Mapana J Sci, **13**, 1 (2014), 75-83
ISSN 0975-3303 | doi:10.12723/mjs.28.5

Improved Technique for Retrieval of Temperature and Humidity from Neutral Atmospheric Refractivity Profiles

Deveerappa Jagadheesha,* Kamsali Nagaraja†
and Balakrishnan Manikiam ‡

Abstract

This paper discusses some improvements to a technique for retrieving temperature and humidity from neutral atmospheric refractivities. A technique previously developed used auxiliary information in the form of surface temperature and pressure along with neutral atmospheric refractivity profiles in the troposphere to retrieve temperature and humidity profiles. The height at which water vapor is presumed to be negligible was based on criteria that most of the times it was around ~ 10 km altitude. A new set of criteria are developed wherein it is shown that it is possible to bring this height further down whenever troposphere is dry at altitudes below ~

* Atmospheric Science Programme, ISRO Headquarters, Bangalore, India; jagadish@isro.gov.in

†Department of Physics, Bangalore University, Bangalore, India; kamsalinagaraj@gmail.com

‡Department of Physics, Bangalore University, Bangalore, India; manikiam@yahoo.co.in

10 km thereby improving the retrieved temperature and humidity.

Keywords: Radio occultation, Refractivity, Temperature and humidity retrieval

1. Introduction

Measurement of temperature and humidity in the neutral atmosphere (below ~ 30 km altitude) using radio occultation is gaining importance in recent decade and several missions are dedicated for this [1-5]. In this technique a space qualified GPS/GNSS receiver is mounted on a low earth orbiting satellite (LEOS) which tracks GPS/GNSS signals as the LEOS orbits round the earth. The radio waves (GPS/GNSS signals) originating from GPS/GNSS satellites undergo a bending while traversing through the earth's atmosphere resulting in excess path over vacuum distance between source and receiver. With the precise knowledge of orbits of GPS/GNSS satellites and LEOS, bending angle can be measured under the assumption of local spherical symmetry of earth's atmosphere. As LEOS is moving in its orbit, it can see a few GPS/GNSS satellites rising/setting and in the process vertical profiling of bending angle/refractivity at different locations on the globe is possible. It is the neutral atmospheric refractivity, which is related to atmospheric parameters, pressure, temperature and humidity [6], by equation (1).

$$N = c_1 \frac{P}{T} + c_2 \frac{e}{T^2} \tag{1}$$

Where N is atmospheric refractivity, P is atmospheric pressure in hPa, T is atmospheric temperature in K, e is partial pressure of water vapor in the atmosphere in hPa, c_1 and c_2 are constants with values 77.6 $KhPa^{-1}$ and 3.73×10^5 K^{-2} hPa. Equation (1) together with integral equation for pressure (2) resulting from hydrostatic assumption for atmosphere, form a system of equations with three unknowns (P, T, e) and two known parameters (N and height z).

$$P(z) = \int_z^{\infty} [-\frac{gm_d N}{77.6R} + \frac{3.73\times 10^5 gm_d e}{77.6RT^2} + \frac{g(m_d - m_w)e}{RT}]dz \qquad (2)$$

1-d variational assimilation of refractivity/bending angle is currently operationally used worldwide to retrieve atmospheric parameters [2, 7]. However, there exist techniques, which use auxiliary information like surface temperature and pressure with some assumptions or empirical evidence and retrieve atmospheric parameter (*P*, *T*, and *e*) vertical profiles from refractivity profiles [8-9]. Improvements to one such technique [9] referred to here as refined temperature (RT) technique is discussed in this paper.

2. A brief description of refined temperature technique

With equations (1) and (2), one can solve them if there is no water vapor present in the atmosphere with the assumption of boundary condition at the top of the atmosphere (typically at ~ 60 km) taken from a climatology, to get temperature and pressure vertical profile. The integrations errors due to any errors in boundary condition at ~ 60 km reduce as one comes to lower altitudes. The temperature/pressure profiles obtained in this way is referred as 'dry' temperatures/pressures. Figure 1 shows a dry temperature profile retrieved from refractivity profile. It may be seen that the 'dry' temperature differs from actual temperatures in the lower troposphere mainly because of errors due to assumption of no water vapor. It can also be seen that water vapor may be generally neglected above ~ 10-12 km altitude. One can normally identify tropopause altitude in the tropical latitudes without much problem using 'dry' temperatures and search for an altitude where temperature reaches 230 K and the altitude so obtained may be treated as demarcation altitude separating 'dry' and 'moist' atmosphere. From this altitude referred here afterwards as water vapor point (wvp) [8], we can estimate a vertical profile of temperature by assuming a linear fit using 'dry' temperature value at wvp altitude and surfce temperature. Another profile of temperature may be estimated by estimating first term of right hand side of equation (1) as a linear fit using surface temperature and pressure and presuming dry term approximates actual value at wvp. The resulting three equations (3) to (5) are solved to obtain a temperature profile between wvp and lowest level where

