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ON THE LOWER ATMOSPHERE EFFECT NATURE IN GPS AND SLR MEASUREMENTS IN POLAR REGIONS

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Abstract
The paper studies some determination peculiarities of atmospheric propagation delay by the microwave- and laser distance measurements in polar regions. On the basis of the average monthly and separate (one-time) aerological sounding data at a number of Antarctic and Arctic stations the distribution analysis of the main meteorological parameters as well as of refractivity both in space and in time is adduced. Zenith atmospheric delay for microwave- and laser range was estimated by the data of these stations. A small effect of moist component (zenith wet delay) in the Central Antarctica is noted. The values of dry and wet components of the zenith tropospheric delay obtained by radiosonde data and Saastamoinen and Hopfield's analytical models are cited.

1. Introduction

At present satellite distance measurements and especially GPS observations find a wide use for solution a lot of diverse scientific and real-world problems in polar regions and first of all in Antarctica. There is the developed network of GPS permanent stations and the yearly 20-day's GPS campaigns acquire more and more prevalence at many Antarctic stations (Ukrainian station "Academic Vernadskyj" participated in 1998), two VLBI stations are working permanently and SLR stations are getting ready for permanent observations. Therefore a study of atmospheric effects on the results of GPS and SLR measurements should be carry out not only on a global or regional scale but also on a local one (at the individual permanent GPS or SLR stations).

2. Peculiarities of the vertical distribution of air temperature, water vapour pressure and refractivity

In polar regions according to long-terms mean monthly aerological sounding data it has been established that the vertical distribution of air temperature in the atmospheric boundary layer is characterized mainly by the stable thermal stratification and by the corresponding vertical distribution of air humidity. The mean capacity of the ground inversion layer amounts 300 m over Antarctic coast zone and 720 m in Central Antarctica (see table 1). The ground inversion intensity makes up in average 2.8 and 17.1°C per year accordingly and its recurrence reaches

75 and 98% (Voskresensky and Tsigelnitsky, 1985). The vertical temperature gradient in the lower 100-metres layer of the continent centre reaches the extremal values on the terrestrial globe ~ 40-50°C/100m. The mean capacity in Central Arctica makes up 1.19 km in January and 0.64 km in July. The air humidity in Central Antarctica is extraordinarily small in winter owing to the lowest near surface air temperature and its value makes up 0.08 hPa only. The vertical distribution of it has there a vividly expressed inversion character. The value variation of air humidity at the Antarctic coast is small in a height in winter – from 1.4 hPa at the surface to 0.5 hPa at the height of 3 km and it decreases in summer uniformly from 4 hPa to 1.2 hPa.

Table 1. Average seasonal characteristics of capacity (H,m), intensity (Δt,°C) and recurrence (f,%) of temperature inversions

Station	Characte-ristics	Season			
		Summer	Autumn	Winter	Spring
Vostok	H	583	800	773	750
	Δt	6.7	23.4	24.9	17.1
	f	96	100	100	96
Mirnyj	H	240	347	353	303
	Δt	1.9	2.7	3.1	2.7
	f	68	73	74	72

Table 2. Average monthly meteorological parameters, air refractivity and their gradients in the atmospheric boundary layer

H	t	P	e	γ_t	γ_e	N_L	G_{NL}	N_R	G_{NR}
		Antarctic		*Vostok station*			*December*		
3.49	-31.7	634	0.29	-4.00	-0.15	211.0	31.7	205.7	29.7
3.69	-30.9	617	0.32	1.94	0.10	204.6	26.2	199.7	25.9
4	-31.5	591	0.29	4.36	0.10	196.5	33.3	191.7	32.8
4.39	-33.2	548	0.25			183.5		178.9	
		Antarctic		*Vostok station*			*July*		
3.49	-67.2	629	0.00	-82.00	-0.20	245.4	124.8	237.1	119.1
3.69	-50.8	610	0.04	-29.03	-0.23	220.4	57.9	213.3	54.5
4	-41.8	583	0.11	0.26	0.00	202.5	30.1	196.4	29.0
4.39	-41.9	549	0.11			190.7		185.0	
		Antarctic		*Mirnyj station*			*January*		
0.04	-3.3	986	3.42	-0.62	1.31	293.4	37.8	301.0	43.3
0.2	-3.2	966	3.21	4.67	1.15	287.4	30.9	294.0	35.1
0.5	-4.6	930	2.87	5.60	1.00	278.1	29.2	283.5	32.8
1	-7.4	872	2.37			263.5		267.1	
		Antarctic		*Mirnyj station*			*July*		
0.04	-17.1	983	1.44	-8.13	0.62	308.4	52.6	306.1	54.9
0.2	-15.8	961	1.34	3.67	0.50	300.0	34.4	297.3	35.8
0.5	-16.9	924	1.19	4.20	0.44	289.7	33.1	286.6	34.3
1	-19	864	0.97			273.1		269.4	
		Arctic		*Heys Isle station*			*July*		
0	0.5	1008.9	5.9	1.11	1.11	296.0	35.0	315.2	39.1
0.18	0.3	986.7	5.7	0.00	0.33	289.7	35.3	308.2	35.8
0.48	0.3	950.6	5.6	-0.60	0.60	279.1	34.4	297.4	36.3
0.98	0.6	893	5.3			261.9		279.3	

