ABSTRACT

The influence of extraterrestrial phenomena is expected to have an impact on human health, and therefore on mortality in particular civilization and degenerative diseases. The main aim of this contribution is to assemble descriptive characteristics that represent the impact of the solar and geomagnetic activity on mortality by cause of death from groups VI. Diseases of the nervous system and IX. Diseases of the circulatory system. We study the daily number of deaths separately for both sexes at the age groups under 39 and 40+. Differences are found for maximum solar activity and during the ascending and descending epoch of the solar cycles.

We have constructed the characteristics that represent the risk of the solar activity on human health on the basis of the previous analysis of association between the daily numbers of death on diseases of the nervous system and diseases of the circulatory system and the solar and geomagnetic parameters in the Czech Republic during the years 1994 – 2013. These characteristics were constructed using the method of graphical models of conditional dependencies (CIG) in time series according to the phases of the solar cycle and the seasonal insolation at mid-latitudes.

The risk characteristics of solar and geomagnetic activity

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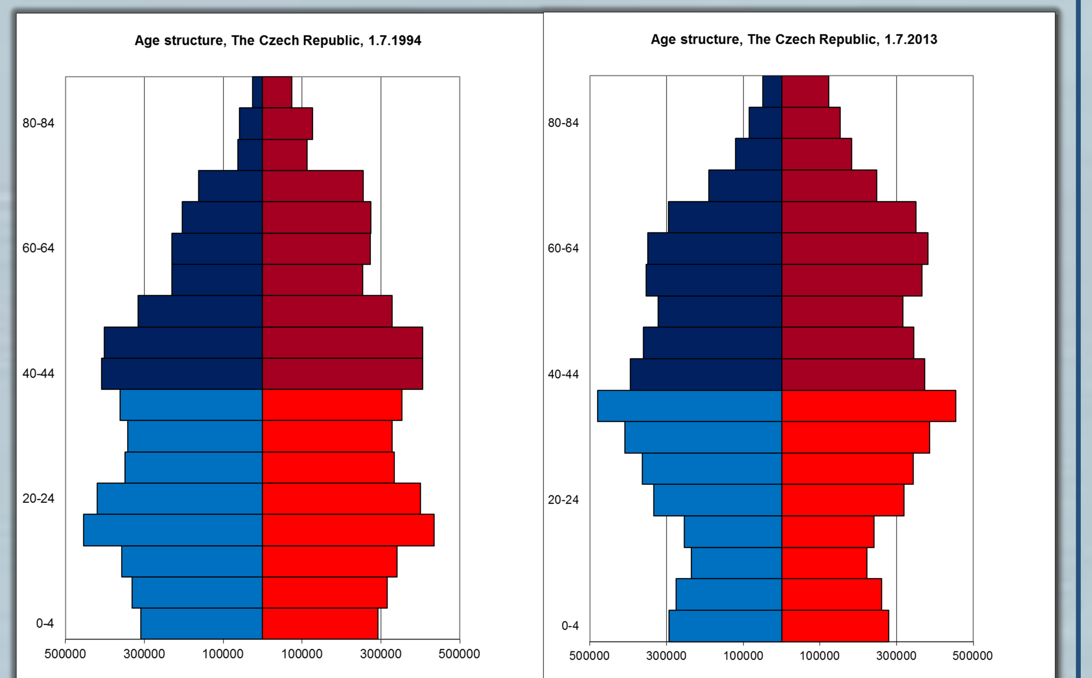
DATA AND REGIONAL DELINEATION