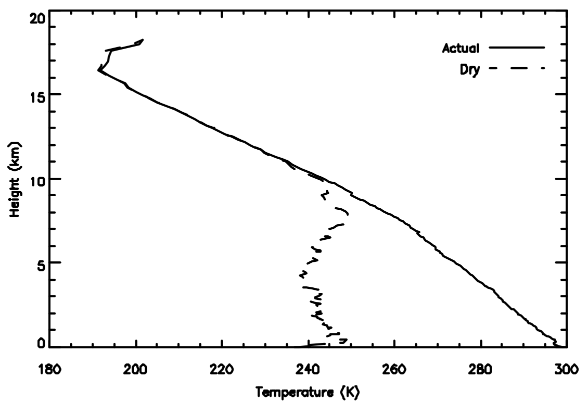

Fig. 1. An example of 'dry' temperatures retrieved from refractivity.

refractivity is available.

$$P = \int_{z}^{z_w} -\frac{g}{R}\left(\frac{N_1 m_d}{77.6} + \frac{e(m_w - m_d)}{T}\right)dz \qquad (3)$$

$$T = c_1 \frac{P}{N_1} \qquad (4)$$

$$e = \frac{N_2 T^2}{c_2} \qquad (5)$$

N_1 and N_2 are first two terms of refractivity in equation (1) respectively. Molecular weight of dry air and water vapor are denoted as m_d and m_w respectively and g is acceleration due to gravity in equation (3). The average of linearly fitted temperature profile and the temperature profile obtained by solving equations (3) to (5) is referred as refined temperature. Using refined temperature profile one can solve (1) and (2) to obtain pressure and water vapor pressure profiles. The technique was applied on a large number of radiosonde derived refractivity profiles and refined temperature is found to be a better approximation. An example of refined temperature thus retrieved is shown in Figure 2.

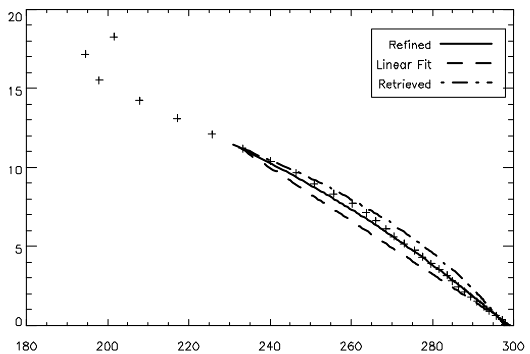

Fig. 2. An example of refined temperature estimated along with actual temperatures (denoted by + symbol in the figure).

In Figure 2 retrieved temperature refers to temperature profile obtained by solving equations (3) to (5).

3. Improved estimation of water vapor point

As pointed out, wvp is determined as the height where temperature approaches ~ 230 K below tropopause. Some times troposphere may be dry at altitudes lower than this. How do we detect such cases? We came up with an approach where in we successfully detected many number of cases where wvp can be at much lower heights. Given refractivity profile say from lower altitude (where refractivity is N_s) to tropopause, we can calculate N_s-1 (nearest integer) profiles of refined temperature by successvily increasing wet term by 1 N units. We can apply constraints to the temperature profiles thus obtained such as (i) relative humidity retrieved should be within 0 to 100%, and (ii) temperature retrieved

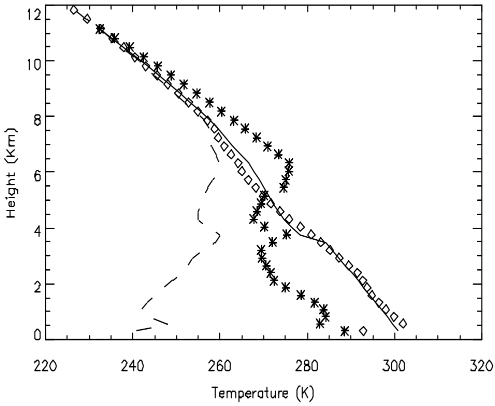

Fig. 3. Actual temperature profile (denoted by open square symbol) along with parameterized temperature profile (solid line), dry temperature (dashed line), and solution where relative humidity is maximum (denoted by star symbol).

should be >= dry temperature so as to rule out unrealistic temperature profiles.

Figure 3 shows an example of actual temperature and a parameterized profile using the above two constraints. It may also be noted from Figure 3 that 'refined temperature' corresponding to maximum relative humidity shows a contrasting behaviour in the 'dry' and 'wet' troposphere. In this example we can easily identify that wvp is around 5 km altitude as opposed to 10 km where temperature is ~ 230 K.

The procedure outlined above is applied to neutral atmospheric refractivity profiles derived from 5040 radiosonde measured profiles [10] of temperature, humidity and pressure in the tropical region (30^0 S – 30^0 N latitudes). The resulting temperature and pressure retrieved at new estimates of wvp is shown in Figures 4 and 5. It may be seen that wvp can be at a height as low as 800 hPa level (~ 2 km above mean sea level). The mean bias and rms for temperatures retrieved at wvp are –0.11 K and 0.85 K respectively. The mean bias and rms for pressure at water vapor point is 0.32 hPa and 0.47 hPa respectively.

