Comparison between microphysical model simulation and observed cirrus clouds formation within a volcanic aerosol layer in the Tropical Tropopause Layer
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Introduction
Lower stratospheric water vapor is mainly transported from the troposphere through the Tropical Tropopause Layer (TTL). Optically thin cirrus clouds appear frequently in the TTL. Because of low temperature, it has been supposed that cirrus ice particles are nucleated homogeneously. However, it is thought heterogeneous nucleation is key process by numerical model calculation recently.

In order to know the formation process of cirrus clouds in TTL, we are using a microphysical numerical model to calculate nucleation and growing process of cirrus cloud particles, and comparing the results of the model simulations with observed results.

Observation
Jan. 6-13, 2011, Biak(1.17°S, 136.06°E)
- grand based Lidar
- balloon-borne Optical Particle Counter (OPC)
- University of Colorado, Cryogenic Frost point Hydrometer (CU-CFH)

Lidar
- 17.5-19km volcanic aerosol layer
- Cirrus clouds were observed in the aerosol layer (12°N, Jan)
backscatter coefficient

\[ \beta_{S32} = 6 \times 10^{-8} \sim 1 \times 10^{-7}/m\text{str} \]

The number concentration of ice particles

\[ N_{\text{ice}} < 10^{5}/m^3 \]

OPC
- Most of the aerosol particles in the TTL were liquid droplets.
- The number concentration of nonvolatile aerosol particles at 200°C might be the maximum number of solid particles (The number at 200°C is the number of solid particles if the particles mix externally).

Numerical Model
Box model, ice nucleation, condensational growth, water vapor
Pressure: 70 hPa (constant), H2O initial value 2 ppmv (CU-CFH)
Aerosols liquid: dν/dρ=4697.3 r^2/dm^2/m^3 (OPC(Ambient))
solid: 10^5 m^3 or 10^7 m^3 (OPC(Heated)), log-normal distribution

Homogeneous nucleation
The higher Relative Humidity of ice (RHi), the higher event probability of homogeneous nucleation (Koop et al., 2001). In this setting, ice nucleates at RHi=170%.

Heterogeneous nucleation
Solid aerosol particles can act as an efficient ice nucleus with RHi values of 110% or 120% (Baustian et al., 2010; Wise et al., 2010).

Experiment 2
<Backward trajectory analysis>
The temperature of the air parcel including the thin cirrus clouds was constant or slightly increasing before arriving at Biak. It is assumed there is a fine vertical structure of temperature, or that smaller scale dynamics like gravity wave decreased temperature to form cirrus clouds.

We calculated with gravity waves superimposed on a slow cooling. Phase offsets for individual wave were randomly set, and calculated 20 times.

Result
(1) ice particles are produced only by homogeneous nucleation

\[ N_{\text{ice}} \text{ and } \beta_{S32} \text{ were a few orders larger than the estimation by the observation.} \]

(2) only by heterogeneous nucleation

\[ \beta_{S32} \text{ were consistent with the estimated values.} \]

(3) by homogeneous nucleation and heterogeneous nucleation

Heterogeneous nucleation occurred after heterogeneous nucleation when the cooling rate set larger, \( N_{\text{ice}} \) and \( \beta_{S32} \) were larger than the estimated value.

The heterogeneous nucleation is more important for cirrus formation in the TTL.

Summary
About the cirrus cloud formation on Jan. 12, 2011, calculated results by model assumed only heterogeneous nucleation or only homogeneous nucleation (cooling rate < 0.1K/h) show agreements with the observed values.

However, if there are both type of aerosol particles, the simulations with heterogeneous nucleation show better agreement with the observation.