AN ANALYSIS OF CONTRIBUTION OF THE TROPOSPHERE AND LOWER STRATOSPHERE LAYERS TO FORMING OF THE TROPOSPHERIC DELAY WET COMPONENT

Fedir Zablotskyj, Alexandra Zablotska and Natalya Dovhan
National University "Lviv Polytechnic"
Chair of Geodesy and Astronomy

Abstract

An estimation was made of the most influential layers of the lower atmosphere into quantity formation of the wet component of zenith tropospheric delay in summer in the Antarctic regions as well as in the West and South-West regions of Ukraine.
The Central Antarctica Region is distinguished especially inasmuch as an extratropospheric part of the wet component and is there dominating in the total value of wet component.
An analysis of the most widely used *Saastamoinen* and *Hopfield* analytical models assigned for the determination of the wet component was realized.

The lower (neutral) atmosphere is one of the main error sources which reduces essentially an accuracy of GPS measurements. The error caused by the neutral atmosphere effect (tropospheric delay) has two components – dry and wet ones.
The total tropospheric delay is expressed as:

$$d_{trop} = d_d^z \cdot m_d + d_w^z \cdot m_w,$$

where d_d^z and d_w^z are zenith dry and wet components respectively; m_d, m_w are mapping functions of the components of zenith tropospheric delay at zenith angles $Z > 0°$.

On the whole it may be defined either by vertical profiles of the meteorological parameters measured at the moment of GPS measurements or by the way of modeling of such profiles. The first way is pretty unwieldy, expensive and inefficient.

The second one presents as a rule the generally averaged vertical profiles in the form of analytical models and resolves to determine the first component of tropospheric delay with relatively high accuracy. A determination of the second component is a problem task as the wet component forecasting is very complicated because of the difficulty of the establishment of water vapour quantity in the lower atmosphere. Therefore the error of the determination of the wet component amounts to several tens of millimetres even in the zenith zone.

The cause of unsatisfactory precision of the determination of the wet component of zenith tropospheric delay in polar regions by means of existing analytical models consists in the following. In general it is accepted that the value of water vapour pressure drops to zero at the boundary of troposphere and tropopause and therefore an air humidity profile for the determination of water vapour pressure is recommended to take into consideration to the upper boundary of troposphere. Practically all analytical models for the determination of the wet component are constructed on that ground. This approach satisfies to some extent the reality for low and middle latitudes. At high latitudes and first of all in Antarctic Region both the stratification itself and the structure of the lower atmosphere differ essentially.

Though the value of the wet component of zenith tropospheric delay is here significantly less than in the middle latitudes, the essential part of it, namely about 20%, concentrates in the lower stratosphere of the Antarctic coast zone. It should be noted that the differences of air temperatures at the altitude of 17 km above sea level average -16°_ in summer period between Odesa and Mirnyj stations and -15°_ between Odesa and Heise Island (the Central Arctic) stations. Thus as a result of the establishment of the "warm" lower stratosphere in polar regions during the summer period, a considerable proportion of water vapour mass part accumulates here and that is what forms a certain increase of water vapour partial pressure and the value of zenith tropospheric delay wet component accordingly.
The averaged percentage of the wet component d_w and the water vapour partial pressure e in three high atmospheric layers of Mirnyj and Odesa stations for summer period are shown in table 1.

Table 1

Average quantitative characteristics (%) of the wet component of zenith tropospheric delay and of the water vapour pressure in the different atmospheric layers at the stations

Wet component d_W^Z			H_{TROP}	H_U	Vapour pressure e		
0.04-2 km	2 km-H_{TROP}	H_{TROP} - H_U			0.04-2 km	2 km-H_{TROP}	H_{TROP} -H_U
M i r n y j							
48.4	30.2	21.4	8.12	25.21	52.8	29.1	18.1
O d e s s a							
60.4	38.9	0.8	10.92	24.00	63.7	35.8	0.5

The values H_{TROP} characterize the upper boundary of troposphere and the values H_U – the upper boundary of relative humidity sounding.
As it is obvious, the value of the wet component of zenith tropospheric delay which is formed by extratropospheric layers of atmosphere exceeds 20% at Mirnyj station and amounts to 0.8% only at Odessa station. According to table 1 a close correlation between the distribution of the wet component of zenith tropospheric delay and water vapour partial pressure is observed.

As long as the aim of our paper was to make an estimation of the most influential layers of the lower atmosphere into quantity formation of the wet component of zenith tropospheric delay in summer period we chose additionally 14 vertical profiles obtained from aerological sounding for each station:
Mirnyj – Antarctic Coast Zone; Vostok – the Central Antarctica;
Lviv - the West region of Ukraine; Odessa - the South-West region of Ukraine.

