On the feasibility of studying wave processes in the surface atmosphere with a solar telescope

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The studies carried out at the Sayan Solar Observatory indicated the existence of quasi-periodic variations in the position and shape of H_2O and O_2 telluric spectral lines. Periods of these fluctuations lie in the region of solar oscillations under study, namely, from 3 to 40 minutes. This fact should be taken into consideration when using telluric lines as a reference. These measurements may also be useful when studying wave processes in the Earth's atmosphere.

Introduction

As known, the solar radiation propagated through the atmosphere experiences rather strong absorption and scattering by a mixture of molecules and atoms of atmospheric constituents. As this takes place, the so-called telluric lines arise in different regions of the solar spectrum. They look like ordinary Fraunhofer lines, but their shape and spectral position do not depend on motions in the solar atmosphere. They are traditionally used in the solar physics as a spectral reference in measurements of radial velocities. The experience showed that this is justified at the measurement accuracy up to $10\$20$ m / s (Ref. 1).

At a higher measurement accuracy needed, it becomes obvious that telluric lines themselves shift due to the motion of air masses responsible for the appearance of these lines. Since the Earth's atmosphere is a complex dynamic system, many types of motions, including oscillations and waves of various periods and spatial scales, are present in it.

Such oscillations may cause synchronous distortion of some parts of the solar image. This, in its turn, may yield serious errors when studying oscillation and wave processes in the solar atmosphere. Thus, the studies of wave motions based on telluric lines not only directly estimate the stability of the spectral reference, but also can become a source of valuable information in the case that telluric lines are not used as a reference. Besides, the studies of characteristics of wave motions are important for investigation of the dynamics of daytime atmosphere.

Method and instruments

It should be noted that conducting such measurements is a very complicated problem. They are conducted, as a rule, with diffraction solar spectrographs, which have internal noise. According to different estimates, the noise amplitude for particular spectrographs is from tens to hundreds of meters per second. The noise is mostly caused by temperature and pressure inhomogeneities of air inside a spectrograph,[2] which manifest themselves at the scales from millimeter and above.[3] Therefore, even the use of an artificial reference (for example, laser) does not completely exclude the spectrograph noise.

The differential methods developed in the 80s for helioseismology[4] turned out to be applicable to the studies of the Earth's atmosphere as well. The idea of the method is as follows: two light rays from different parts of the solar surface are simultaneously directed by a polarization prism onto the spectrograph's entrance slit. The paths of the light beams in the Earth's atmosphere are slightly different, and if the physical conditions at these paths are different, the position of the corresponding spectral components of the telluric lines is different as well. In the spectrograph, these rays are orthogonally polarized and shifted by a deflector in the direction of dispersion by a certain constant value $\Delta\lambda_0$. This shift is usually taken equal to the halfwidth of the working spectral line. Modulating the state of polarization, one can change the direction of the shift of spectral components. If the radial velocity of both image parts is the same, then the distance between the components does not change. Otherwise, it is $\Delta\lambda_0 + \Delta\lambda_d$ in one modulation stroke and $\Delta\lambda_0 \$ \Delta\lambda_d$ in the other one. Subtraction gives $2\Delta\lambda_d$, where $\Delta\lambda_d$ is the difference between the Doppler shifts for two rays. Since the rays passes through the spectrograph under the same conditions, the instrumental shift of both spectral components is always the same and does not affect $\Delta\lambda_d$. This is also valid for modulationless measurements with CCD photodetectors.[5]

In some cases, with accumulation time of 10 s, the inner noise of a spectrograph was decreased down to 0.1 m / s. At such a noise level, it becomes possible to measure atmospheric oscillation processes from telluric lines. Matching of rays at the spectrograph entrance can be made with various facilities.[4] The maximum split of the image is limited by 0.5, i.e., the angular size of the visible solar disk. The studies were conducted with the automated solar telescope (AST) of the Sayan Astrophysical Observatory.

Observations and results

The below results were obtained from observations of different years since 1985 until 2001. Oxygen O_2 and water vapor H_2O lines were chosen for measurements. The total duration of measurements was 35 h for several oxygen lines at the spectral region of 687$ 690 nm and about 28 h for water vapor lines with λ = 590.1 and 656.42 nm. A fragment of the time series shown in Fig. 1 illustrates the effect of the spectrograph noise. It can be seen from Figs. 1 and 2 that the measurements conducted using one line but at different time may differ markedly. Spectral estimates were obtained through application of the standard Fast Fourier Transform procedure. Before this, the time series was centered by subtraction of the mean and smoothed at the ends (usually with the use of the œsquare cosineB filter), and the linear trend was removed whenever necessary. The power spectra of different time series usually differ, though some similarity can be found in them. Figure 3 depicts the power spectra of the radial velocity signal measured using the oxygen line at λ = 688.38 nm.