We wish to state here that the results obtained here are by no means complete and further work is under progress. Though a large number of cases were there, where wvp could be identified much below 10 km, there are also a good number of cases where the refractivity profiles could not be constrained and wvp was detected at a height of ~10 km though they may be much lower.

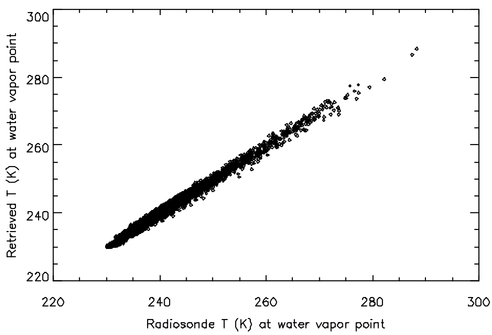

Fig.4. Temperature retrieved at water vapor point versus measurements at water vapor point.

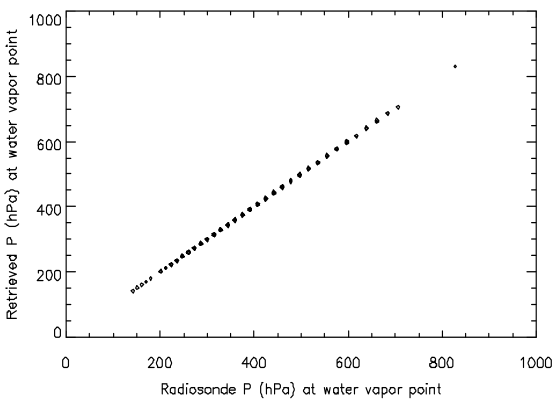

Fig. 5. Pressure retrieved versus actual measurements at water vapor point.

4. Concluding remarks

Preliminary results of our work to improve temperature and humidity from neutral atmospheric refractivity profiles are outlined here. Refined temperature method is used to improve estimation of water vapor point in the tropical region using neutral atmospheric refractivity profile. There is a significant reduction in water vapor height for the cases when atmosphere is dry above ~ 5 km. This is a distinct improvement from the earlier studies which used the height below tropopause where temperature approached ~ 230 K as wvp which resulted in wvp around ~ 10 km or above over the tropics most of the times. These results are encouraging and were able to detect water vapor point to a good accuracy for a large number of refractivity profiles. Further work is under progress to apply it on real radio occultation derived refractivity profiles and application during important weather events like cyclones and depressions.

Acknowledgment

We thank Chairman, ISRO/Secretary, DOS and Scientific Secretary, ISRO for the kind support and encouragement.

References

[1] R. A. Anthes and Coauthors, "The COSMIC/FORMOSAT-3 mission: Early results," *Bull. Amer. Meteor. Soc.,* vol. 20, pp. 313-333, 2008.

[2] M. E. Gorbunov and L. Kornblueh, "Principles of variational assimilation of GNSS radio occultation data", Max-Planck Institut fur Meteorologie, Report 119, pp. 58, 2003.

[3] E. R. Kursinski, G. A. Hajj, J. T. Schofield, R. P. Linfield, and K. R. Hardy, "Observing the Earth's atmosphere with radio occultation measurements using the Global Positioning System", *J. Geophys. Res.,* vol. 102, pp. 23429-23465, 1997.

[4] C. Rocken, Y. H. Kuo, W. Schreiner, D. Hunt, S. Sokolovskiy, and C. McCormick, "COSMIC system description", *Terr. Atmos. Oceanic Sci.,* vol. 11, pp. 21-52, 2000.

[5] S. Sokolovskiy, "Tracking tropospheric radio occultation signals from low earth orbit", *Radio Sci.,* vol. 36, pp. 483-498, 2001.

[6] E. K. Smith, and S. Weintraub, "The constants in the equation for atmospheric refractive index at radio frequencies", *Proc. IRE,* vol. 41, pp. 1035-1037, 1953.

[7] A. von Engeln, G. Nedoluha, G. Krichengast, and S. Buhler, "One dimensional variational (1-D Var) retrieval of temperature, water vapor, and a reference pressure from radio occultation measurements: A sensitivity analysis", *J. Geophys. Res.,* vol. 108, pp. 4337-4349, 2003.

[8] D. B. O'Sullivan, B. M. Herman, D. Feng, D. E. Flittner, and D. M. Ward, "Retrieval of water vapor profiles from GPS/MET radio occultations,"*Bull. Amer. Meteor. Soc.,* vol. 81, pp.1031-1040, 2000.

[9] D. Jagadheesha, B. Simon, P. K. Pal, P. C. Joshi, and A. Maheshwari, "A new technique for estimation of lower tropospheric temperature and water vapor profiles from radio occultation refractivity", *J. Atmos. Oceanic Technol.,* vol. 26, pp. 1075-1089, 2009.

[10] S. W. Seemann, J. Li, W. P. Menzel, and L. E. Gumley, "Operational retrieval of atmospheric temperature, moisture and ozone profiles from MODIS infrared sounders", *J. Appl. Meteorol.,* vol. 42, pp. 1072-1091, 2003.