ESTIMATED RADIO REFRACTIVE INDEX IN THE TROPOSPHERE OF HANOI USING EXPERIMENTAL DATA FROM THE RADIO OCCULTATION AND RADIOSONDE METHODS

ƯỚC LƯỢNG CHỈ SỐ KHÚC XẠ VÔ TUYẾN TẦNG ĐỐI LƯU KHU VỰC HÀ NỘI SỬ DỤNG SỐ LIỆU THỰC NGHIỆM PHƯƠNG PHÁP CẮT LỚP VÔ TUYẾN VÀ BÓNG THÁM KHÔNG

Cong Pham Chi[1], Anh Nguyen Xuan[2], Trung Tran Hoai[3]

[1]Vietnam Research Institute of Electronics, Informatics and Automation, Vietnam
[2]Institute of Geophysics, Hanoi, Vietnam
[3]University of Transport and Communications, Hanoi, Vietnam

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Abstract:

The article proposes a solution to use radio occultation and radiosonde data to estimate the atmospheric refractive index. The results show that the relative difference in radio refractivity between two methods changes from positive to negative, regardless of small or large altitudes, and has a magnitude of less than 4 %.

Keywords:

Radio refractive index, radio wave propagation, radio occultation, radiosonde.

Tóm tắt:

Bài báo đề xuất giải pháp sử dụng số liệu cắt lớp vô tuyến và bóng thám không để ước lượng chỉ số khúc xạ vô tuyến tầng đối lưu. Kết quả cho thấy sự khác biệt tương đối giá trị độ khúc xạ vô tuyến giữa hai phương pháp thay đổi từ dương sang âm, không phụ thuộc vào độ cao nhỏ hay độ cao lớn và có độ lớn ở mức dưới 4%.

Từ khóa:

Chỉ số khúc xạ vô tuyến, truyền sóng vô tuyến, cắt lớp vô tuyến, bóng thám không.

1. INTRODUCTION

The radio refractive index of the troposphere is an important parameter in predicting the operation of radio communication links. The refractive index structure of the troposphere is the cause of transmission delay and many complex mechanisms such as multipath effects, absorption, scattering of radio signals, etc. The refractive index is seasonal and changes by day, night, and region. The effectiveness of navigation, radar, and communication systems largely depends on the propagation conditions of radio waves between the transmitter and receiver. It is determined by the state of atmospheric refraction that is the spatial distribution of refractivity. Therefore, the study of refractive index, and creating statistical models plays an important role in predicting the range of radio systems for various purposes. Having accurate rules about the refractive index contributes to calibrating the data of altimeter satellites. Other applications use atmospheric refractive index such as in below-horizon radar systems; problem of determining satellite orbital position from ground station; problems in atmospheric physics and climate such as turbulent motion in the atmosphere, atmospheric microphysics, radiation balance research, etc.

The Hanoi area is defined as the area with coordinates located around 21.01^{o}N north latitude and 105.80^{o}E east longitude, within a radius of 2^o longitude. There are not many studies on radio refractive index for the Hanoi area, recently there has been research using radio occultation data in [1]; research using radiosonde data in [2]; or research using a combination of radio occultation and radiosonde data in [3]. In the above works, comparing the absolute difference of refractivity with the model method from the recommendation of ITU-R P.453 and between methods has been researched, but comparing the relative difference is not yet available. This is the content of the research conducted in this article.

2. THEORETICAL BACKGROUND

The radio refractive index n is defined as the ratio between the electromagnetic wave propagation speed in vacuum (or free space) c_0 to the wave propagation speed in a physical medium c defined by the formula:

$$n = \frac{c_0}{c} \quad (1)$$

Radio refractivity N can be calculated through atmospheric parameters such as temperature, humidity, and pressure [4]:

$$N = (n-1)^6 = 77{,}6\frac{P}{T} - 5{,}6\frac{e}{T} + 3{,}75.10^5\frac{e}{T^2}$$

(N-units) (2)

which P total atmospheric pressure (hPa), e vapor pressure (hPa), and T absolute temperature (^{o}K).

The reference profile can be used to calculate the value of refractivity N_s at height h_s (km) above the earth's surface as follows [5]:

$$N_s = N_0.\exp(-h_s/h_0) \text{ (N-units)} \quad (3)$$

where N_0 average value of atmospheric refractivity above sea level, and h_0 reference altitude. Normally take N_0 = 315 N-units, h_0 = 7.35 km.

Determining the radio refractive index according to formula (1) is called the direct method, performed using a refractometer. Determination according to formula (2) is called the indirect method. Determined according to formula (3) is called the refractive index model method from the recommendation of ITU-R P.453, the radio refractive index: its formula and refractivity data.

