Atomic line parameters inference from spectropolarimetric observations using a global inversion approach

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Motivation

The reliability to retrieve atmospheric parameters of the solar atmosphere from high-resolution spectropolarimetric observations of spectral lines depends on the accuracy of adopted atomic parameters (e.g. transition probability log(gf), rest wavelength). Only for a limited number of spectral lines atomic parameters were determined in laboratory setup (e.g. Blackwell et al. 1986). For many spectral lines, especially in the ultra-violet (UV) range, only theoretical estimates or estimates derived from the mean average quiet Sun spectrum are available (e.g. Gurtovenko and Kostik 1981, Thevenin 1989, Thevenin 1990, Borrero et al. 2003). All these values can exhibit large differences when comparing the computed synthetic spectrum to an observed one.

Aim: improve the adopted values of log(gf) parameter for spectral lines from the near-ultraviolet to the infra-red wavelengths using so-called global spectropolarimetric inversions.

Method – global inversion approach

The gobal multi-line inversion approach is:

- simultaneous inversion of all spectra within the observed field of view using unique (global) values for the free atomic parameters of the selected spectral lines.
- simultaneous retrieval of both, precise atomic and atmospheric parameters in each pixel, for different solar features (granules, intergranular lanes, sunspots and other).

We use the Levenberg-Marquardt minimization that:

- require construction of the global Jacobian matrix from the Jacobian matrices of each pixel.
- the global Jacobian matrix has a sub-block-diagonal part containing response functions to atmospheric parameters, where the far right side is filled with response functions to atomic parameters (Figure 1).

To test this approach, we wrote an inversion engine named *globin* in Python where we use *RH* code (Uitenbroek 2001) for forward spectrum modeling. Code development is still in progress and source code can be distributed per individual request.

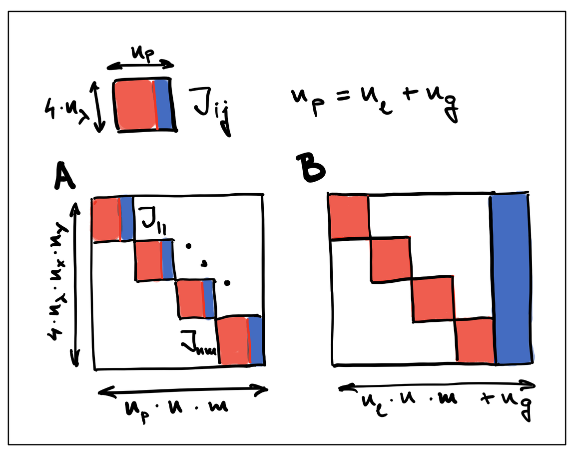

Figure 1. Construction of the global Jacobian matrix from the Jacobian matrix of each pixel. The red color represents the response functions for atmospheric (local) parameters, while the blue color represents the response functions for atomic (global) parameters. The Jacobian matrix in step **A** presents the case of pixel-by-pixel inversion of atmospheric and atomic parameters. The Jacobian matrix in step **B** does not have a coupling in atmospheric parameters (sub-block-diagonal form) while for the atomic parameters we have a coupling over all pixels.

Inversions of spectra from MHD atmospheres

This inversion test has a goal to:

- invert Stokes I synthetic spectra at 401.6 nm from sample of pixels from a MURaM MHD model of a sunspot.
- retrieve temperature (4 nodes) and log(gf) values for every spectral line (18 in total); rest of atmospheric parameters are fixed to exact value.

Results that were obtained are:

- the cross-talk between temperature and log(gf) is removed (Figure 2).
- better results achieved with the global than with the pixel-by-pixel approach.
- retrieved temperature from the global inversion is close to the one retrieved when log(gf) values were fixed to the exact values.

Inversions of Hinode data

Aim: test of the global approach on the Hinode data from an active region.

Method: select pixels representing various solar features (Figure 3).

Setup: 3 nodes in atmospheric parameters (T, B, v_{LOS}, γ, Φ) at -2.0, -0.8, 0 in optical depth scale; constant v_{mic}; global values for log(gf) parameter of two Fe I lines.

