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The radiative role of ozone and water vapour in the temperature annual cycle in the tropical tropopause layer

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The prominent annual cycle in temperatures (with maximum peak to peak amplitude of $\sim$ 8 K around 70 hPa and $\sim$6 K at 90 hPa) is a key feature of the tropical tropopause layer (TTL). There is also a strong annual cycle observed in both ozone and water vapour in the TTL, with the latter understood as a consequence of the temperature annual cycle. The radiative contributions of the annual cycle in ozone and water vapour to the temperature annual cycle are studied, first with a seasonally evolving fixed dynamical heating calculation (SEFDH) where the dynamical heating is assumed to be unaffected by the radiative heating. In this framework, the variations in ozone and water vapour derived from satellite data lead to variations in temperature that are respectively in phase and out of phase with the observed annual cycle. The ozone contribution is at the upper range of previous calculations. This difference in phasing can be understood from the fact that an increase in water vapour cools the TTL, predominantly through enhanced local emission, whereas an increase in ozone warms the TTL, mostly through enhanced absorption of upwelling longwave radiation from the troposphere. The relative phasing of the water vapour and ozone effects on temperature is further influenced by the fact that for water vapour there is a strong non-local effect on temperatures from variations in concentrations occurring in lower layers of the TTL. In contrast, for ozone it is the local variations in concentration that have the strongest impact on local temperature variations. The factors that determine the vertical structure of the annual cycle in temperature are also examined. Radiative damping time scales are shown to maximize over a broad layer centred on the cold point. Non-radiative processes in the upper troposphere are inferred to impose a strong constraint on temperature perturbations below 130 hPa. These effects, combined with the annual cycles in dynamical and radiative heating, which both peak above the cold point, result in a maximum amplitude of temperature response that is relatively localized around 70 hPa. Finally, the SEFDH assumption is relaxed by considering the temperature responses to ozone and water vapour variations in a zonally symmetric dynamical model. While the magnitude of the tropical averaged temperature annual cycle in this framework is found to be consistent with the SEFDH results, the effects of the dynamical adjustment act to reduce the strong latitudinal gradients and inter-hemispheric asymmetry in the temperature response. This results in a temperature response that shows a considerably smoother structure than inferred from the SEFDH model. Whilst precise numerical values are likely to be sensitive to changes in the details of radiation code and of ozone and water vapour concentrations, the net contribution to the annual cycle in temperature from both ozone and water vapour averaged between 20° N–S, calculated in this work, is substantial and around 35 % of the observed peak to peak amplitude at both 70 hPa and 90 hPa.