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Comparison between microphysical model simulation and observed cirrus clouds formation within a volcanic aerosol layer in the Tropical Tropopause Layer

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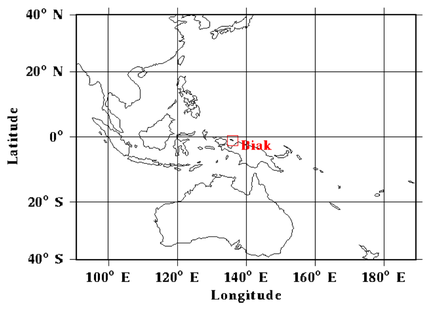
Introduction

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

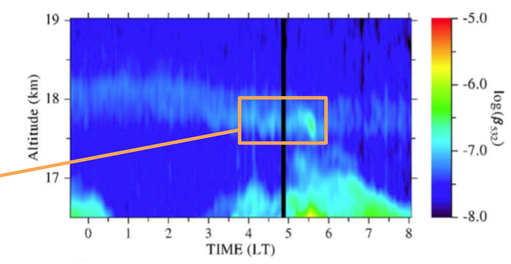
- 17.5～19km volcanic aerosol layer
- Cirrus clouds were observed in the aerosol layer (12th,Jan)

backscatter coefficient

β_{532} 6×10^{-8} ～1×10^{-7}/m/str

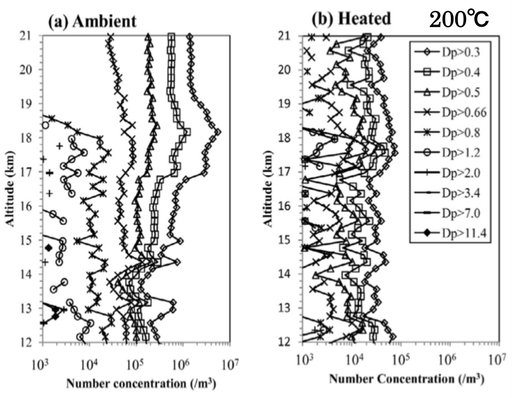
the number concentration of ice particles

$N_{ice} < 10^5/m^3$



OPC

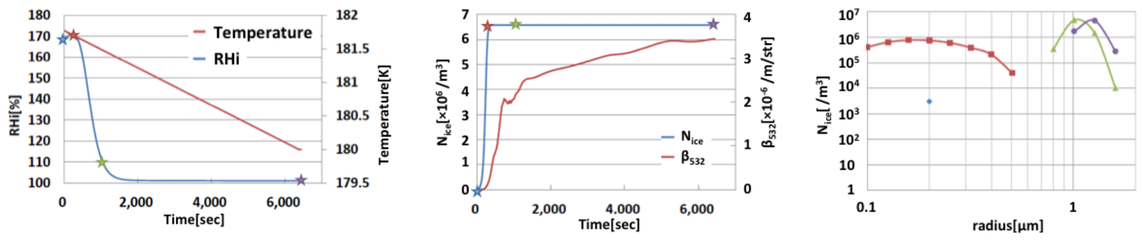
- Most of the aerosol particles in the TTL were liquid droplets.
- The number concentration of nonvolatile aerosol particles at 200℃ might be the maximum number of solid particles (The number at 200℃ is the number of solid particles if the particles mix externally).



Experiment 1

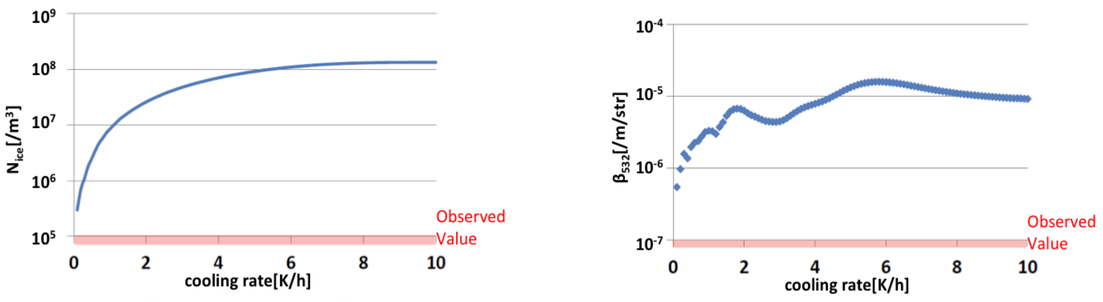
Cooling rate was set constant. We assumed three cases: **(1)** ice particles are produced only by homogeneous nucleation, **(2)** only by heterogeneous nucleation, **(3)** by both of them.