3. MATERIALS AND METHODS

The article uses radio occultation data (wet profile, at level 2) of the COSMIC/FORMOSAT-3 satellites. This is a system that includes meteorological, ionospheric, and climate observation satellites, also known as the COSMIC-1, it is a cooperative space program between Taiwan (China) and the US launched in April 2006 with the placement of 6 satellites into low earth orbit at an altitude of 700-800 km and now replaced by the COSMIC-2 program. These satellites are equipped with GPS signal receivers. Based on processing the received GPS signal, parameters in the Earth's troposphere atmosphere will be calculated. The data fields included in the wetPrf file include altitude above sea level (*MSL_alt*) from 0.1 km to 39.9 km, the distance between each data layer is 0.1 km; latitude (*Lat*); longitude (*Lon*); Radio refractivity (*Ref*) can be calculated from the parameters pressure (*Pres*), temperature (*Temp*), relative humidity (*Vp*) as in formula (2) and some other data fields.

A radiosonde is a type of balloon used to carry equipment that measures meteorological factors at altitude such as atmospheric pressure, temperature, humidity, and wind (direction and speed). Measurements will be sent back to ground-based tracking equipment every one to two seconds using radio waves. The time of releasing the radiosonde in the day, the number of atmospheric monitoring parameters, and the sharing of data comply with the regulations of the World Meteorological Organization (WMO). In Hanoi, radiosondes are released twice a day at 00Z (+7GMT) and 12Z (+19GMT) from the Lang Thuong Meteorological Station (Dong Da, Hanoi). Parametric data includes altitude (*HGHT*) from the earth's surface to 20 km (altitude above sea level), at each altitude radio refractivity is calculated through pressure (*PRES*), temperature degree (*TEMP*), relative humidity (*RHLH*) as in formula (2). There is also other information related to wind direction, dew point, etc.

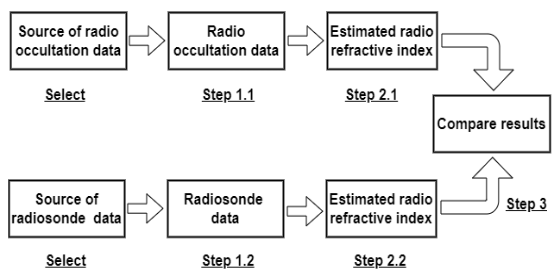
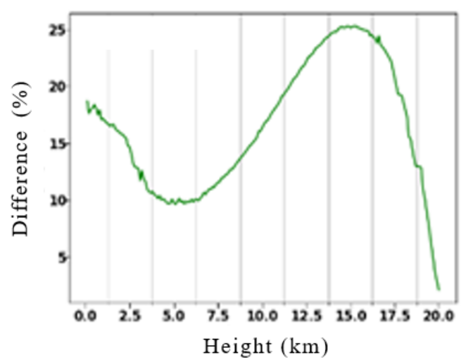


Figure 1. Steps to estimate radio refractive index using radio occultation and radiosonde data

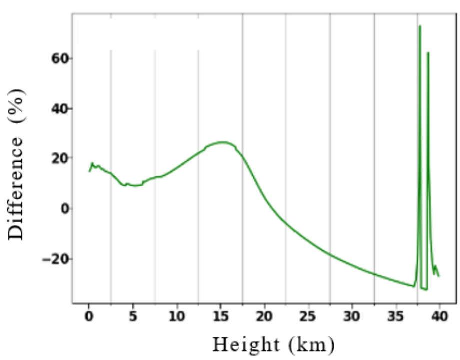
Radio occultation and radiosonde data allow for determining the spatial structure of the refractive index, so they will be studied and applied to determine wave propagation conditions in the atmosphere. Data collection, data format, and data structure are available in [1] [2]. In the content of the article, radio occultation data from the years 2014-2016 and radiosonde data from the years 2016-2018 are studied and used because they have the most complete data in these years. The steps to estimate the refractive index are shown in Figure. 1.

4. RESULTS AND DISCUSSION

Calculating the relative difference in radio refractivity between the radiosonde method and the radio occultation method with the value from the recommendation of ITU-R P.453, the model method, gives the results shown in Figure. 2.