		Arctic			*Heys Isle station*			*January*	
0	-28.2	1010.7	0.5	-10.00	-0.56	331.5	57.1	323.4	52.0
0.18	-26.4	986.6	0.6	-6.33	-0.33	321.2	51.6	314.0	48.0
0.48	-24.5	946.3	0.7	-3.60	-0.20	305.8	44.8	299.6	42.2
0.98	-22.7	883.4	0.8			283.4		278.5	

Legend: H - layer height (km); t - air temperature (°C); P - total air presse (hPa); e - water vapour pressure (hPa); γ_t - vertical temperature gradient (°C/km); γ_e - vertical gradient of water vapour pressure (hPa/km); N_L, G_{NL} - air refractivity for laser range (N un.) and its vertical gradient (N un./km); N_R, G_{NR} - air refractivity for radio waves (N un.) and its vertical gradient (N un./km).

In summer, the air humidity changes from 0.3 hPa to 0.4 hPa within the altitude range from 0 to 3 km and it is similar to humidity values of a wintry period in Arctica. On the whole, the vertical distribution of air humidity is in keeping with the air temperature distribution.

From analysis of the vertical distribution of air refractivity for light-and radio waves in troposphere by the data of aerological soungings in different geographical regions it follows that (Zablotskyj and Kachmar, 1984; Zablotskyj, 1986; Zablotskyj, 2001,b):

- the ratio $|G_{NR}| > |G_{NL}|$ is typical at the normal stratification of the lower layers of atmosphere in all regions with the exception of Central Antarctica. At the super- adiabatic gradients $|G_{NR}| >> |G_{NL}|$;
- at the isothermal stratification the ratio is close to equality $G_{NR} \approx G_{NL}$;
- increase of temperature inversion causes an abrupt decrease of the air refractivity both for radio- and light waves with a height. In every cause $|G_{NR}| < |G_{NL}|$, and at sizeable increase of air humidity inversion the values G_{NL} exceed much more G_{NR} in absolute value. At the super intensive inversions of air temperature (Vostok station, wintry period), gradients G_{NR} and G_{NL} exceed modulo 10-15 times as much corresponding quantities for the conditions of normal temperature stratification or the close to isothermal one in the lower layers of atmosphere.

The nature of refractivity propagation in polar regions has some peculiar properties in comparison with the middle and low latitudes. From the surface meteorological data it follows:

- the ratio $N_R < N_L$ predominates in polar regions, and in particular in Antarctica, in contrast to another regions where the refractivity of radio waves is much greater;
- the most stable difference $\Delta N = N_R - N_L$ is observed in Central Antarctica and its annual amplitude (A) does not exceed 3 units of N. At the Antarctic coast zone the value ΔN is positive in January and February only;
- in Arctic regions the ratio $N_R > N_L$ is being observed from June till September and annual amplitude of ΔN amounts to 30 units of N;
- a daily variation of refractivity both light- and radio waves is not large, a maximal amplitude falls in the autumn period in Arctica and in the spring period in Antarctica (by data of Mirnyj station) and it does not exceed 6-8 units of N.

3. Some results of the atmospheric effect on GPS and SLR Measurements

On the basis of the average monthly aerological sounding data of four Antarctic and three Arctic stations as well as of double per day soundings (at 6 and 18 o'clock of the local mean time) during one summer month – January at the Mirnyj station the values of zenith atmospheric delay for microwave- and laser range were calculated by integration. In table 3 are shown only some results, more detail ones and their analysis are illustrated in the publications (Zablotskyj, 2000; Zablotskyj, (2001,a).

It should be noted that .in polar regions for the exception of Central Antarctica the determination of atmospheric delay for laser range is realised with more high accurasy than tropospheric delay for radio range sinse the wet component is determined unreliably. The value ΔS_L or d_{total} forms at the Vostok station only ~ 60% of corresponding delay in comparison with other stations (Antarctic coast zone and Arctica). That is caused by a great height of the station about see level. The wet component is very small there as the atmospheric air is close to dry one especially in winter.