Results: atmospheric parameters in Figure 4 along the yellow line in Figure 3; retrieved log(gf) values are compared to values from Kurucz/VALD database in Table 1; example fit of Stokes profiles in Figure 5.

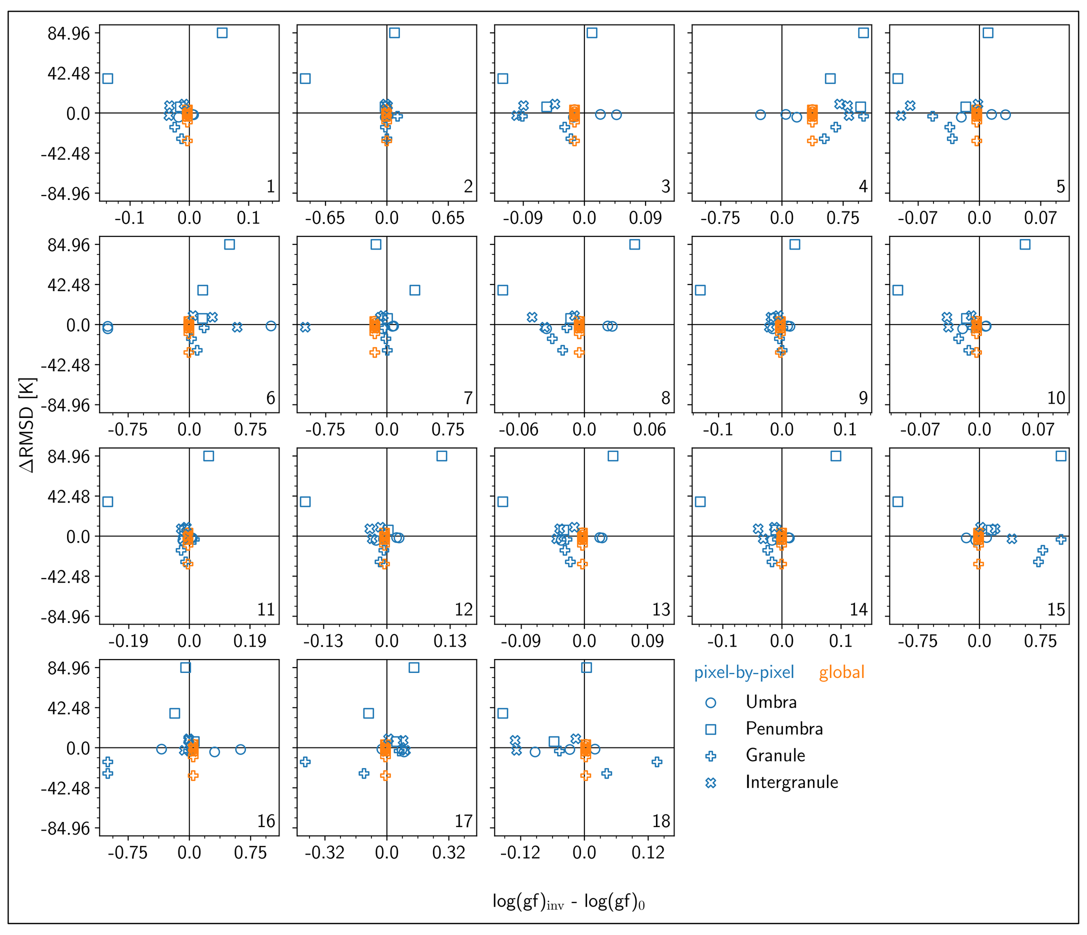

Figure 2. Comparison of retrieved temperature and log(gf) value of each spectral line. The quality of temperature inference is estimated by the root-mean-square deviation, while the log(gf) values are compared to the exact ones used to synthesize spectra.

