 (.) AND JUL. 72 (x).

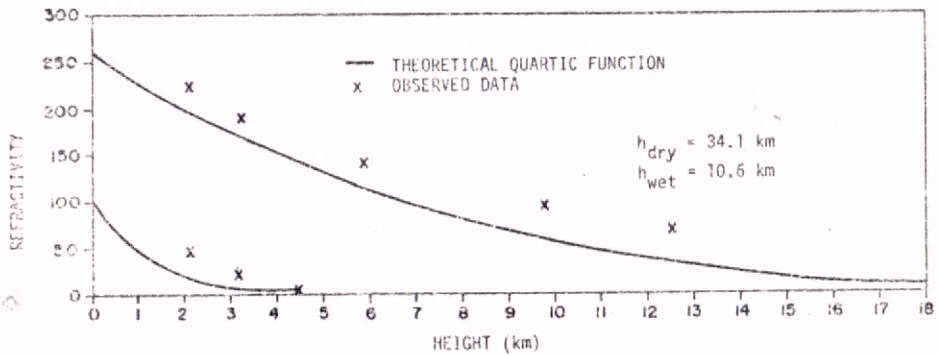

Fig. 4C - PROFILE OF TROPOSPHERIC REFRACTIVITY, SÃO PAULO (JAN. 72).

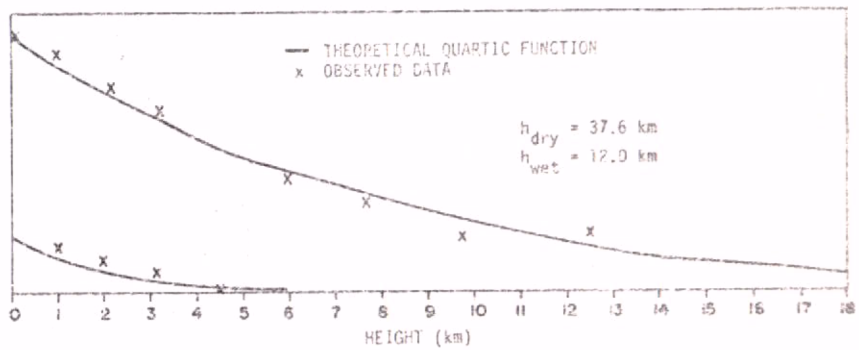

Fig. 4D - PROFILE OF TROPOSPHERIC REFRACTIVITY, SÃO PAULO (JUL.72).

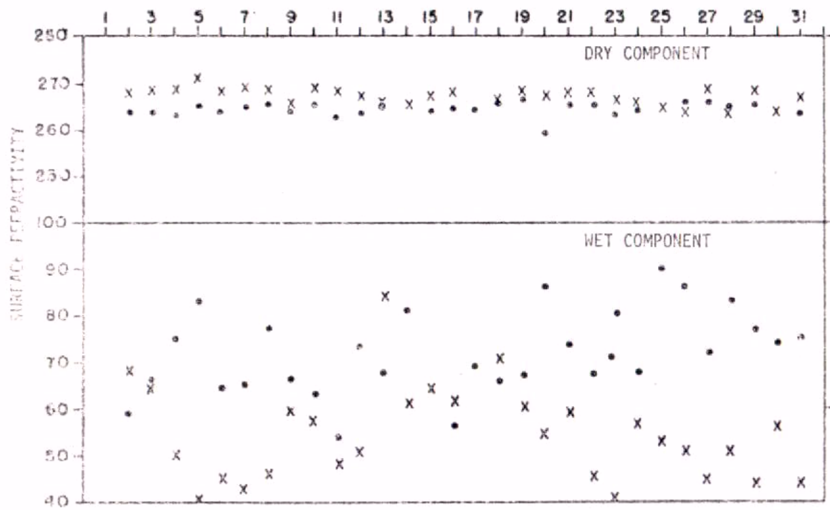

Fig. 5A - REFRACTIVITY AT THE SURFACE, BRASILIA, JAN. 72 (.) AND JUL. 72 (x).

