Atmospheric Chemistry and Physics
An Interactive Open Access Journal of the European Geosciences Union

Atmos. Chem. Phys., 8, 1621-1633, 2008
www.atmos-chem-phys.net/8/1621/2008/

Formation of large (≈100 μm) ice crystals near the tropical tropopause

E. J. Jensen[1], L. Pfister[1], T. V. Bui[1], P. Lawson[2], B. Baker[2], Q. Mo[2], D. Baumgardner[3], E. M. Weinstock[4], J. B. Smith[4], E. J. Moyer[4], T. F. Hanisco[4], D. S. Sayres[4], J. M. St. Clair[4], M. J. Alexander[5], O. B. Toon[6], and J. A. Smith[6]

[1]NASA Ames Research Center, Moffett Field, CA, USA
[2]SPEC Inc., Boulder, CO, USA
[3]Centro de Ciencias de la Atmosfera, Universidad Nacional Autonoma de Mexico, Circuito Exterior, Mexico
[4]Harvard University, Cambridge, MA, USA
[5]Colorado Research Associates, Boulder, CO, USA
[6]University of Colorado, Boulder, CO, USA

Abstract. Recent high-altitude aircraft measurements with in situ imaging instruments indicated the presence of relatively large (≈100 μm length), thin (aspect ratios of ≈6:1 or larger) hexagonal plate ice crystals near the tropical tropopause in very low concentrations (<0.01 L^{-1}). These crystals were not produced by deep convection or aggregation. We use simple growth-sedimentation calculations as well as detailed cloud simulations to evaluate the conditions required to grow the large crystals. Uncertainties in crystal aspect ratio leave a range of possibilities, which could be constrained by knowledge of the water vapor concentration in the air where the crystal growth occurred. Unfortunately, water vapor measurements made in the cloud formation region near the tropopause with different instruments ranged from <2 ppmv to ≈3.5 ppmv. The higher water vapor concentrations correspond to very large ice supersaturations (relative humidities with respect to ice of about 200%). If the aspect ratios of the hexagonal plate crystals are as small as the image analysis suggests (6:1, see companion paper (Lawson et al., 2008)) then growth of the large crystals before they sediment out of the supersaturated layer would only be possible if the water vapor concentration were on the high end of the range indicated by the different measurements (>3 ppmv). On the other hand, if the crystal aspect ratios are quite a bit larger (≈10:1), then H_2O concentrations toward the low end of the measurement range (≈2–2.5 ppmv) would suffice to grow the large crystals. Gravity-wave driven temperature and vertical wind perturbations only slightly modify the H_2O concentrations needed to grow the crystals. We find that it would not be possible to grow the large crystals with water concentrations less than 2 ppmv, even with assumptions of a very high aspect ratio of 15 and steady upward motion of 2 cm s^{-1} to loft the crystals in the tropopause region. These calculations would seem to imply that the measurements indicating water vapor concentrations less than 2 ppmv are implausible, but we cannot rule out the possibility that higher humidity prevailed upstream of the aircraft measurements and the air was dehydrated by the cloud formation. Simulations of the cloud formation with a detailed model indicate

that homogeneous freezing should generate ice concentrations larger than the observed concencentrations (20 L^{-1}), and even concentrations as low as 20 L^{-1} should have depleted the vapor in excess of saturation and prevented growth of large crystals. It seems likely that the large crystals resulted from ice nucleation on effective heterogeneous nuclei at low ice supersaturations. Improvements in our understanding of detailed cloud microphysical processes require resolution of the water vapor measurement discrepancies in these very cold, dry regions of the atmosphere.

Citation: Jensen, E. J., Pfister, L., Bui, T. V., Lawson, P., Baker, B., Mo, Q., Baumgardner, D., Weinstock, E. M., Smith, J. B., Moyer, E. J., Hanisco, T. F., Sayres, D. S., Clair, J. M. St., Alexander, M. J., Toon, O. B., and Smith, J. A.: Formation of large (≃100 μm) ice crystals near the tropical tropopause, Atmos. Chem. Phys., 8, 1621-1633, 2008.