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Stratospheric water vapour and climate: sensitivity of climate response to the representation of radiative processes

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Past changes in stratospheric water vapour (SWV) have been shown to be important for determining stratospheric temperature trends (e.g. Forster and Shine, 2002), global surface temperature trends (Solomon et al., 2010) and regional surface climate (Joshi et al., 2006). In this study, we show that the impact of a change in SWV on stratospheric temperatures is sensitive to the representation of radiative processes in the far infra-red spectral region and at low pressures. In the stratosphere, water vapour predominantly absorbs and emits radiation in the pure rotation bands (λ >25 µm). At these wavelengths the Doppler widths of the lines which constitute the rotation bands are very narrow (around 0.0001 cm-1 at 100 µm). We show that this feature makes the magnitude and structure of the change in heating rate that results from an SWV perturbation (ΔQ) highly sensitive to the spectral sampling resolution in line-by-line (LBL) calculations. Past studies have mostly focused on differences in the representation of the tropopause radiative forcing (ΔF) due to an SWV perturbation. The approach of this study is to identify differences in ΔQ, which is what, to first order, determines the sensitivity of stratospheric temperatures to changes in SWV. We show that LBL calculations of ΔQ for a uniform SWV perturbation converge at a sampling resolution higher than that often used for LBL calculations. In addition, to achieve convergence of ΔQ at pressures less 10 hPa requires a higher sampling resolution than to achieve convergence of ΔF. This is because ΔF is most sensitive to changes in absorption in the lower stratosphere, where the spectral lines are broader. Hence, ΔF is an insufficient metric to test how models represent the response to an SWV perturbation in the mid and upper stratosphere. We show that calculations of the ΔQ for a uniform SWV perturbation are different by up to a factor of two in several broadband radiation codes. This is likely to be due to the representation of the transmission function for water vapour at low absorber amounts and low pressures, which are characteristic of water vapour in the stratosphere. We present results from two atmospheric general circulation models (GCMs), which employ broadband radiation codes with different SWV/ΔQ sensitivities. We show that there are large differences between the models in terms of the amplitude and structure of the equilibrium temperature response to the same uniform change in SWV. Fixed dynamical heating calculations verify that the difference in the GCM temperature response is largely due to the differences in ΔQ. We conclude that accurate modeling of the links between changes in SWV and climate is reliant on the reliable representation of radiative processes, predominantly in the far infra-red spectral region. The fluxes, heating rates and sensitivity of heating rates due to changes in SWV derived using broadband codes need to be tested against benchmark radiative transfer calculations.