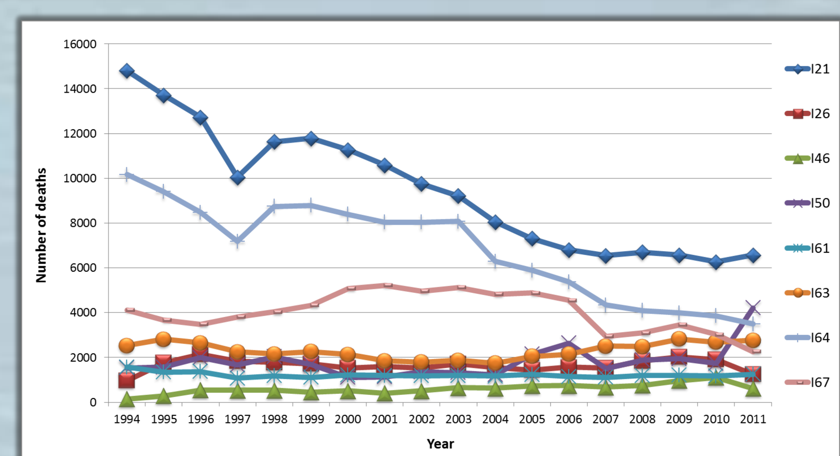


Figure 1: top: Age structure of the population of The Czech Republic with coloured investigated age and sex groups in the begin and the end of investigated period 1994–2013. The age groups under 39 and 40+ in the analysis were used.
below: Numbers of deaths on main causes of diseases of cardiovascular system in the Czech Republic, 1994–2011.

The mortality in the Czech Republic (population of about 10 million) in a investigated period of years from 1994 to 2013 has significantly decreased. Registration of deaths by cause of death is very stable in the Czech Republic in long-term. The most frequent group of causes of death are in long terms diseases of the circulatory system; in 2013 their share in the total standardised death rate (standardised by WHO European standard) was 44.8 % (43.1 % in men and 46.8 % in women). The next were malignant neoplasms with shares 26.4 % in men and 25.8 % in women. In 2012, according to the Eurostat data Healthy Life Years (HLY) reached the values 62.3 years of 75.1 years of life expectancy at birth for men and 64.1 years of 81.2 years of life expectancy at birth for women. With the increase in life expectancy is increasing incidence of neurodegenerative diseases occurring in the elderly. Age structure of the population of The Czech Republic with coloured investigated age and sex groups in the begin and the end of investigated period 1994–2013 are plotted in the Figure 1.

The radiation solar activity indices R (Relative number of sunspots), F10.7 (Intensity of the Sun radio flux) and the geomagnetic solar activity indices Kp planetary index, and Dst (Disturbance Storm Time) represent solar activity in models. Physical parameters describe the ionospheric effects are foF2 (critical frequency of the ionospheric F2 layer) and TEC (Total Electron Content) and were also included to the model. The ionospheric parameters foF2 and TEC were related to the geographic location of the Czech Republic.

The time series of daily aggregated numbers of deaths by cause, men and women separately at the age groups under 39 and 40+ were used. The data were provided by Czech Statistical Office. Whole observed period belongs to time of validity of ICD-10.

For detailed analysis were chosen causes of death of the chapter VI. Diseases of the nervous system and IX. Diseases of the circulatory system of ICD-10 with higher daily numbers of deaths.

