The Secret Life of Small Ice Particles in Tropospheric Clouds

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2013-05-29
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In-situ measurements

Satellite Atmospheric Science Group

Satellite data

New satellite instrument design

Radiative transfer

Simulated with ARTS

www.sat.ltu.se
Ice cloud over Great Britain as seen by visible, IR

(AVHRR, Channel 1, 580-680nm, 25.1.2002, 13:30 UTC, Data Source: Met Office / Dundee Receiving Station)

(AVHRR, Channel 4, 10.3-11.3μm, 25.1.2002, 13:30 UTC, Data source: Met Office / Dundee Receiving Station)
PhD instrument development and validation

- Particle Mass
- Counting particles

Prototype of the new instrument.
Urban air pollution: Los Angeles

- microphysical properties of urban aerosol
- field studies (variety of instruments and techniques)
Research Associate in Waterloo

• Research
  – transport of aerosol into Arctic
  – homogeneous ice nucleation
  – ice crystal growth and habit

• teaching experience
  – teaching,
  – developing new course,
  – student supervision,
  – outreach
Nucleation of cloud ice particles: in liquid

- Nucleation, also called *freezing*, is similar to creation of droplet via condensation:
  - New surface (here between solid and liquid) => energy barrier, water does not freeze at 0° C!

- Supersaturation, now also called *supercooling*, necessary for nucleation
  (supercooling increases likelihood of ‘ice-like’ cluster of H₂O molecules that can act as nucleus)

- If **ice nuclei (IN)** are present, less supercooling required
Freezing  If humidity is above liquid water saturation, the water condenses first, then freezes. This can happen already at warmer temperatures (a few degrees below zero) if IN (freezing nuclei) in liquid droplets (heterogeneous), otherwise homogeneous nucleation. (No IN inside liquid droplets (freezing nuclei) => droplets can be supercooled down to around -38°C)

Deposition  Ice particles form and then grow by direct deposition on ice nuclei (IN, also deposition nuclei).

Contact freezing  Also contact nuclei: IN that touches supercooled droplet => droplet freezes

- Good IN should have crystal structure similar to ice.
- Good CCNs are not necessarily good ice nuclei.
- INs more rare than CCNs
Ice Particle Growth

Growth from the vapor phase

- Saturation to liquid water means supersaturation to ice.

Ice particles grow rapidly on the expense of droplets.

- Growth through the ice phase
- Dominant at mid- and high-latitudes
- also called Bergeron-Findeisen mechanism
- Falling ice particles may melt => Rain

Wallace and Hobbs.
Ice Particle Growth

Growth by collection of droplets (also called *riming*)

- Larger ice crystals fall through smaller cloud droplets.
- Supercooled droplets freeze on contact.

Ice particles grow to rimed snowflakes; *graupeL* if shape of crystal disappears.
Ice Particle Growth

Growth by collection of many large droplets

- Ice particles grow fast in convective cloud with high liquid water content
- may get wet surface during growth

Grow to *hailstones*
Ice Particle Growth

Growth by aggregation

- Ice crystals collide and stick together.
Ice Particle Growth from Vapour Phase: Ice Crystal Structure (Ih)

- Every O has four bonds to ‘O-neighbours’
  - Three in same layer
  - One either above or below

Layer: one O at every corner

Seen from top
Faceted growth

- Finite crystal lattice, with min. surface energy
  - Certain planes are preferred (lower surface energy)
    - Few open/broken bonds
    - Attaching molecules tend to fill these planes (smoothening)
  - Facets are the resulting faces on crystal

Next layer
First molecules have more broken bonds

Complete, smooth surface
Every second O has only one broken bond
Simple ice crystals

- Faceted growth
  - Small crystals
  - Slow growth
- Depending on dominant growth:
  - thin plate
  - long column
Ice Particle Growth from Vapour Phase: Growth Modes

- Growth depends strongly on temperature and humidity
  - T: plate → column → plate → column
  - RH: simple → embellished (branching)

K.G. Libbrecht, American Scientist, 2007. (Originally Ukichiro Nakaya ~1930s)
Ice crystal branching

- Diffusion: transport of molecules to ice surface
- Transport faster to points that protrude further out
  - ‘Bumps’ and corners will grow faster
  - **Branching instability**
- Growth complex competition between *faceting* and *branching*

Branched, evaporating
Kiruna snowflake (one particle) 2012, Thomas Kuhn
University of Waterloo
Cryogenic Aerosol Flow Tube:
Ice crystal growth habits

- 70 s growth time
- -3 to -33 °C
- RH fixed to water saturation
- 1 CCD pixel = 0.2 μm

Ice nuclei
Water droplets
Cooling coils
Vacuum jacket
Illumination

CCD
Microscope objective
(Flash lamp)
Optical fiber
Focusing lens

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Early ice growth in mixed-phase “ice cloud”
Ice crystal early-growth habits
Habit diagram

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Snowflake Shape = Snowflake History

Figures: Ken Libbrecht
Ice Particles – Optical Phenomena

- Reflection
- Refraction
- Diffraction
Sun pillar (or *light pillar*)

- Light reflected by horizontally aligned crystal faces
  - Sun
  - Car headlights, street lamps, …
Sun dogs

Alep Gierkav
Andrea Barghi
Halo

Piazza del Quirinale, Roma
Marco Meniero
Halo

- hexagonal columns or plate acts like a 60° prism
- Thin plates, sun, and observer horizontally “aligned” => sun dogs

Special symmetrical case gives lowest deviation angle of 22°

- Sharp edge on one side of halo (towards lower deviation angle)
- Angles close to 22° are more frequent than larger angles
- Like a prism => angle depends on colour
Mother-of-pearl cloud

Type of polar stratospheric cloud (PSC)

Also called nacreous cloud

**mother-of-pearl** (Oxford Dictionary)

- a smooth iridescent substance forming the inner layer of the shell of some molluscs, especially oysters and abalones, used as ornamentation.
Mother-of-pearl cloud
Wikipedia: Iridescent clouds are a **diffraction** phenomenon. Small water droplets or even small ice crystals in clouds individually **scatter** light.

- **Diffraction** of sunlight as it passes through zones of rather uniform ’droplet’ size, with sizes not much larger than the wavelength of visible light.
Diffraction around spheres

- Diffraction theory: minima at $\sin(\theta) = (n+0.22) \lambda/d$, $n = 1, 2, \ldots$
  (approximate solution)
- Mie scattering:
  (exact solution)

Radius 9 µm
Green: 546 nm

$n=1$, $\theta = 2.1^\circ$
$n=2$, $\theta = 3.9^\circ$
$n=3$, $\theta = 5.6^\circ$

Corona around moon, particles (probably droplets) around 9 µm.
Thank you!