Table 3. Values of zenith atmospheric and tropospheric delay at the polar stations

H_0 (km)	P_0 (hPa)	t_0 (°C)	e_0 (hPa)	ΔS_L (mm)	$\delta\Delta S_L$ (mm)	d_{total} (mm)	δd_{total} (mm)
"Vostok" December, 1966/July, 1966							
3.49	634	-31.7	0.29	1491	-1	1448	3
3.49	629	-67.2	0.004	1476	-4	1428	- 2
"Mirnyj" January/ July							
0.04	986	-3.3	2.16	2323	3	2292	10
0.04	983	-17.1	0.91	2318	5	2261	7
"Mirnyj" 1.01.1959/21.01.1959							
0.04	985	-4.0	4.14	2323	5	2312	25
0.04	988	-3.4	3.95	2328	3	2269	-23
"Akademik Vernadskyj" January/August							
0.01	987	0.0	5.38	2327	4	2317	16
0.01	991	-13.8	2.12	2340	8	2297	20
"Heys Isle" July/January							
0.02	1009	0.7	5.98	2387	14	2.401	42
0.02	1011	-28.2	0.58	2389	12	2.323	20

Legend: t_0, P_0, e_0 – meteorological parameters at a station height H_0; ΔS_L, d_{total} - zenith atmospheric
delay for laser and radio range from radiosonde data; δS_L, δd_{total} - difference between radiosonde
delay and computed one by Murray & Marini and Saastamoinen's analytical model.

Table 4. Zenith tropospheric delay of radio waves by radiosonde data and analytical models (mm)

Station	Month or Date	d_d	d_w	δd_d (SA)	δd_w (SA)	δd_d (HO)	δd_w (HO)
Vostok	December July	1441 1427	7 1	-1 -3	4 1	-3 -2	1 1
Mirnyj	January July	2242 2238	50 23	1 4	27 13	-6 -2	20 8
Mirnyj	1.01.59 21.01.59	2241 2248	71 22	2 2	27 -20	-5 -5	13 -33
Akademik Vernadskyj	January August	2245 2259	72 38	1 6	15 14	-6 1	1 4
Heys Isle	July January	2301 2307	100 16	9 11	37 9	0 5	21 4

In table 4 the following designations are cited:

d_d, d_w - dry and wet components of zenith tropospheric delay computed by the radiosonde data;

δd_d(SA), δd_w(SA), δd_d(HO), δd_w(HO) - differences between the radiosonde components and calculated by Saastamoinen and Hopfield's analytical models.

At the Antarctic coast zone and in North Arctica the value of vet component of tropospheric delay makes up 3÷4% of its total value in sumer and 1÷2 in winter. As is obvious from table 4 the results obtained by the Saastamoinen and Hopfield's analytical models are approximatelt of equal accurasy. However there is a steady displacement between both dry and wet components calculated by these models. A determination method of zenith tropospheric delay wet component in polar regions was developed and published (Zablotskyj, 2001,a).

In conclusion it should be noted one more specificity. The superintensive ground and elevated temperature inversions in polar regions and especially in Central Antarctica provoke not only the quick decrease of refractivity with a height but appreciable bending of a ray path in the atmospheric boundary layer. In this connection is of fundamental importance a selection matter of the correct mapping function in GPS and SLR measurements at the large zenith angles. At the same time, the supplementary investigations are required for the final conclusion.

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Про характер впливу нижньої атмосфери на GPS і SLR виміри в полярних регіонах

Федір Заблоцький

Анотація

В роботі висвітлені деякі особливості визначення атмосферної затримки при лазерних і і радіовіддалемірних супутникових вимірах. На основі середньомісячних і разових даних із аерологічного зондування на декількох антарктичних і арктичних станціях проведено аналіз розподілу основних метеорологічних параметрів, індексу показника заломлення повітря, а також оцінку атмосферної затримки для оптичного- і радіодіапазону. Приведені величини сухої і вологої складових зенітної тропосферної затримки, отримані як шляхом інтегрування, так і за аналітичними моделями Саастамойнена і Хопфілд.

O charakterze wpływu dolnej atmosfery na GPS i SLR pomiary w regionach polarnych

Fedir Zablockyj

streszczenie

W pracy przedstawiono niektóre osobliwości wyznaczenia pochłaniania atmosfery przy pomiarach laserowych i w paśmie radiowym. Na podstawie średnio-miesięcznych danych z radiosond na kilku antarktycznych i arktycznych stacjach przeprowadzono analizy rozkładu głównych parametrów meteorologicznych, współczynnika refrakcji i dokonano oceny pochłaniania atmosfery dla zakresów :optycznego i radiowego . Wartości suchej i wilgotnej składowej zenitalnej pochłaniania troposfery, otrzymano drogą całkowania i przez zastosowanie modeli analitycznych Saastamoinena i Hopfielda.