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X-shooter-based climatologies of intensity, solar cycle effect, and residual variability for 298 OH lines

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Line emission from the various roto-vibrational bands of the OH radical is an important tracer of the chemistry and dynamics in the Earth's nocturnal mesopause region between about 80 and 100 km. As most studies have focused either on a few bright lines or integrated emission from relatively wide wavelength windows, there is still a lack of knowledge with respect to the variability of faint lines from high rotational levels (**Fig. 1**) as well as the change of the variability patterns depending on the line parameters, which influence the effective emission height h_{eff} (**Fig. 2**).

Thanks to a large data set of about 90,000 near-infrared X-shooter spectra taken at Cerro Paranal in Chile (25°S) within a time interval of 10 years (Oct 2009 to Sep 2019), we have been able to derive line-specific climatologies of relative intensity, solar cycle effect (SCE), and residual variability for local time (LT) and day of year based on a set of 298 OH lines **[3]**. Results for two example lines of OH(4-2) with very different rotational excitation N' (and, hence, very different h_{eff}; see **Fig. 2**) are shown in **Fig. 3**. The climatologies relative to the mean intensity in **(a)** and **(b)** indicate tidal patterns with a mininum and maximum in the middle of the year. In addition, the line with N' = 1 shows a steep intensity decrease in the evening (with maxima around the equinoxes), which is related to the decay of an atomic oxygen population produced by O_2 photolysis at daytime. As this decay is faster at lower heights, the evening component is stronger for lines with lower vibrational (v') and rotational (N') upper level (**Fig. 2**).

The relative response of the emission to changes of the solar radio flux averaged for 27 days in **Fig. 3 (c)** and **(d)** shows a clear maximum around July, where the peak in LT is later for lower N'. As the peak moves out of the night for lines with low excitation, these lines tend to have a weaker effective nighttime SCE. The residual intensity variation in **(e)** and **(f)** also indicates a maximum in austral winter, but somewhat earlier in LT. An investigation of the sample variance depending on the time difference Δt revealed that the maximum is mostly caused by time scales of the order of hours, which suggests enhanced gravity wave (GW) activity that might also influence the SCE. Moreover, the Δt-resolved variance analysis showed that the secondary maximum in austral summer is caused by a mixture of GWs and quasi-2-day waves (Q2DWs), which can be quite strong at this latitude in this season.

With the analysis of the climatologies of all 298 OH lines by means of a principal component analysis (PCA), we found that the 1st component is a measure of the amplitude of the variation. As shown by **Fig. 4 (a)** for the SCE, **(c)** for the GW activity, and **(e)** for the Q2DW activity, the amplitudes are always higher for lower v' and intermediate N'. The latter can be explained by additional variance due to the temperature-dependent mixing of cold thermalised and hot non-thermalised rotational populations (**Fig. 1**: example for v' = 6). The lower panels of **Fig. 4** show the scaling factors for the 2nd PCA component, which mainly describes the shift of the climatological variability pattern with LT. As the data distribution strongly correlates with h_{eff} in **Fig. 2**, a perturbation tends to be earlier in LT at larger heights. As the LT shifts are consistent with a vertical wavelength of about 30 km for a period of 24 h, the migrating diurnal tide seems to affect the amplitude of variations related to very different time scales.

