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Troposphere-to-stratosphere transport of materials by convective storms

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Recent satellite observations have shown unmistakably that irreversible troposphere-to-stratosphere (TTS) mass transport occurs during both regular deep convective storms and fire-induced thunderstorms. Both the naturally occurring convective storms and storms that seemed to have been caused partially by forest fires are capable of injecting aerosol particle as well as gases (water vapor, other trace gases) into the stratosphere. The author has demonstrated previously using a numerical cloud model that such transport can be a result of cloud top gravity wave breaking. The present paper will provide an in-depth analysis of the physical mechanism that produces the wave breaking. First of all, more up to date satellite data will be presented to show ever more clearly that the TTS transport indeed occurs and it occurs in lower latitudes as well as midlatitudes. Then analysis of numerical model results will be presented to show that the wave breaking is due to the buildup of local critical layers in the thunderstorm. Animations of the storm development and TTS transport as well as the local Richardson number field will be shown to strengthen the viewpoint. The same mechanism also explains the previously unresolved issue of Ted Fujita's observation of jumping cirrus. The corroboration of Fujita's aircraft observation and satellite observations highly enhances the plausibility of this explanation. In addition, model simulation results including the in-cloud production of sulfate particles from chemical reactions between SO2 and water droplets and their re-distribution, including also the TTS transport, will be presented. Finally, strategy of future observational studies will be suggested based on the findings from model results.