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Interactive Comment

Interactive comment on "A global climatology of the mesospheric sodium layer from GOMOS data during the 2002–2008 period" *by* D. Fussen et al.

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Comments on "A global climatology of the mesospheric sodium layer from GOMOS data during the 2002-2008 period" by D. Fussen et al.

This paper presents a climatology of the mesospheric sodium layer obtained from GOMOS stellar occultation using the Na D multiplet near 589 nm. This work builds on a 7-year database and is a follow-up on the work by Fussen et al. (2004) who analyzed one year of GOMOS data from 2003. A basic improvement as compared to Fussen et al. (2004) is the treatment of the Doppler-shaped atmospheric absorption lines of the Na D multiplet. In the limb direction, conditions near the resonance line centres of the Na D multiplet can become optically thick. This results in a non-linear relationship between sodium density and measured transmission. This was not taken into account in the earlier paper, which resulted in an error of sodium densities by about 30%, according to the present analysis.

The precision of the sodium occultation data is limited. The atmospheric Na D absorption lines are approximately 1000 times narrower than the GOMOS spectral resolution. As a consequence, while extinction near the Na D line centres is strong (limb optical thickness $\sim$ 1), the actual occultation signal observed by GOMOS is weak ($\sim$0.005) as the extinction is "smeared out" over the instrument resolution. This results in a limited precision of the GOMOS sodium measurements. Nevertheless, climatological sodium data can be obtained by averaging many occultation profiles in suitable latitude and time bins. The resulting global sodium data still seem rather noisy (Figure 9a). However, the authors manage to obtain instructive insights in sodium climatology by applying a latitude-dependent bivariant fit to the data (Figure 9b). A major result of this analysis is a time pattern with semi-annual variation at low latitudes and annual variation at high latitudes. This is important and can serve as an interesting input to future dynamical/chemical model studies of mesospheric sodium.

The above analysis is thorough and makes maximum use of the GOMOS occultation data. However, I have major concerns about the underlying spectral analysis! What bothers me is the validity of the transmittance analysis in the present case of narrow absorption lines and possible Fraunhofer structures in the stellar irradiance. This is discussed in the following:

The occultation analysis is based on the spectral inversion described e.g. by Kyrölä et al. (ACPD, 10, 10145-10217, 2010). At the core of the retrieval is a comparison of measured and simulated transmittance. To this end, an effective transmittance is used that has been integrated over a suitable wavelength interval (e.g. equation 5 in the current manuscript; equation 30 in Kyrölä et al., 2010). Alternatively, this can be expressed by a convoluted cross section (equation 36 in Kyrölä et al., 2010). In the present case, the wavelength interval is 1.25 nm, which corresponds to 4 GOMOS wavelength pixels. I argue that this use of the effective transmittance in the retrieval

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only works when the stellar irradiance can be considered constant over the wavelength interval of interest. This is not the case here.

Expressed in a simplified way, the measured transmittance from a tangent height h averaged over a chosen wavelength interval is

Teff(h) = 1 -

Integral (E0(lambda) * exp (-tau(lambda,h) * d lambda) /

Integral (E0(lambda) * d lambda)

Here, "Integral" symbolizes the spectral integration over the wavelength interval. E0(lambda) is the stellar irradiance at the top of the atmosphere. tau(lambda,h) is the spectrally resolved optical thickness as expressed e.g. in equation 3 in the manuscript. (For simplicity, I have ignored that there should be a summation over the individual hyperfine lines. And I have left out the point spread function from the above equation.)

If E0 (or tau) is constant over the wavelength interval, E0 vanishes from the above ratio and the above equation reduces to equation 5 in manuscript (or equation 30 in Kyrölä et al., 2010). However, if E0 cannot be considered constant over the wavelength interval, it remains part of the above expression. In other words, the spectral dependence of the stellar irradiance must be known in order to analyze the occultation measurement. More specifically, the stellar irradiance must be known with a spectral resolution that corresponds to the spectral structure of the atmospheric absorption ($\sim$ 0.001 nm in the case of the Na D absorption lines)!

I consider this as critical since the stellar spectrum can be expected to feature substantial Na D Fraunhofer structures in the wavelength interval of interest. In the case of our Sun, the Na D1 and D2 Fraunhofer minima have a width of $\sim$0.02 nm, and the irradiance in the Fraunhofer minima is only about 5% of the irradiance in the neighbouring spectral regions. The problem can be illustrated with an even more extreme case: Consider a hypothetical star with extreme Fraunhofer minima so that there is no

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irradiance at all in the Na D lines. GOMOS would not see any occultation signal (i.e. Teff would remain 1) no matter how much sodium there is along the path in the Earth's mesosphere.

In general, ignoring the presence of Na D Fraunhofer minima in the stellar spectrum should lead to a (substantial) underestimation of retrieved mesospheric sodium densities.

At the same time, the current sodium analysis seems to be validated well. The manuscript shows good agreement of the current retrievals with both resonance lidar (Fort Collins) and other space-borne retrievals (OSIRIS). I am puzzled. So maybe I am wrong, after all. But in that case, the manuscript should explain why I am wrong. Currently, there is no mentioning of possible effects of Fraunhofer structures at all.

I have thought about a possible solution of this problem: There could be a substantial Doppler shift between the stellar irradiance and the mesospheric absorption. This could lead to conditions where there is no more overlap between the stellar Na D Fraunhofer minima and the mesospheric Na D absorption lines. However, this does not seem to be the case: The speed of the Sirius system relative to the Earth is $\sim$ -10 km/s. This corresponds to a blueshift of $\sim$0.02 nm. This is significant, but it is presumably not more than the width of the Na D Fraunhofer minima.

So much about my major concern about the paper. I have some minor comments as well. I will submit those separately within short.

Interactive comment on Atmos. Chem. Phys. Discuss., 10, 6097, 2010.