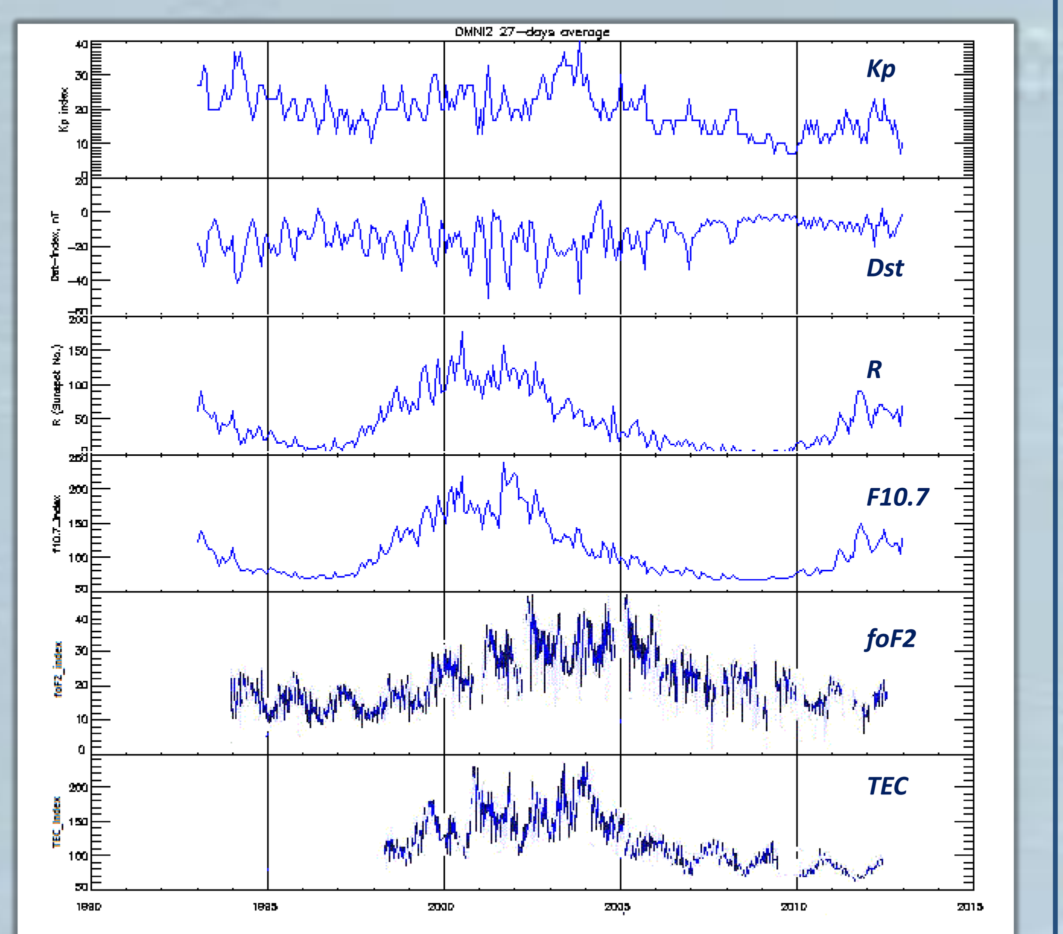
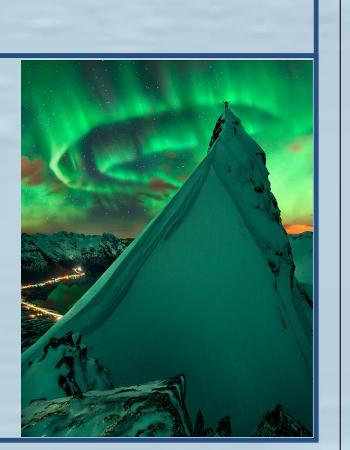


Figure 2: Solar activity variability, investigated period from years 1994 to 2013, Solar Cycles No.23 and No.24

DATA SOURCES

Number of deaths by cause: Czech Statistical Office (CZSO), *Czech Health Statistics Yearbook 2013*, Prague, 2014.
Kp index: World Data Center for Geomagnetism, Kyoto University, Japan.
R, Dst, F10.7: Space Physics Interactive Data Resource, National Geophysical Data Center, Boulder, USA.
Solar cycle evolving: NWRA/CoRA, NorthWest Research Associates, Boulder, USA, Deutsches GeoForschungs Zentrum, Helmholtz-Zentrum, Germany.
foF2: UK Solar System Data Centre, Rutherford Appleton Laboratory, Oxfordshire, GB, ionosonde JR055 Juliusruth/Rugen.
TEC: Institut Géographique National (IGN), France.