At the same time the atmospheric models were made up for the vertical profiles with the measurements of the relative humidity not less than up to the altitude of 24 km above sea level (the mean isobaric surface corresponds to 30 hPa).
A special attention was devoted to the Central Antarctica where the extremely low temperatures cause a very small content of water vapour in the air. Thus, the average monthly surface quantity of water vapour pressure at Vostok station amounts to only 0.25 hPa for January and declines to 0.03 hPa at the upper boundary of the troposphere.

Table 2

Averaged meteorological parameters and parts of the wet component of zenith tropospheric delay d_w (mm)

H_0 km	P_0	t_0	U_0	d_w 850	d_w 700	d_w 500	d_w H_{TROP}	d_w 30	d_w total.	δd_w (SA)	δd_w (HO)
O d e s s a											
0.04	1010.4	18.8	77	84.6	51.6	30.8	8.4	1.4	176.7	10.1	8.8
L v i v											
0.33	976	17.8	77	68.8	54.6	36.5	12.3	2.4	174.7	22.1	18.7
M i r n y j											
0.04	983.8	-4.2	73	16.1	11.7	8.3	2.4	7.9	46.4	10.2	-0.7
V o s t o k											
3.49	633.0	-34.5	70	-	-	3.1	2.2	14.1	19.4	16.1	13.6

Notice: P_0, t_0, U_0 - atmospheric pressure (hPa), air temperature (°_) and relative humidity (%) at the station level H_0;

d_w - part of the wet component of zenith tropospheric delay in the atmospheric layers "station level – 850 hPa ", "850 – 700 hPa ", "700 – 500 hPa ", "500 hPa – upper boundary of the troposphere ", " upper boundary of the troposphere – 30 hPa ";

$d_{w(total)}$ - total value of the wet component of zenith tropospheric delay;

δd_w (SA) and δd_w (HO) – differences between the total value of the wet component of zenith tropospheric delay obtained by means of the aerological profile and the total value of the wet component calculated after *Saastamoinen _ Hopfield* models.

In addition, we give the results (table 2) which characterize the percentage part of the wet component of zenith tropospheric delay in the above mentioned atmospheric layers.

Table 3

Averaged parts of the wet component of zenith tropospheric delay in the atmospheric layers

Station	H_0 - 850 hPa	850- 700 hPa	700- 500 hPa	500 hPa - H_{trop}	H_{trop} - 30 hPa
Odessa	47.9	29.3	17.4	4.6	0.9
Lviv	39.4	31.2	21.0	7.0	1.4
Mirnyj	34.8	25.2	17.9	5.2	16.9
Vostok	-	-	16.0	11.3	72.7

As it is obvious from the data of tables 1-3, the two lower layers of troposphere "station level – 850 hPa" and "850 – 700 hPa" import about 70% into the total quantity of the wet component in the middle latitudes. The next layer "700 – 500 hPa" adds another almost 20%. Hence, the three lower layers of the troposphere import about 95% of the wet component into the total quantity of it at Odessa station and over of 90% - at Lviv one.
The contribution of these layers at the Antarctic coast zone decreases to 80%, and in the Central Antarctica it amounts to only 16%.

On the basis of our investigations the following should be noted for the summer period:

- in the middle latitudes a predominant mass of the atmospheric water vapour is located in the lower half of the troposphere. The part of the wet component of zenith tropospheric delay amounts to 5.5% and 8.4% in the layers of the atmosphere between 500 and 30 hPa at the Odessa and Lviv stations accordingly;
- at the high latitudes and especially in Antarctica the water vapour is pushed up into higher layers of the atmosphere. At the same time this process increases with displacement from the coast zone to the central part of the continent. So the part of the wet component of zenith tropospheric delay makes up in the atmospheric layers from 500 to 30 hPa 22.1% at Mirnyj station and 84% (!) at Vostok one;
- the existing analytical models, as it is shown in table 2, do not provide a high accuracy of determination of the wet component of zenith tropospheric delay.

Conclusions

The extratropospheric contribution to the formation of the total value of the wet component of zenith tropospheric delay is very essential in polar regions and first of all in Antarctica in contrast to the middle latitudes. For more precise account of the wet component of tropospheric delay influence on the results of GPS measurements in summer period in polar regions it is necessary to include to the total humidity the extratropospheric part of it up to the about 25 km height. This value may be modelled on the basis of detailed analysis of the lower atmosphere stratification by means of aerological data of the polar stations at which the permanent GPS observations or the long GPS campaigns are already being carried out.