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Physical Processes in Polar Stratospheric Ice Clouds

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A one dimensional model of cloud microphysics has been used to simulate the formation and evolution of polar stratospheric ice clouds. Some of the processes which are included in the model are outlined in Fig. 1 to 3. It is found that the clouds must undergo preferential nucleation upon the existing aerosols just as do tropospheric cirrus clouds. Therefore, there is an energy barrier between stratospheric nitric acid particles and ice particles implying that nitric acid does not form a continuous set of solutions between the trihydrate and ice. The Kelvin barrier is not significant in controlling the rate of formation of ice particles. We find that the cloud properties are sensitive to the rate at which the air parcels cool. In wave clouds, with cooling rates of hundreds of degrees per day, most of the existing aerosols nucleate and become ice particles. Such clouds have particles with sizes on the order of a few microns, optical depths on the order of unity and are probably not efficient at removing materials from the stratosphere. In clouds which form with cooling rates of a few degrees per day or less, only a small fraction of the aerosols become cloud particles. In such clouds the particle radius is larger than 10μm, the optical depths are low and water vapor is efficiently removed. Seasonal simulations (Fig 4, 5) show that the lowest water vapor mixing ratio is determined by the lowest temperature reached, and that the time when clouds dissappear is controlled by the time when temperatures begin to rise above the minimum values. Hence clouds occur in the early winter at temperatures which are higher than those at which clouds occur in the late winter. The altitude of the clouds declines during the winter because the temperatures in the Antarctic increase earlier at the higher altitudes. The rate of decline of cloud altitude is not an indication of particle fall speed or of vertical air motion as had been previously suggested. The ice clouds are not able to remove a significant amount of nitric acid through physical process such as coagulation or nucleation. Such removal must occur through other processes not included in our simulations such as vapor phase transfer. A considerable amount of further work could be done to improve upon our simulations. Improvements would include a treatment of the three dimensional structure of wave clouds, a more complete treatment of the interactions between clouds and atmospheric motions on the seasonal time scale, and a treatment of the nitric acid vapor phase interactions with ice particles. Laboratory studies of the vapor pressures of water and nitric acid above ice crystals are needed. In addition laboratory investigations of the ice nucleating properties of nitric acid crystals would be useful. Direct observations of the sizes and concentrations of the particles in clouds formed over a few day time period are not available and are important to obtain since these dominate the sedimentation removal process.

Figure Captions

Fig. 1 Illustrated are the basic components of the cloud physics model. The preexisiting nitric acid aerosols nucleate to form impure ice crystals. These ice crystals grow by condensation of water. Once formed the ice particles begin to sediment, removing materials from the stratosphere. The model is one dimensional.

Fig. 2 Illustrated is the time required for hexagonal columns which are three times as long as they are wide to fall a distance of 1 km starting at altitudes of 20 km or 12 km. The fall time is not a strong function of the altitude, but it does vary greatly with the radius of the particles. Since ice clouds will generally have lifetimes on the order of a few days due to the varying temperatures experienced by air parcels as they move around the vortex, particle sizes on the order of 10μm are needed for substantial removal to occur during the lifetime of a cloud.

Fig. 3 Illustrated is the time required for a hexagonal column to double or half its size at a supersaturation of 100% assuming that 5ppmv of water vapor is present. When growth occurs the supersaturation will be reduced. In rapidly cooling clouds with many particles the supersaturation will become less than 1% and sizes will be limited. In slowly cooling clouds with a small number of particles the supersaturation may remain at the 10% level and large particles can form.

Fig. 4 Simulations of the seasonal evolution of ice cloud backscatter are compared with observations from the Syowa station in 1983 (Iwasaka et al., Geophys. Res. Lett. 13,1407,1986). With no energy barrier (m=1) all of the particles nucleate, clouds with optical depths greater than 1 form and the clouds have more backscatter than observed. With a modest energy barrier (m=.95) only a few particles form , optical depths are order 10^{-2} and the backscatter is of the magnitude observed.

Fig. 5 The clouds are able to remove water vapor very effectively. Therefore the timing of water vapor removal and the amount of water removal are controlled by the temperatures. A further 2 degree cooling would have reduced the water to 2ppmv.