	Males <39										
Cause of death		b_0	R	F10.7	Kp	Dst	foF2	TEC	R-squared	% Variability	$D_{<39}^{M}$
I21	Acute myocardial infarction	0,96	-0,0014	0,0017					0,0103	1,03	742
I26	Pulmonary embolism	0,78	-0,0033	0,0032	0,0450	0,0017			0,1448	14,48	231
I50	Heart failure	1,49		0,0012	-0,0688	-0,0013	-0,1363	0,0020	0,0837	8,37	462
I61	Intracerebral haemorrhage	1,11			-0,0567	-0,0039			0,1152	11,52	222
G40	Epilepsy	1,01		0,0003		0,0011			0,0138	1,38	494
Males 40+											
Cause of death		b_0	R	F10.7	Kp	Dst	foF2	TEC	R-squared	% Variability	D_{+40}^{M}
I21	Acute myocardial infarction	6,10	0,0074	0,0457	0,2522	0,0096	0,8076	-0,0148	0,2610	26,10	100191
I26	Pulmonary embolism	3,17	-0,0032	0,0044	-0,0332	0,0022	-0,1043		0,0091	0,91	12656
I50	Heart failure	5,61	0,0099	-0,0136	-0,0751	0,0023	-0,1714		0,0483	4,83	17412
I61	Intracerebral haemorrhage	3,06			-0,0304		-0,1443	0,0030	0,0037	0,37	11881
I63	Cerebral infarction	4,63	0,0020	-0,0056	-0,1356	-0,0030	-0,0779	0,0009	0,0244	2,44	18701
I64	Stroke	1,71	-0,0013	0,0301	0,4245	0,0080	0,6611	-0,0119	0,1999	19,99	48210
I67	Other cerebrovascular diseases	2,84	-0,0023	0,0143	0,1377	0,0014	0,2721	-0,0051	0,0651	6,51	27504
G20	Parkinson disease	1,07			0,0497	0,0013		0,0010	0,0350	3,50	1663
G30	Alzheimer disease	1,51	-0,0014	0,0016				-0,0006	0,0047	0,47	3603
G31	Other degenerative diseases of ns	0,90	-0,0012	0,0034	-0,0134			-0,0012	0,0827	8,27	421
G35	Multiple sclerosis	1,10				0,0010			0,0054	0,54	682
G40	Epilepsy	1,04					0,0583	-0,0010	0,0037	0,37	989
Females <39											
Cause of death		b_0	R	F10.7	Kp	Dst	foF2	TEC	R-squared	% Variability	$D_{<39}^{F}$
I26	Pulmonary embolism	0,91					0,0201		0,0415	4,15	185
G40	Epilepsy	1,12	-0,0008	0,0015	0,0143	0,0011	-0,0749	0,0009	0,1074	10,74	248
Females 40+											
Cause of death		b_0	R	F10.7	Kp	Dst	foF2	TEC	R-squared	% Variability	D_{+40}^{F}
I21	Acute myocardial infarction	5,14	-0,0032	0,0341	0,3064	0,0122	0,4531	-0,0047	0,2097	20,97	75567
I26	Pulmonary embolism	4,18	-0,0049	0,0078	-0,0300	0,0034	-0,1501	-0,0020	0,0274	2,74	17789
I50	Heart failure	6,33	0,0103	-0,0151	-0,1359	0,0044	-0,2306	0,0012	0,0506	5,06	19057
I61	Intracerebral haemorrhage	2,27	-0,0024	0,0016	-0,0548	-0,0022	0,1125	-0,0020	0,0057	0,57	11008
I63	Cerebral infarction	6,86	0,0026	-0,0077	-0,2165	-0,0030	-0,2901	0,0028	0,0611	6,11	25670
I64	Stroke	2,57	0,0025	0,0474	0,3961	0,0020	1,1151	-0,0201	0,2574	25,74	77292
I67	Other cerebrovascular diseases	2,91	-0,0079	0,0303	0,3112	0,0013	0,7255	-0,0149	0,1116	11,16	47478
G20	Parkinson disease	0,92			0,0682	0,0018	0,0702	-0,0014	0,0173	1,73	1205
G30	Alzheimer disease	2,22		-0,0013	0,0355				0,0032	0,32	7315
G31	Other degenerative diseases of ns	0,99						0,0004	0,0209	2,09	392
G35	Multiple sclerosis	1,58		0,0013	0,0294	0,0015	-0,1702	0,0019	0,0511	5,11	1150
G40	Epilepsy	0,88	-0,0022	0,0017	0,0344	0,0020		0,0007	0,0441	4,41	491