e.g.) **(1)** only by homogeneous nucleation, cooling rate 1K/h



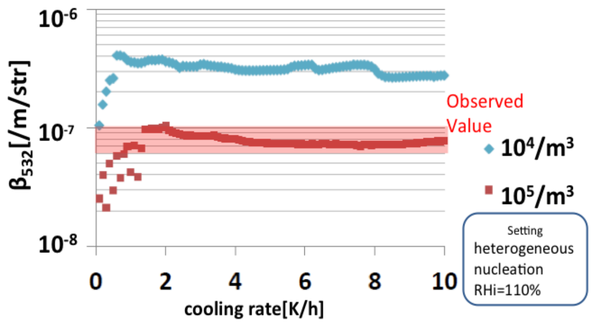
Result

(1) ice particles are produced only by homogeneous nucleation



N_{ice} and β_{532} were a few orders larger than the estimation by the observation.

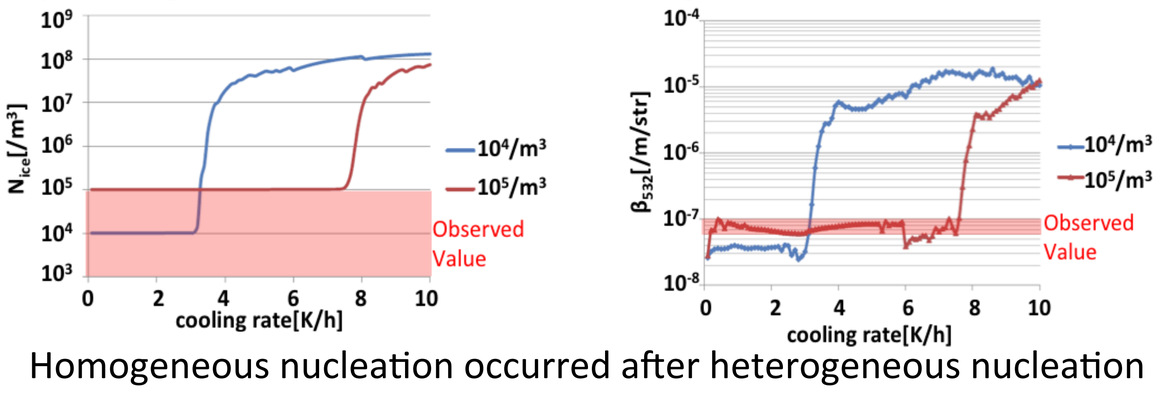
(2) only by heterogeneous nucleation



Number concentration of ice nuclei was set 10^4 or 10^5 /m^3 to agree with observed value by OPC with a heated inlet tube (at 200℃).

β_{532} were consistent with the estimated values.

(3) by homogeneous nucleation and heterogeneous nucleation



Homogeneous nucleation occurred after heterogeneous nucleation when the cooling rate set larger, N_{ice} and β_{532} were larger than the estimated value.

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

Numerical Model

Box model; ice nucleation, condensational growth, water vapor

Pressure 70 hPa(constant), H_2O initial value 2 ppmv (CU-CFH)
Aerosols liquid: $dn/dr=4697.3\ r^{-5.024}$[/m/m³] (OPC(Ambient))
solid: 10^4/m³ or 10^5/m³ (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>

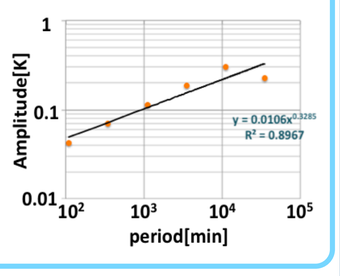
The temperature of the air parcel including the thin cirrus clouds was constant or slightly increasing before arriving at Biak. It is assumed there is a fine vertical structure of temperature, or that smaller scale dynamics like gravity wave decreased temperature to form cirrus clouds.

We calculated with gravity waves superimposed on a slow cooling.

Phase offsets for individual wave were randomly set, and calculated 20 times.

