Microphysics of Contrail to Cirrus

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Contrail

An artificial, linear cloud created by an aircraft

Composed with ice crystals, below about -40℃

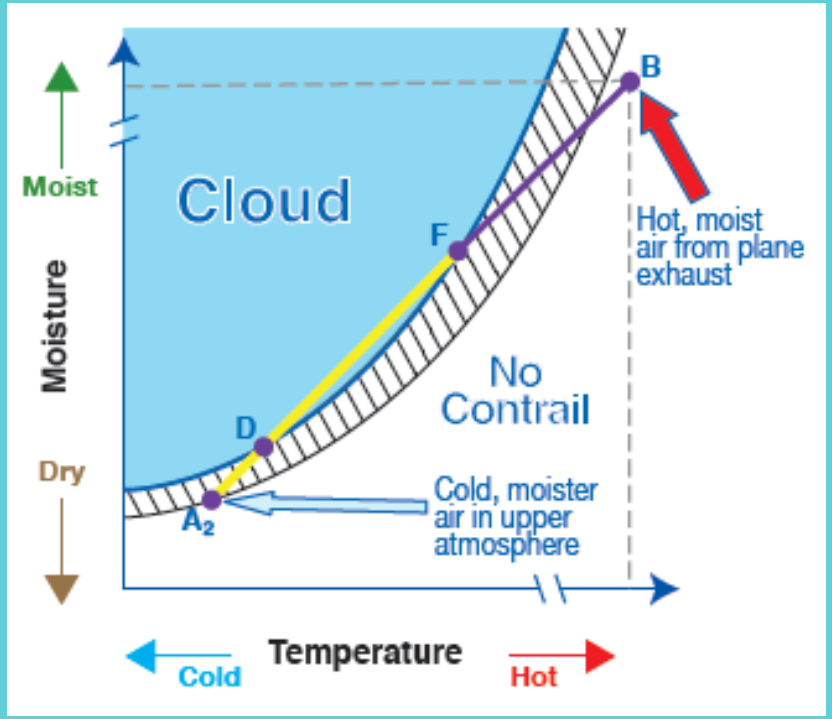
Visible human influence to atmosphere

Contrail Formation

Mixing process

Thermodynamically decided

- Temperature
- RH
- The fuel energy content
- The amount of water vapor exhausted
- Propulsion efficiency



Contrail Cirrus

- Line-shaped persistent contrails transform into irregularly shaped ice clouds, or contrail cirrus

- Condition
  - Wind shear
  - Turbulence
  - Ice-saturated air

- Contrail cirrus .vs. Natural cirrus

Difficult to distinguish! – visual, microphysical, optical aspects

Observing the Contrail – Cirrus Changing

Contrail → Developing → **Cirrus**

High concentration

Spherical ice crystal

Diameter 1~10 μm

?

Typical concentration

Irregular ice crystal

Diameter 10~20 μm

Contrail Evolution ; Three Phases

- Initial jet phase (~20 sec)
  - 배기가스 배출, 혼합
  - Schmidt-Appleman criterion – nucleation, forming ice crystal

- Vortex phase (20 sec ~ 2 min)
  - 비행기 날개 뒤
  - 하강하며 단열압축, 얼음 결정 승화 (상대습도, 온도의 영향)
  - Unstable, 2분 뒤 소멸

- Final dispersion Phase (minutes ~ hours)
  - Atmosphere turbulent & wind shear – lower the concentration
  - **Contrail become Cirrus in this phase**

What happens in dispersion phase

A simplified parcel model

By Schroder et al(1999)

$$\frac{dx_w}{dt} = -j_w x - (x_w - x_{wa})\frac{\alpha}{t}$$

$$\frac{dm}{dt} = -m_w j_w$$

$$x(t) = x_0\left(\frac{t_0}{t}\right)^{\alpha}$$

$$T(t) = T_0 + v\left(\frac{dT}{dt}\right)_{ad}(t - t_0)$$

Simplified Parcel Model - Approximation

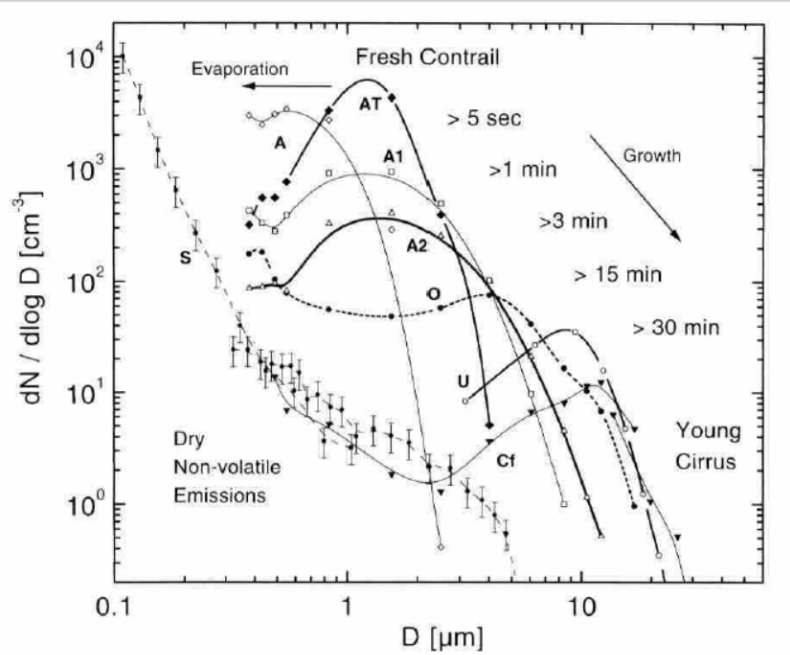
- Consider
  - Dilution by mixing
  - Deposition of water vapor