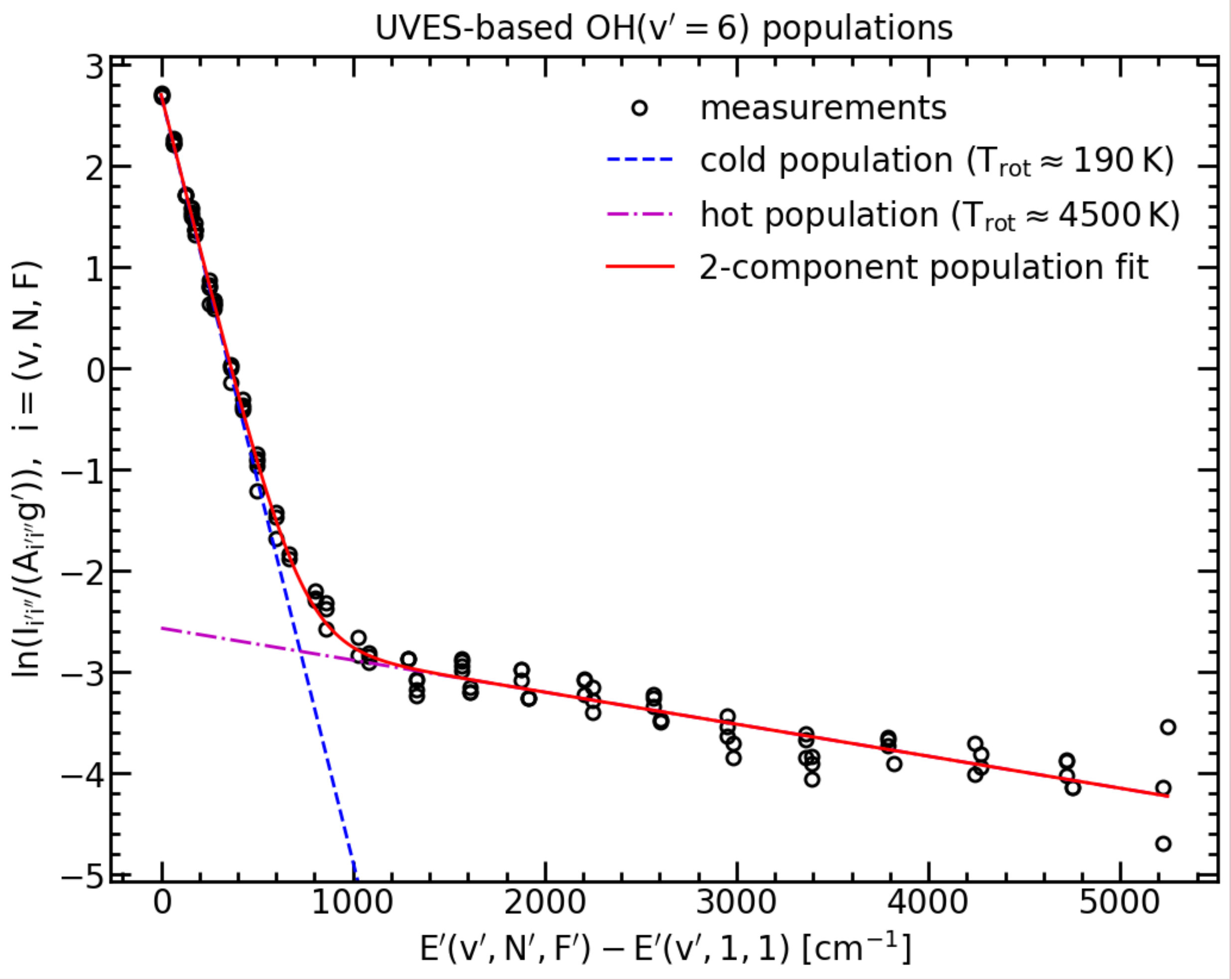

Fig. 1: Logarithmic population (intensity divided by Einstein-A coefficient and statistical weight) for OH levels with vibrational quantum number v' = 6 as measured in a UVES mean spectrum from Cerro Paranal **[1]**. The abscissa shows the excitation due to rotation (N') and spin–orbit coupling (F'). The measurements were fitted by a two-component model with fixed rotational temperatures T_{rot}.