Table 1: Estimated coefficients of the linear regression model with solar, geomagnetic and ionospheric parameters regressors.
In the calculation residual analysis was performed. We calculated 95 % confidence intervals for estimates of the mean value of the dependent variable, 95 % confidence intervals for individual estimates and 95 % confidence intervals for estimates of model parameters. Variables were included from the model at the significance level 0.05. When were gradually excluded all explanatory variables from the model, then the model is not listed in the table.

METODOLOGY

The linear regression model (LRM) was performed in SAS 9.4™ by procedure REG to verify the number of deaths dependence on solar and ionospheric parameters during the **solar cycles No.23 and No.24** were used. The linear regression model with regressors solar, geomagnetic and ionospheric parameters is described by the equation [1]:

$$Y = b_0 + b_1Kp + b_2R + b_3F10.7 + b_4Dst + b_5foF2 + b_6TEC + e_i. \qquad [1]$$

where: Y is dependent variable of time series of number of death e.g. *I21, I64, G20, G30; Kp, R, F10.7, Dst, foF2, TEC* are explanatory variables of physical parameters, b_i are the regression coefficients, e_i is the error term.

The best model is selected by the value of the adjusted coefficient of determination, which indicates the percentage of variability of the number of deaths by cause of death explained by the regression model for the given data. Summary of results of the linear regression models with solar activity parameters are shown in the **Table 1**.

Method of graphical models of conditional dependencies (CIG) is stochastic way to find out dependecies between solar, geomagnetic and ionospheric parameters. Due to the character of the solved problem, this method appears as useful for studying the correlationships between physical parameters in evolving Solar cycle. Construction of the likelihood function, the logarithmic likelihood function [2]:

$$2 \log l(W) = \vartheta - N (W^{-1}S)^T - N \log \det W, \qquad [2]$$

where N random sample size, ϑ unknown parameter, S likelihood estimator.

Setting the unknown parametres ϑ_i by maximalization of the likelihood function through unknown parameters set. Likelihood function requirements follow from the graphical model selection. Using the goodness-of Ht test to selected the graphical model with data. The test statistics is the deviance with χ^2 asymptotic probability distribution.

The deviance of the excluded edge was computed by IPF (Iterative Proportional Fitting) algorithm. For selecting the particular graphical model by goodness-of H_t test we used the program Backward2 realised in Mathematica 7.0 . Model selection: all edges with computed deviance < 3.84 were excluded at significance level: 0.05.

Summary of computed risky characteristics on the basis of the LRM and the association of the solar activity parameters during the solar cycles No.23 and No.24 using CIG are shown in the **Table 2**.

CONCLUSION

We constructed the risky characteristics using the method of graphical models of conditional dependencies (CIG) in time series according to the phases of the solar cycle and the seasonal insolation at mid-latitudes.

The reaction of the nervous system to electromagnetic phenomena is significantly differentiated by age and gender. Mortality on epilepsy (G40) in the age group under 40 for both sexes is mostly influenced by magnetic phenomena. In contrast, for this diagnosis the age groups 40+ are mostly influenced by both radiation and ionospheric phenomena.

The age groups 40+ are mostly influenced by all of the radiation, magnetic and ionospheric phenomena except of the diseases of the nervous system.