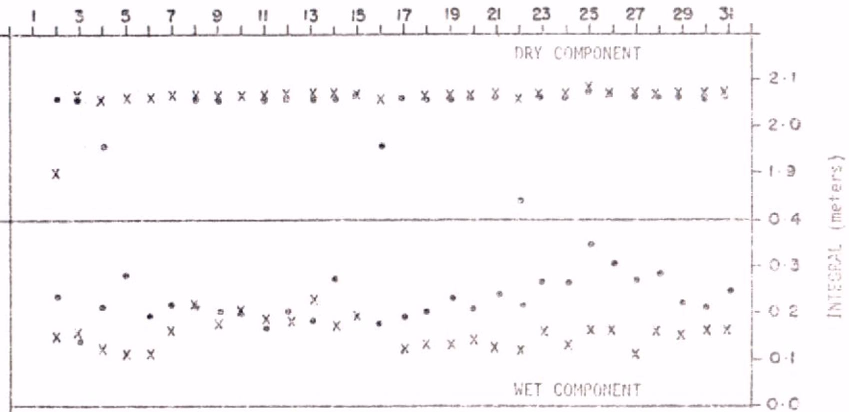

Fig. 5B - VERTICAL INTEGRALS OF REFRACTIVITY, BRASILIA, JAN. 72 (.) AND JUL. 72 (x).

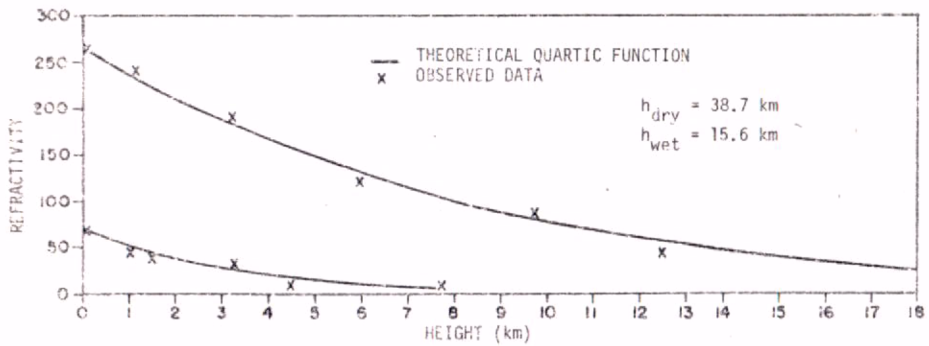

Fig. 5C - PROFILE OF TROPOSPHERIC REFRACTIVITY, BRASILIA (JAN. 72).

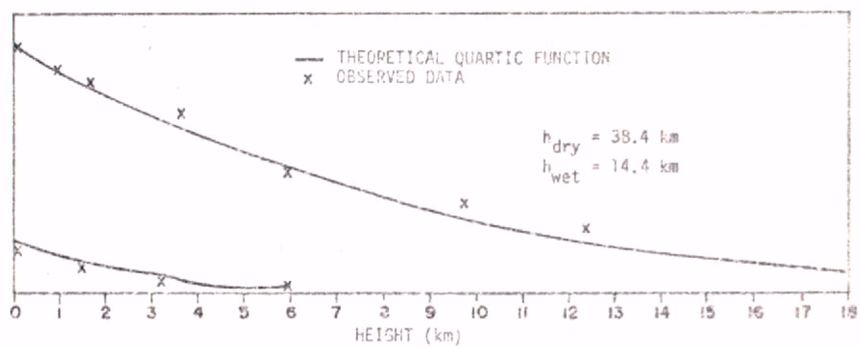

Fig. 5D - PROFILE OF TROPOSPHERIC REFRACTIVITY, BRASILIA (JUL. 72)