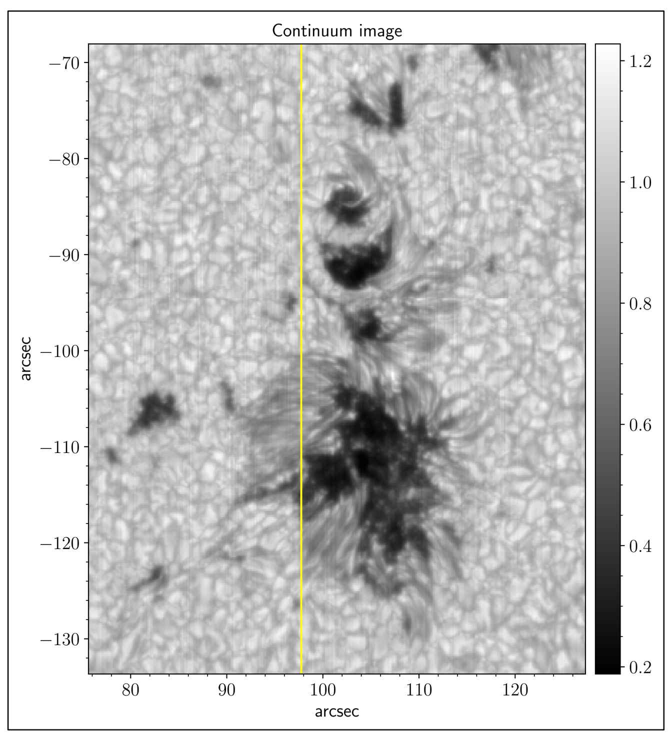

Table 1. Kurucz/VALD values for log(gf) of Fe 6301.5 and 6302.5 lines and the log(gf) retrieved with the global approach.

	6301.5	6302.5
Kurucz/VALD	-0.710	-0.969
Inferred	-0.855	-1.023

Figure 3. Continuum intensity of active region. Yellow line designate pixels that were inverted using the global approach.