The results of mortality on cardiovascular diseases analysis for age groups under 40 might be biased by low numbers of deaths on this diagnoses. The obtained results are in accordance with the point of view, which was not direct correlation between the number of deaths on acute myocardial infarction (I21) and brain stroke (I64) with geomagnetic solar indices in the maxima of the solar cycle.

Thus, the analysis shows that the ionospheric parameters foF2 and TEC may, due to the geographically specific values, better explain the variability in the number of deaths than other indices. Thus, the cardiovascular diseases respond to changes in solar activity and occurrence of abnormal solar events indirectly through a concentration of electrical charge in the environment in which the monitored population lives.

Cause of death		Composition of the risky characteristics			rsq
		RAD	MAG	IONO	
Males <39					
I21	Acute myocardial infarction				0,92
I26	Pulmonary embolism				1,31
I50	Heart failure				0,12
I61	Intracerebral haemorrhage				0,21
G40	Epilepsy				1,03
Males 40+					
I21	Acute myocardial infarction				3,09
I26	Pulmonary embolism				1,14
I50	Heart failure				1,66
I61	Intracerebral haemorrhage				0,14
I63	Cerebral infarction				2,00
I64	Stroke				2,93
I67	Other cerebrovascular diseases				3,70
G20	Parkinson disease				3,50
G30	Alzheimer disease				0,02
G31	Other degenerative diseases of ns				1,91
G35	Multiple sclerosis				0,37
G40	Epilepsy				0,36
Females <39					
I26	Pulmonary embolism				4,66
I50	Heart failure				2,45
I61	Intracerebral haemorrhage				4,29
I67	Other cerebrovascular diseases				9,96
G40	Epilepsy				2,16
Females 40+					
I21	Acute myocardial infarction				3,36
I26	Pulmonary embolism				2,70
I50	Heart failure				1,42
I61	Intracerebral haemorrhage				0,53
I63	Cerebral infarction				4,23
I64	Stroke				4,40
I67	Other cerebrovascular diseases				5,01
G20	Parkinson disease				0,24
G30	Alzheimer disease				0,08
G31	Other degenerative diseases of ns				0,79
G35	Multiple sclerosis				1,21
G40	Epilepsy				2,28

***Table 2: Summary of computed risky characteristics** on the basis of the linear regression models and the association between radiation (RAD), magnetic (MAG) and ionospheric (IONO) components of the solar activity parameters using method of graphical models of conditional dependencies.*
Risky characteristics components RAD, MAG and IONO are signed by red colour in the table. Seasonal daylight correction adjusted for 50°N (geographical latitude of Prague) for radiation components was used. Model for computing the risk characteristics was used in form:

$$Y = b_0 + b_1 RAD.\Theta + b_2 MAG + b_3 IONO + e_i.$$

where: Y is dependent variable of time series of number of death e.g. I21, I64, G20, G30; RAD is risk characteristic composed on solar indices, MAG is risk characteristic composed on geomagnetic indices IONO are explanatory variables is risk characteristic composed on ionospheric indices, Θ is duration of daylight, b_i are the regression coefficients, e_i is the error term.