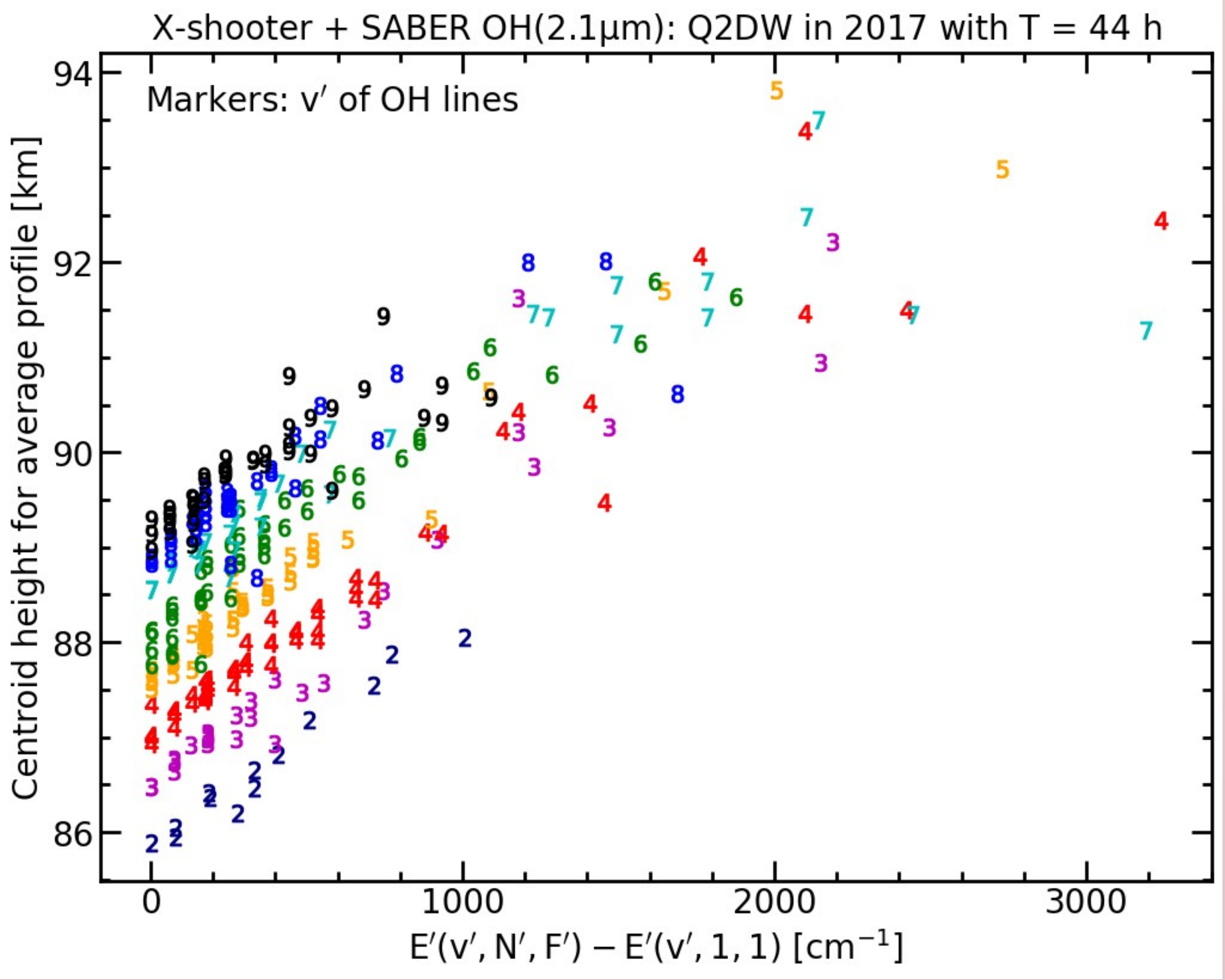

Fig. 2: Mean centroid emission heights for 298 OH lines derived from combined measurements of a quasi-2-day wave in eight nights in 2017 with X-shooter at Cerro Paranal and the TIMED/SABER OH channel at 2.1 µm **[2]**.