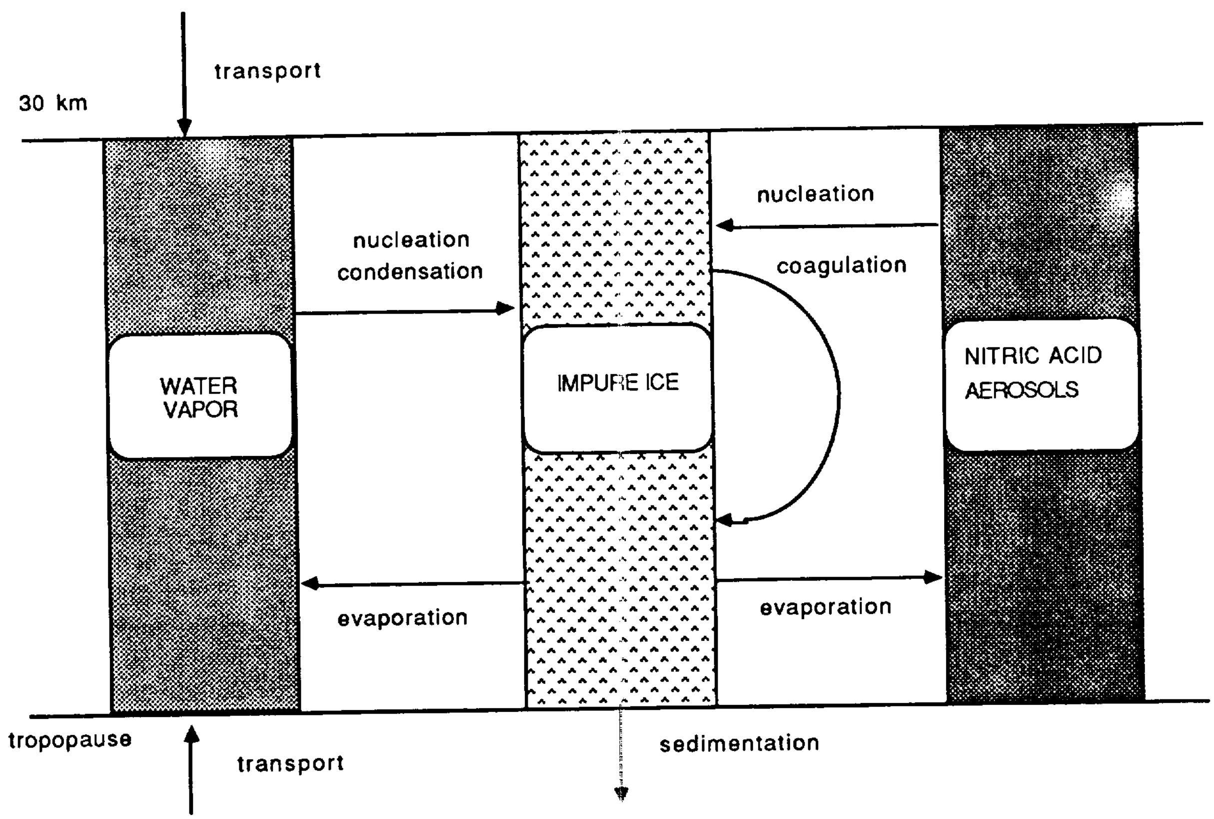

Fig. 1

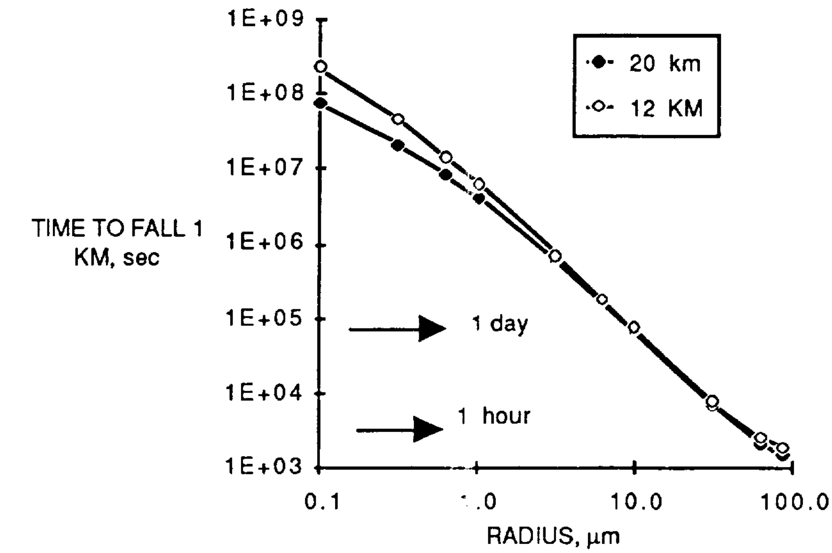
20 km
12 KM
TIME TO FALL 1 KM, sec
1E+09
1E+08
1E+07
1E+06
1E+05
1E+04
1E+03
1 day
1 hour
0.1
10.0
100.0
RADIUS, µm

