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The impact of sudden stratospheric warmings (SSWs) on UTLS composition, local radiative effects and air quality

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Midwinter sudden stratospheric warmings (SSWs), characterised by the reversal of the temperature gradient poleward of 60°N and the 10 hPa climatological zonal mean wind from westerly to easterly at 60°N, are known to have pronounced impacts on tropospheric circulation which lead to regional changes in temperature, precipitation and other meteorological variables. Such abrupt events are furthermore known to be associated with large-scale changes in the distribution of stratospheric chemistry constituents, such as ozone (O_3) and water vapour (H_2O), although the implications for stratosphere-troposphere exchange (STE) have not been previously investigated. The evolution of O_3 and H_2O anomalies during an SSW life cycle are first examined from the surface up to 1 hPa using specified-dynamics simulations from the European Centre for Medium-Range Weather Forecasts – Hamburg (ECHAM)/Modular Earth Submodel System (MESSy) Atmospheric Chemistry (EMAC) model over the period 1979-2013. We show that significant positive anomalies in O_3 occur around the onset of an SSW in the middle to lower stratosphere, with persistence timescales of around 50 days in the upper troposphere-lower stratosphere (UTLS). Similarly, we find significant H_2O anomalies in the lowermost stratosphere (± 25 %) for up to 75 days. The extent and magnitude of the anomalies are largely confirmed in both Copernicus Atmospheric Monitoring Service (CAMS) reanalysis and ozonesonde measurements at five different Arctic stations. These chemical perturbations result in local temperature changes of up to 2 K, which may impact numerical weather prediction (NWP) of the tropospheric response to SSWs. Evaluation of the vertical residual velocity (w*) support the notion of transport changes being the driver of the temporal evolution of the anomalies. Using a stratospheric-tagged O_3 tracer, a signal for enhanced STE of ozone is subsequently inferred (~ 5-10 %), which is maximised around 50 days after the SSW onset date. We furthermore attempt to elucidate STE transport pathways using a tropopause fold identification algorithm applied to ERA-Interim during this period, and assess such changes in folding frequency and distribution during such events. Our results highlight that SSWs can induce significantly disturbed O_3 and H_2O distributions in the UTLS, leading to enhanced STE of O_3, with potentially significant implications for radiative fluxes, atmospheric heating rates and air quality.