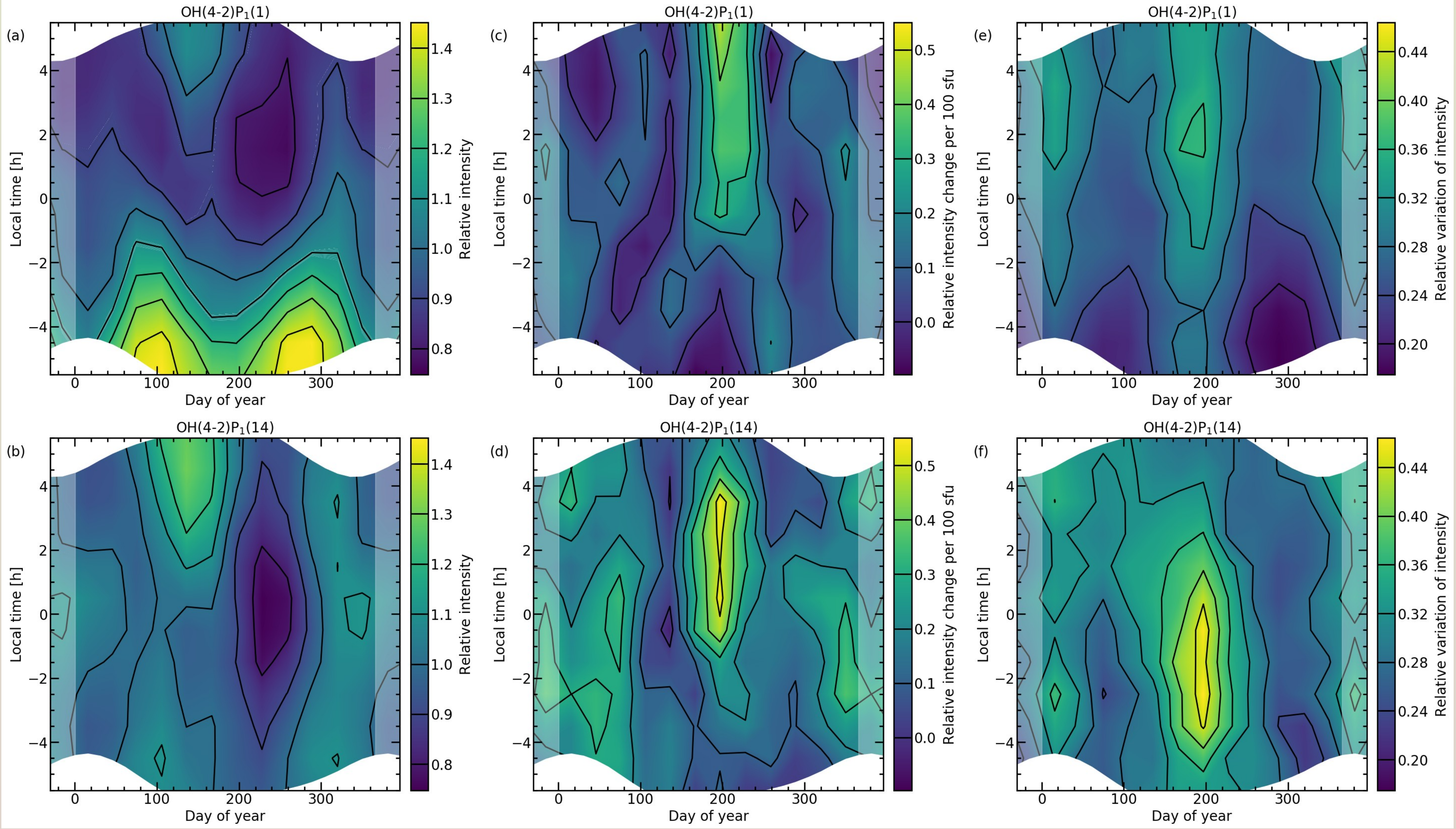

Fig. 3: Climatologies of relative intensity, SCE, and residual variability for OH(4-2) lines with N' = 1 and 14.

