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Ice injection up to the Tropopause by Deep Convection: in the Austral Convective Tropics with an emphasis over the Maritime Continent

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The impact of deep convection on the injection of ice in to the tropical Upper Troposphere (UT, around 146 hPa) and the Tropopause Level (TL, around 100 hPa) is investigated. Ice water content (IWC) and water vapour (WV) measured in the UT and the TL by the Microwave Limb Sounder (MLS, Version 4.2) are compared to the precipitation (Prec) measured by the Tropical Rainfall Measurement Mission (TRMM, Version 007). The two datasets, gridded within $2°\times2°$ horizontal bins, have been analyzed during the austral convective season: December, January and February (DJF) from 2004 to 2017. MLS observations are performed at 01:30 and 13:30 Local Solar Time whilst the Prec dataset is constructed with a time resolution of 1 hour. The new contribution of this study is to provide a much more detailed picture of the diurnal variation of ice than is provided by the very limited (2 per day) MLS observations. Firstly, we show that IWC represents 70 and 50% of the total water in the tropical UT and TL, respectively and that Prec is spatially highly correlated with IWC in the UT (Pearson linear coefficient R=0.7). We propose a method using Prec as a proxy of deep convection bringing ice up into the TL during the growing stage of the convection, in order to estimate the diurnal cycle of ice in the UT and the TL. We estimate the method using ice measurements from the Superconducting Submillimeter-Wave Limb-Emission Sounder (SMILES) during the period DJF 2009-2010. Next, the diurnal amount of IWC injected into the UT and the TL by deep convection is calculated by the difference between the maximum and the minimum in the estimated diurnal cycle of IWC in these layers and over selected tropical convective zones. Six tropical highly convective zones have been chosen: South America, South Africa, Pacific Ocean, Indian Ocean, and the Maritime Continent region, split into land (MariCont-L) and ocean (MariCont-O). IWC injection is found to be 2.73 and 0.41 mg $m-3$ over tropical land in the UT and TL, respectively, and 0.60 and 0.13 mg $m-3$ over tropical ocean in the UT and TL, respectively. The MariCont-L region has the greatest ice injection in both UT and TL (3.34 and 0.42-0.56 mg $m-3$, respectively). The MariCont-O region has less ice injection than MariCont-L (0.91 mg $m-3$ in the UT and 0.16-0.34 mg $m-3$ in TL), but has the highest diurnal minimum value of IWC in the TL (0.34-0.37 mg $m-3$) among all oceanic zones. A final part of the study evaluates the impact of El Nino Southern Oscillation and the Madden Julian Oscillation on ice injection into the UT and TL, focusing primarily on the Maritime Continent region.

Key words: Tropical Tropopause Layer, diurnal cycle, ice, Maritime Continent