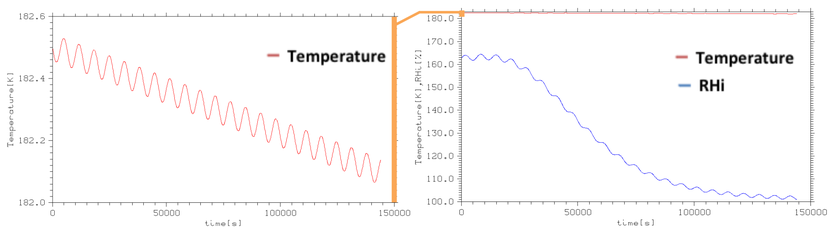
Gravity wave (Jensen and Pfister,2004)

Amplitude [K]	Period [min]	[hour]
0.227	3.50×10^4	583
0.303	1.11×10^4	185
0.186	3.50×10^3	58.3
0.114	1.11×10^3	18.5
0.0698	3.50×10^2	5.83
0.0428	1.11×10^2	1.85



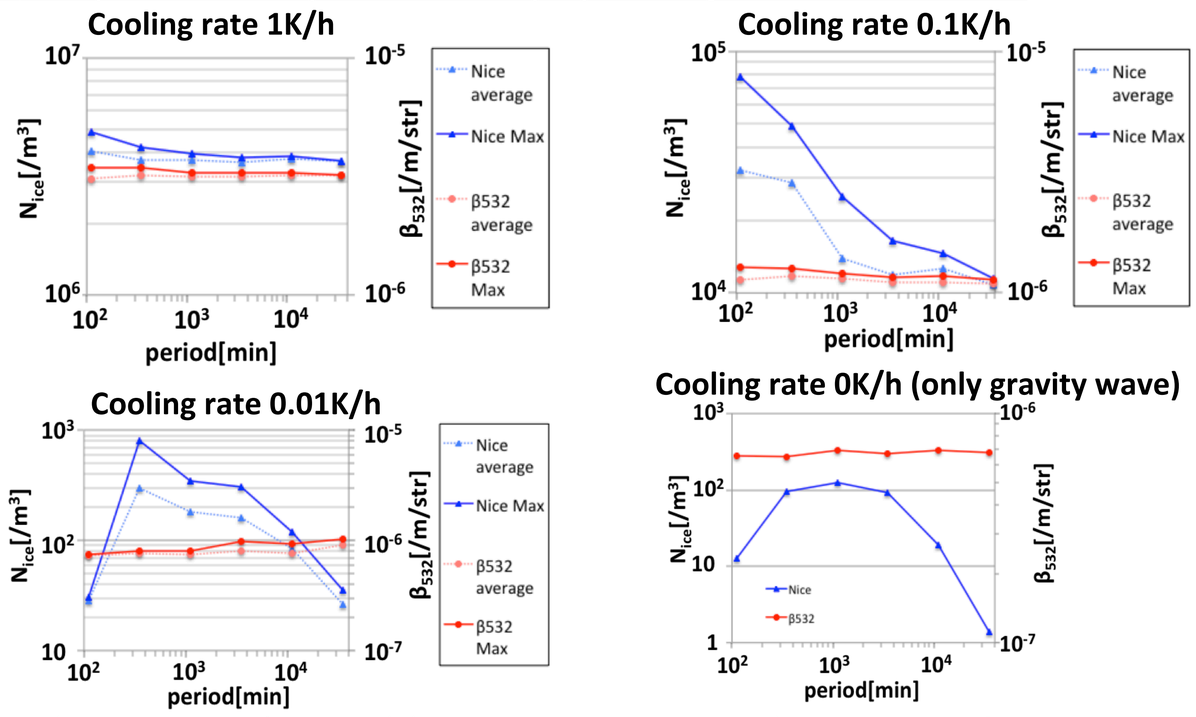
e.g.)
(1) only by homogeneous nucleation
cooling rate 0.01K/h
gravity wave

Amplitude [K]	Period [min]	[hour]
0.0428	1.11×10^2	1.85



Result

(1) ice particles are produced only by homogeneous nucleation



When wave period is enough long not to interrupt ice nucleation process due to rise in temperature and wave driven cooling rate is fast, N_{ice} is largest.

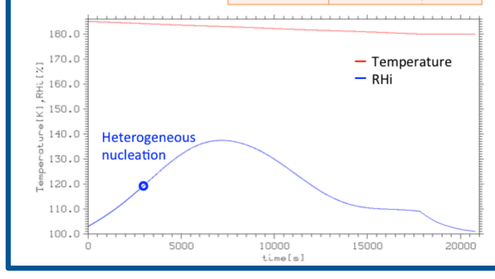
When cooling rate was smaller than ～0.1 K/h, N_{ice} are closer to the observed values.

Because of small N_{ice}, ice particles grow larger and β_{532} is larger than observed values. Since large ice particle will be removed by gravity, β_{532} may be smaller than calculated value.

(2) by homogeneous and heterogeneous nucleation

Cooling rate 1K/h

Amplitude [K]	Period [min]	[hour]
0.0428	1.11×10^2	1.85



Homogeneous nucleation could not occur because ice particles which nucleated heterogeneously grow and the vapor has been depleted.

Summery

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.