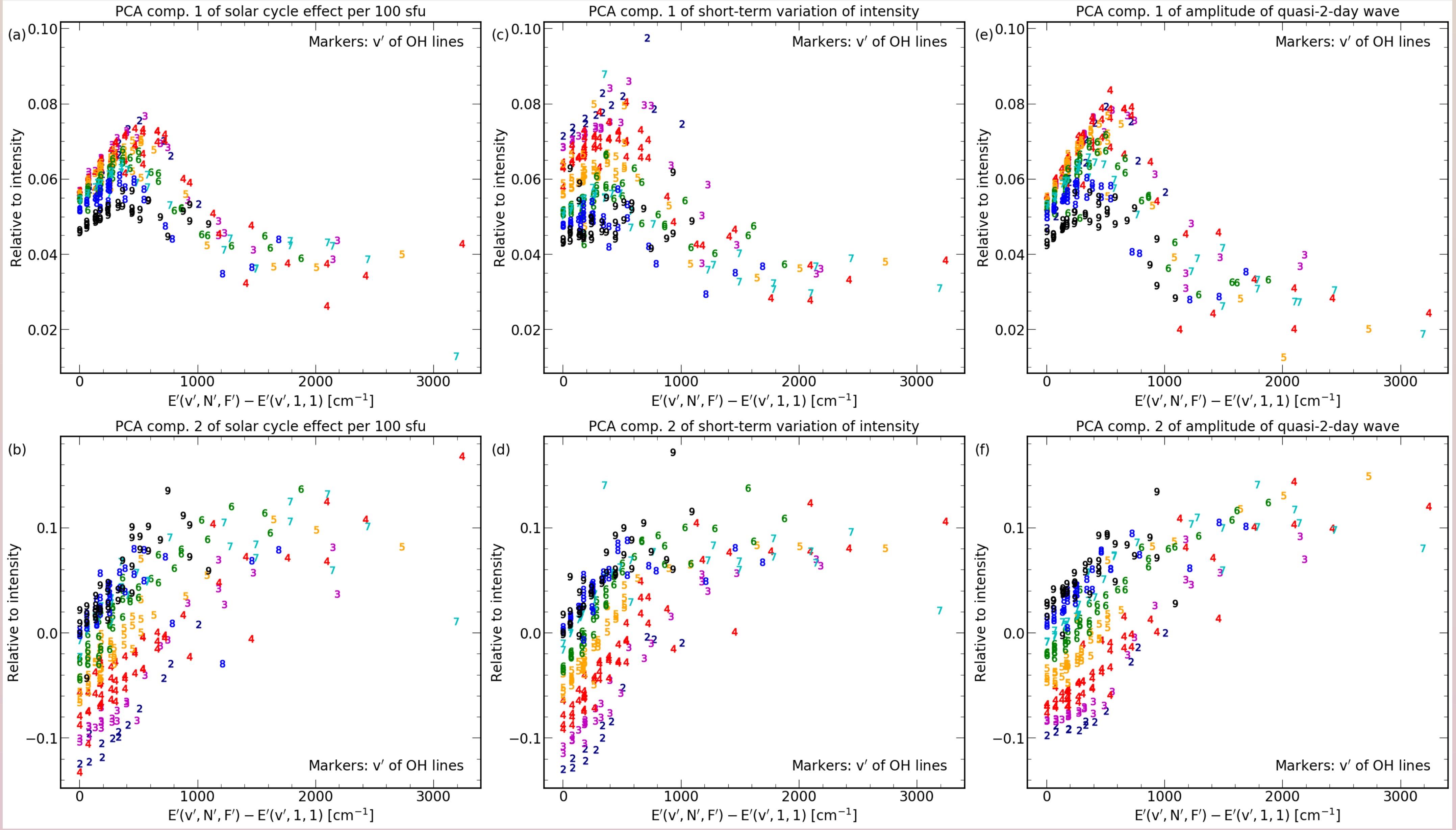

Fig. 4: Scaling factors of 298 OH lines for the 1st and 2nd PCA-based climatologies of relative SCE, short-term (< 1 day) variability, and Q2DW amplitude.

[1] Noll et al., 2020, ACP, 20, 5269-5292, DOI:10.5194/acp-20-5269-2020
[2] Noll et al., 2022, JGR Atmos., 127, e2022JD036610, DOI:10.1029/2022JD036610
[3] Noll et al., 2023, JGR Atmos., accepted, DOI:10.1029/2022JD038275

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