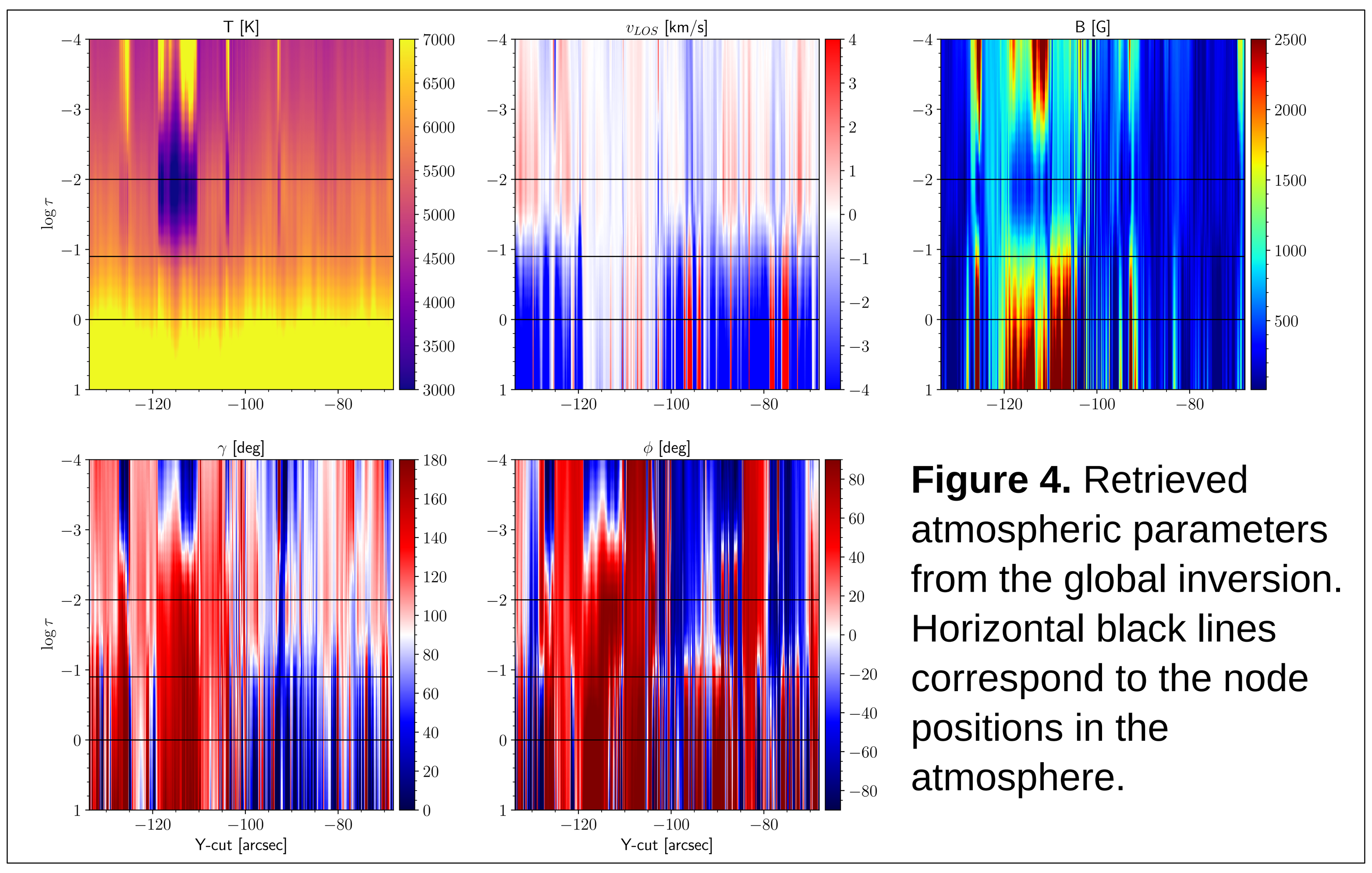

Figure 4. Retrieved atmospheric parameters from the global inversion. Horizontal black lines correspond to the node positions in the atmosphere.

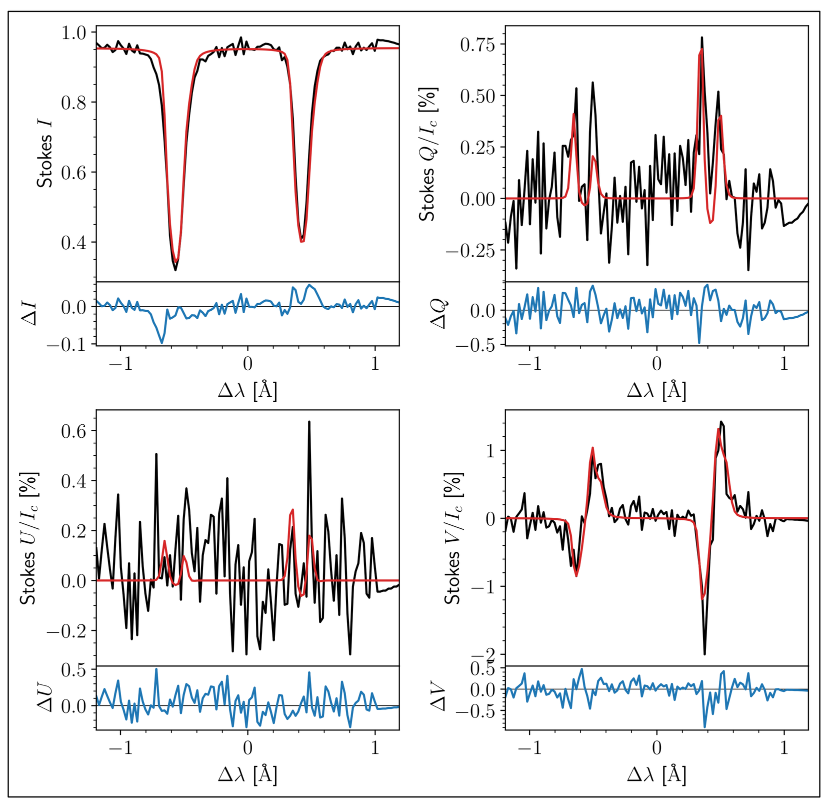

Figure 5. An example of comparison of observed and inverted Stokes profiles with the global approach.

Summary and outlook

- diverse line profiles constrain significantly the range of values for log(gf).
- we have reliable inversion of atmospheric and atomic parameters.
- check the influence of stray-light contamination on Hinode line profiles.
- regularize the depth stratification of atmospheric parameters.

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