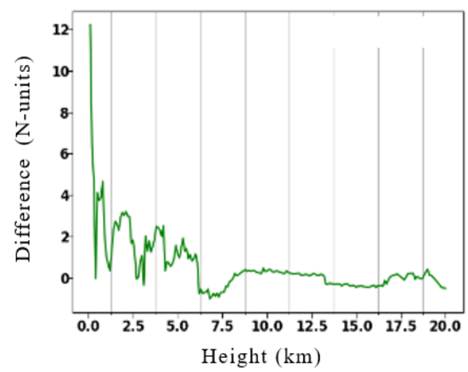
a. Radiosonde



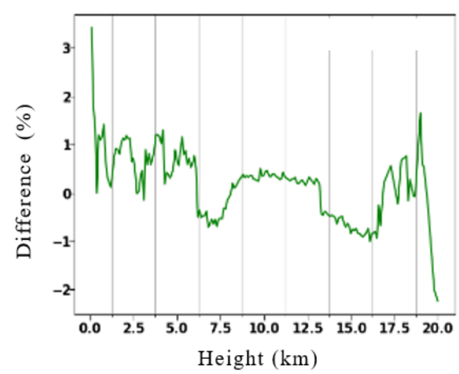
b. Radio occultation

Figure 2. Relative difference of the refractivity with the model method

At altitudes from 0.1 to 5 km, the relative difference from the model value tends to decrease with altitude from 20% to 10%. From an altitude of 5-15 km, the relative difference tends to increase with altitude (10% to 25%). Then it decreases again at altitudes of 15-20 km (25% to 0%). Above an altitude of 20 km, the difference tends to continue to decrease and decreases to -40 % at altitudes up to 36 km. At an altitude of 36-40 km, there is an unusual change in the value of relative difference, with a fluctuation range from -40% to 80%. However, because at high altitudes the value of refractivity gradually returns to 0 N-units, the large fluctuation of relative difference does not have much practical meaning.



a. Absolute difference



b. Relative difference

Figure 3. Compare the refractivity calculated by the radiosonde method and the radio occultation method

Determining the absolute difference between the radio refractivity calculated by the radiosonde method and the radio occultation method in the troposphere at an altitude of less than 20 km gives the results in Figure 3a. The value of radio refractivity in the radiosonde method in most altitudes is larger than the value in the radio occultation method. Only around the altitudes of 2.5 km, 7.5 km, and 15.0 km, the value of the radio occultation method is larger than the value of the aerial survey method but not much at less than 2 N-units. The maximum value difference of the two measurements is less than 13 N-units. Meanwhile, the largest average value difference between the radiosonde method and the radio occultation method is 6.32 N-units. At altitudes below 6.25 km, the difference in the values of the two measurements is higher than at higher altitudes. At low altitudes, the difference is more evident.

Calculating the relative difference gives the results in Figure 3b. The relative difference variation changes from positive to negative values, regardless of small or large altitudes. The largest positive value of the relative difference is below 4%, and the smallest negative value of the relative difference is above -3%. Comparing the relative difference of each method, specifically for the radiosonde (Figure 2a, below 25%) and radio occultation (Figure 2b, below 80%) with data from the ITU-R P.453 model, the relative difference between the radiosonde method and radio occultation method is much less, with an absolute value of less than 4%.

Radiosonde data is a type of actual measurement data in the field (in-situ), this is one of the valuable data sources often used to run models or to calibrate measurement data by different methods. The results showed the difference between the two determination methods and gave recommendations to prioritize the use of radiosonde data to obtain an accurate refractive index when studying wave propagation conditions in the atmosphere, and when there is no experimental data, the model will be used.

4. CONCLUSIONS

The article has proposed a solution to simultaneously use radio occultation data and radiosonde data to estimate radio refractivity in the troposphere of the Hanoi area. Evaluation of the determined radio refractivity differences and recommendations for use are also given.

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Biography:

Cong Pham Chi, successfully defended a doctoral thesis in Telecommunication Engineering in early 2024, working at the Vietnam Research Institute of Electronics, Informatics, and Automation.

His main research interests are directions are wave propagation, artificial intelligence, intelligent systems, and the Internet of Things (IoT).

Anh Nguyen Xuan, received his doctorate in 2000, majoring in Physics, working at Institute of Geophysics, Vietnam Academy of Science and Technology.

His main research interests are directions on navigation, LIDAR, measurement, and lightning protection systems.

Trung Tran Hoai, got Bachelor degree in University of Transport and Communications (UTC) in 1997 and hold the post of lecturer at the University. He then got a Master degree from Hanoi University of Science and Technology (HUST) in 2000. In the period 2003 to 2008, he had concentrated on researching in the field of Telecommunication engineering and got his PhD at University of Technology, Sydney (UTS) in Australia. He is currently a lecturer at the UTC.

His main research interests are digital signal processing (DSP), applied information theory, radio propagation, MIMO antenna techniques and advanced wireless transceiver design.