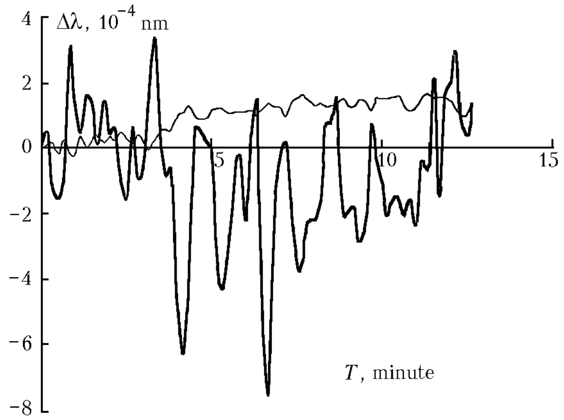

Fig. 1. Shifts of telluric line; Doppler shift + spectrograph noise (thick line) and differential signal without spectrograph noise (thin line).

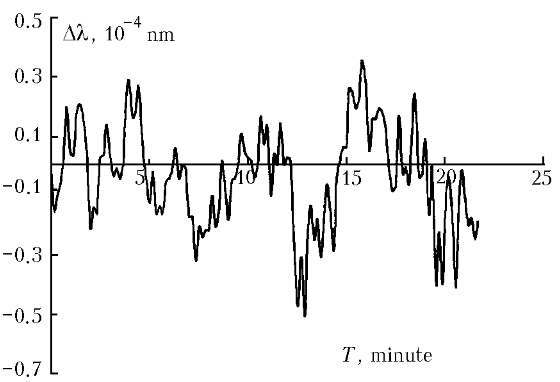

Fig. 2. Fragment of time series without spectrograph noise.

Figure 4 depicts the spectra of two time series for measurements conducted using water vapor line at λ = 656.5 nm. It can be seen from analysis of the spectra that the spectral peaks are located near the periods of 2.5$3, 5, 15$20, and 30$40 min. Since the whole profile was not recorded at measurements of line shifts, we can assume that the signal is caused by both the shift of the line as a whole and deformation of the line profile in the central part. The latter is also due to Doppler speeds, but caused by spatially unresolved periodic motions.

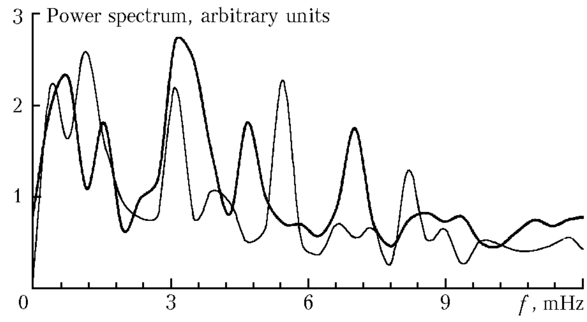

Fig. 3. Power spectrum for the oxygen line (λ = 688.38 nm): time series of 04.25.2001 (thick line) and 04.23.2001 (thin line).

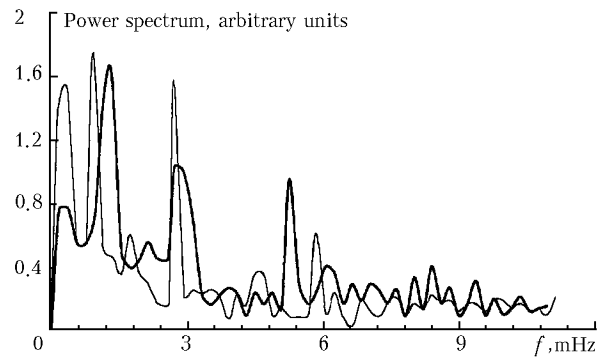

Fig. 4. Two power spectra for the H_2O line (λ = 656.42 nm): 06.02.2001 at 01:52$03:18 UT (thick line) and 06.02.2001 at 05:45$07:12 UT (thin line).

It should be noted that such shifts of the telluric lines are caused not only by Doppler speeds. It is also known that H_2O lines experience the wavelength shift due to temperature or pressure variations.[6] Sensing of the surface atmosphere with up-to-date devices reveals rather sharp spatial and temporal anomalies of these characteristics.[7] In any case, detected periodicities are indicative of the oscillation processes in the surface atmosphere. In the future, we plan to study the temporal characteristics of bisectors of some telluric lines.

Conclusions

Joint analysis of the materials dated to 1984$2001 indicate that the periods of 5 and 15$20 min are observed most often. Longer periods (30$40 min) are observed far more rarely, as well as the periods of 1.5$ 2.5 min. It should be noted that in the late 70s Soviet scientists studied the γ-radiation of the Earth's atmosphere using balloon-borne measurements and found similar periodicities.[8] It is also interesting that close periods are observed in studying various solar phenomena. The results presented in this paper are useful in two aspects. On the one hand, they are needed to take into account all artifacts when studying solar wave processes. On the other hand, they carry the information on the physical phenomena in the Earth's atmosphere.

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