Fig. 2

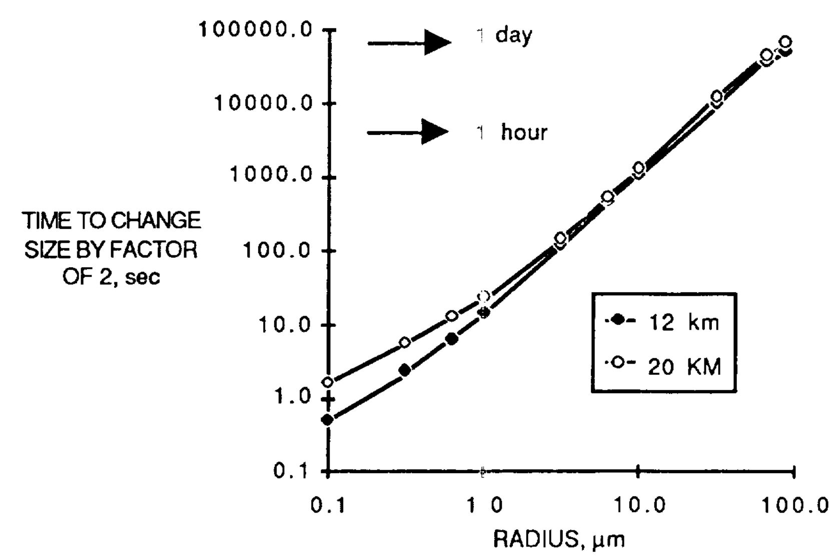
100000.0
10000.0
1000.0
100.0
10.0
1.0
0.1
1 day
1 hour
TIME TO CHANGE SIZE BY FACTOR OF 2, sec
12 km
20 KM
0.1
10.0
100.0
RADIUS, µm

Fig. 3

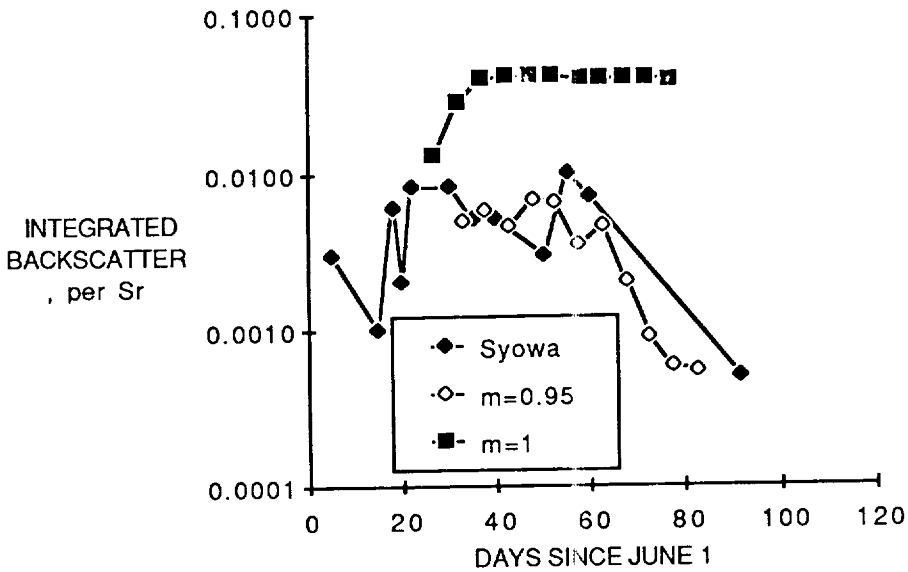
0.1000
0.0100
0.0010
0.0001
INTEGRATED BACKSCATTER , per Sr
Syowa
m=0.95
m=1
0
20
40
60
80
100
120
DAYS SINCE JUNE 1

Fig 4

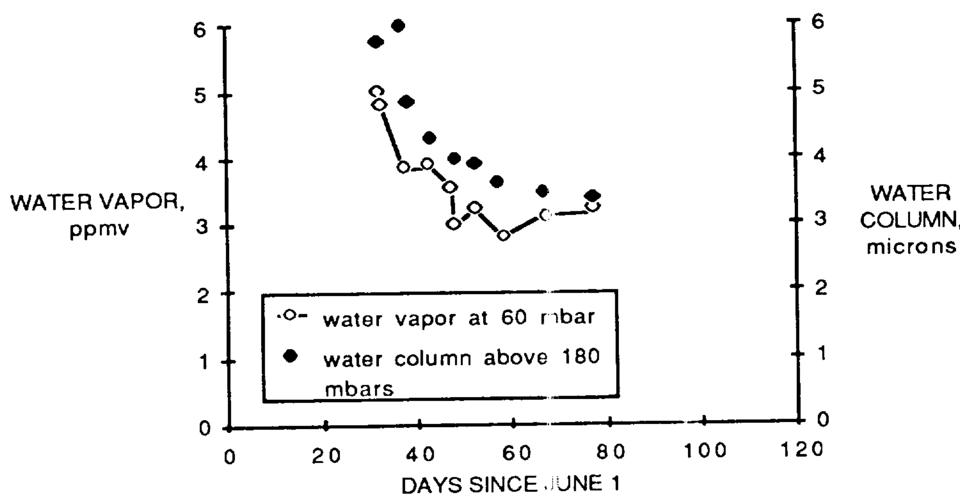
WATER VAPOR, ppmv
WATER COLUMN, microns
water vapor at 60 mbar
water column above 180 mbars
0
1
2
3
4
5
6
0
20
40
60
80
100
120
DAYS SINCE JUNE 1

Fig. 5