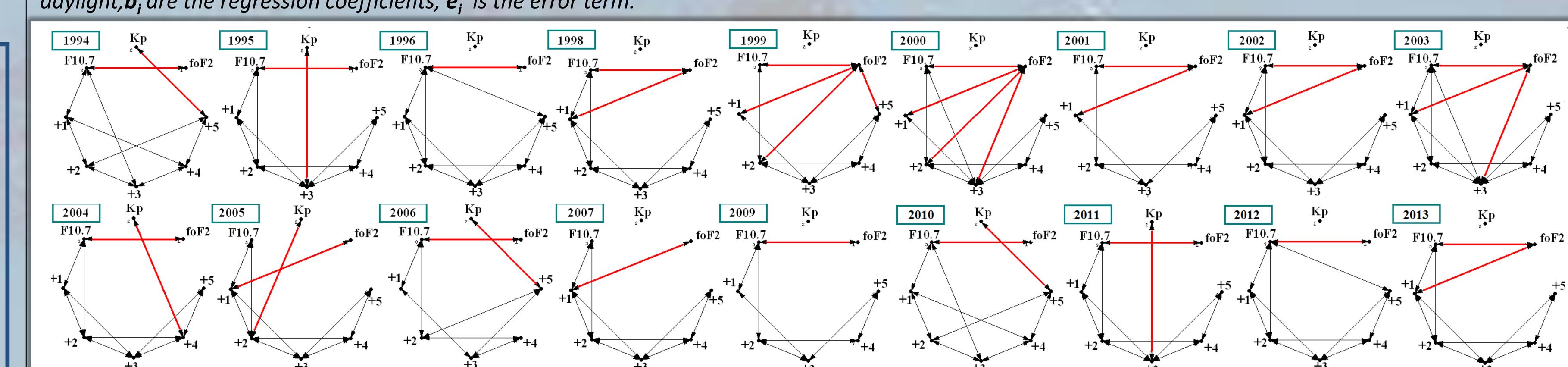


Figure 3: The figure presents minimalized graphs for F10.7, F10.7 +1/ +2/ +3/ +4/ +5 days shifted, Kp and foF2 series during 1994 - 2013 period . The red edge labels significant conditional dependence of the series (vertices are labeled by the number of days of the shift). The series of missing graphs unmatch the preconditions for continuous time series models: Independence of logarithmical values of time serie ($\log (K_t / K_{t-1}) = \log K_t - \log K_{t-1}$) was tested by the difference test.

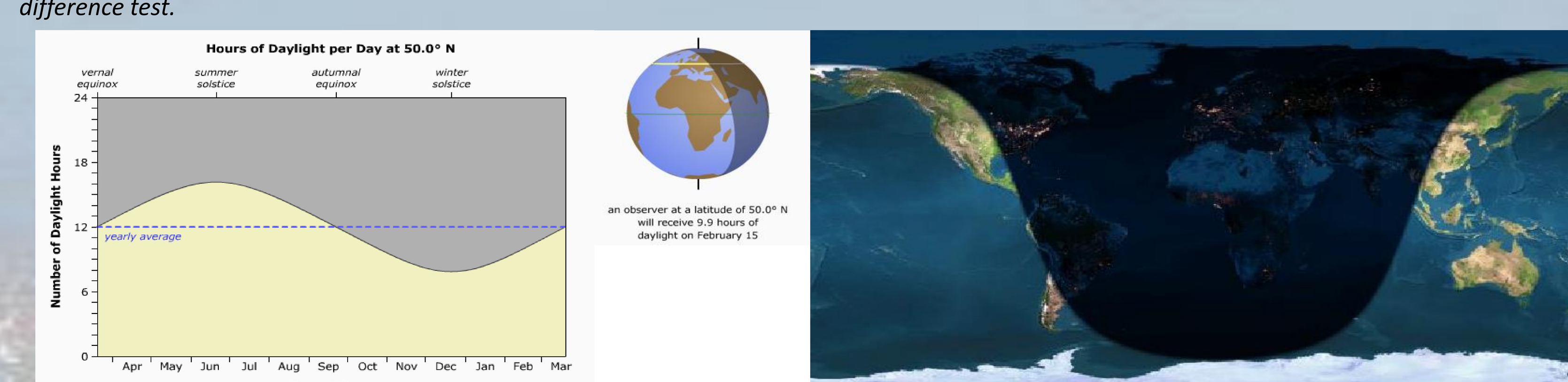


Figure 4: A contour plot of the hours of daylight as a function of latitude and day of the year, using the most accurate models described in sunrise equation. Latitude 50°N (approximately Prague, CZ) is highlighted for reference.

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