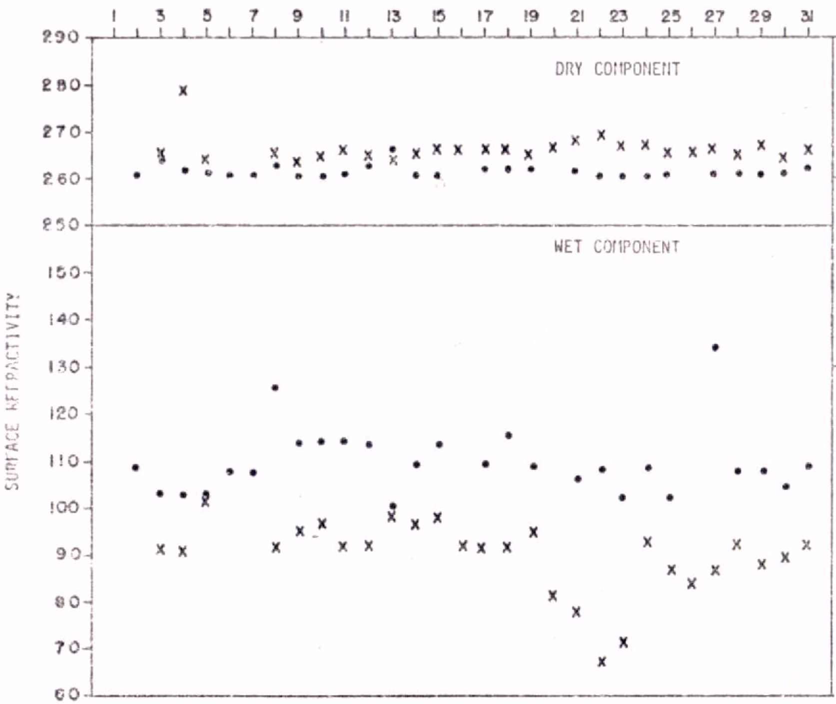

Fig. 6A - REFRACTIVITY AT THE SURFACE, TRINDADE,JAN.72 (.) AND JUL.72 (x).

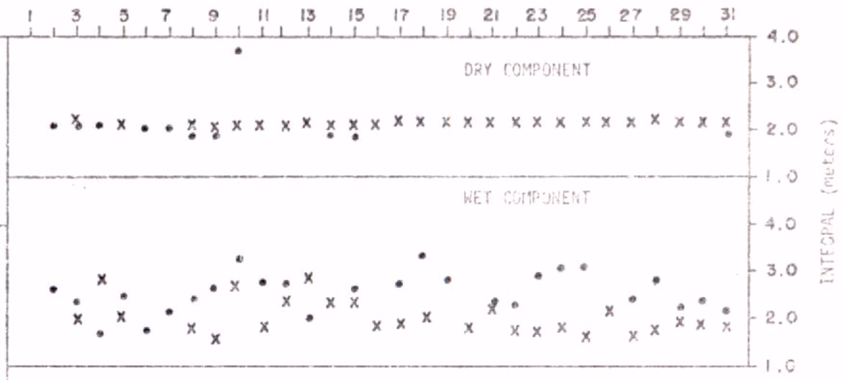

Fig. 6B - VERTICAL INTEGRALS OF REFRACTIVITY, TRINDADE,JAN. 72 (.) AND JUL. 72 (x).

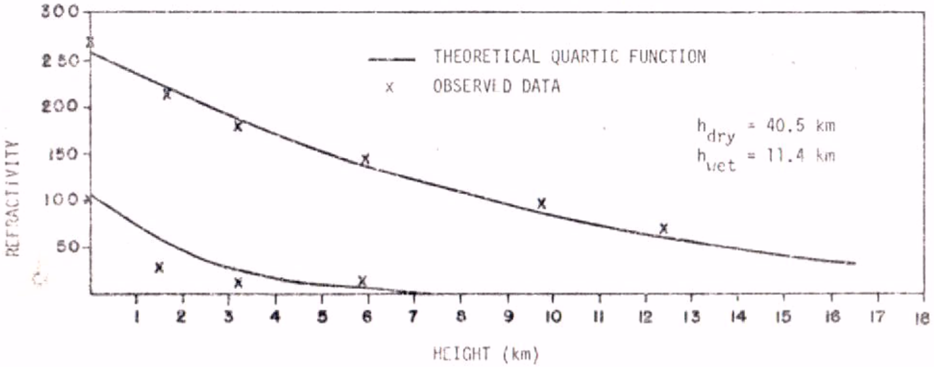

Fig. 6C - PROFILE OF TROPOSPHERIC REFRACTIVITY, TRINDADE (JAN.72)

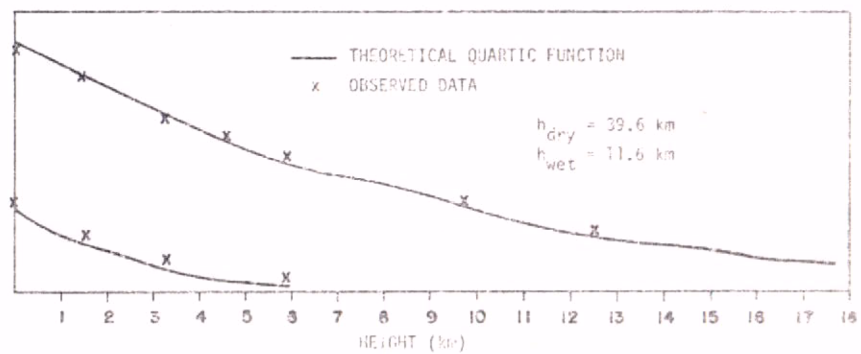

Fig. 6D - PROFILE OF TROPOSPHERIC REFRACTIVITY, TRINDADE (JUL.72)