Crystal size of contrail is very small

- Ignore
  - Ventilation
  - Latent heat
  - Crystal coagulation $\propto$ exp(temp.) , ignore sat., crystal strct.
  - Break up process
  - Sedimentation loss $\propto$ $a*D^b$ (D=0.01 for contrail)

The process happen in very short time

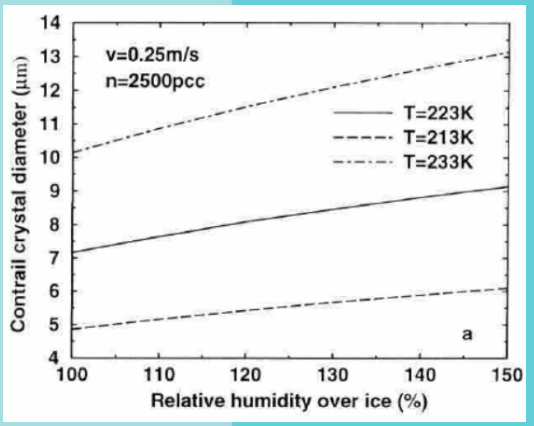
Results of Model ~ Observation

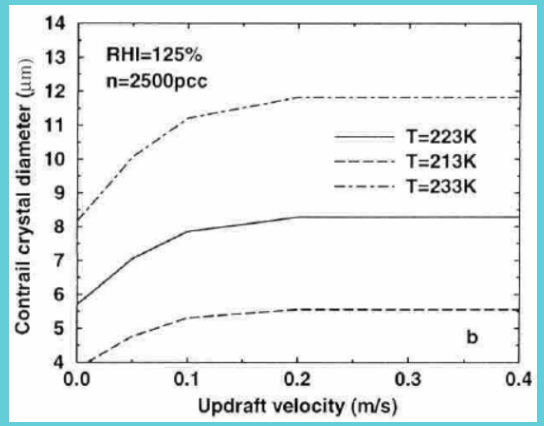


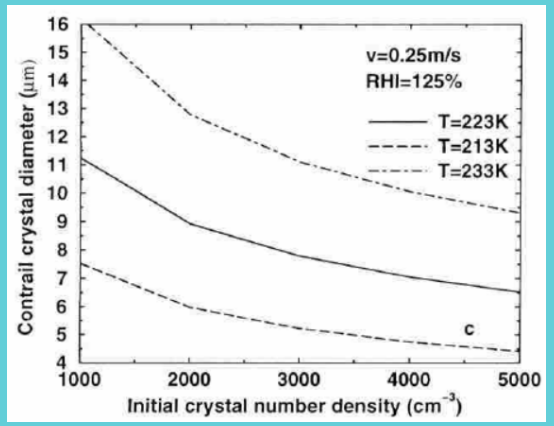
- Ice crystal concentration
  - 2~3 order decreased
- Mean diameter
  - 9μm increased

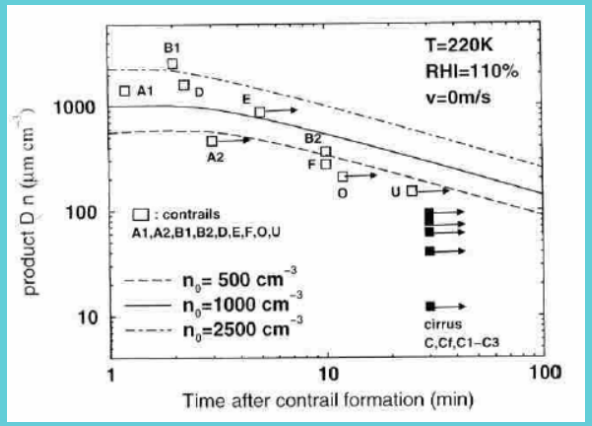
Similar to observation
But some microphysical process is omitted

Results of Model ~ Observation









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SUMMARY

Some contrail changes to cirrus

How does it change? – Contrail evolution (3 phases)

Dispersion phase – Simplified Parcel Model

Results

REFERENCES

Schröder, F., and Coauthors, 2000: On the transition of contrails into cirrus clouds. *J. Atmos. Sci.*, **57,** 464–480.

Heymsfield, A., *et. al.*, 2010: Contrail Microphysics. *Bulletin of American Meteorological Society,* **94(4)**, 465-472.

THANK YOU FOR LISTENING
&
ANY QUESTION