Precipitation Systems and Microphysical Processes
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Precipitation Systems

Generating Clouds and Precipitation
- Clouds form when water vapor in the atmosphere condenses into cloud droplets or ice crystals
  - Requires air to become supersaturated through evaporation or cooling
  - Ascent and associated adiabatic expansion and cooling is the primary (but not only) mechanism for generating supersaturation in precipitating clouds
- Precipitation occurs when hydrometeors grow sufficiently large to fall and reach the ground
  - Typically cannot be accomplished through condensation alone
  - May involve multiple microphysical processes

Group Discussion

What weather systems are primarily responsible for precipitation in the tropics and extratropics?

Extratropical Cylcones/Fronts

NASA Earth Observatory
Cyclone Contribution


Large-scale forcing

Convection

- Vertical motions due to an imbalance of forces in the vertical
- Precipitating clouds generated by rising parcels that are warmer than their environment, resulting in an updraft
- Key ingredients — Instability, moisture, & lift

Mesoscale Convective Systems

- Organized collection of two or more cumulonimbus clouds that interact to form an extensive region of precipitation
- Precipitation region is nearly contiguous and contains convective and stratiform elements, with the latter typically more extensive

Source: Trapp (2013)

Convection

https://www.youtube.com/watch?v=Py9thWefI

Mesoscale Convective Systems

- Hydrometeor detrainment and transport from convective line and “layer lifting” important in precipitation dynamics of the stratiform region
- Example is of a convective-line MCS (a.k.a. squall line)

Tropical Cyclones

Orographic

Microphysical Processes

- Cloud droplet formation
  - CCN and droplet size spectra
- Warm cloud processes
  - Collision-coalescence
- Mixed-phase processes
  - Ice nucleation
  - Ice multiplication
  - Depositional growth (a.k.a., the Bergeron-Findeisen Process)
  - Accretional growth
  - Aggregation

Microphysical Processes

Droplet Formation

- Cloud droplets form on soluble atmospheric aerosols
  - Heterogeneous nucleation
- Cloud condensation nuclei (CCN)
  - Aerosol which serve as nuclei for water vapor condensation
- On average, there is an order of magnitude more CCN in continental air than maritime air.
Continental clouds frequently feature:
- Large cloud droplet number concentrations & smaller cloud droplets

Maritime clouds frequently feature:
- Smaller cloud droplet number concentrations & larger cloud droplets

- In continental areas, however, there are large intra- and inter-storm variations depending on aerosol characteristics
  - Maritime size spectra are rare, but possible
- Significance: Impacts hydrometeor growth (more later)

Warm Cloud Processes

- “Warm Cloud”
  - Clouds that lie entirely below the 0°C level or consistent entirely of liquid water

- Mechanisms for warm cloud hydrometeor growth
  - Condensation
  - Collision-coalescence

Condensation

- Droplet growth by condensation is initially rapid, but slows with time
- Condensational growth too slow to produce large raindrops

Collision–Coalescence

- Growth of small droplets into raindrops is achieved by collision-coalescence
- Fall velocity of droplet increases with size
- Larger particles sweep out smaller cloud droplets and grow
- Becomes more efficient as radius increases
- Turbulence may contribute to this growth mechanism

- Cloud droplet growth initially dominated by condensation
- Growth into raindrops dominated by collision-coalescence
- Most effective in maritime clouds due to presence of larger cloud droplets (due to fewer CCN)
Hawaiian Warm-Phase Clouds

Seasonal transition (3-4°C)

Freezing Level (0°C)

Liquid water cloud droplets &
Collision-coalescence

Rain

Mixed-Phase Cloud Processes

• Glaciation
  – Ice nucleation & multiplication

• Depositional growth

• Accretion

• Aggregation

Glaciating Cloud Example

Steenburgh (2014)

Ice Nucleation

• Water does not freeze at 0°C
  – Pure water does not freeze until almost -40°C (homogeneous nucleation)
  – Supercooled liquid water (SLW) – water (rain or cloud droplets) that exists at temperatures below 0°C
  – Ice nuclei – enable water to freeze at temperatures above -40°C

• The effectiveness of potential ice nuclei is dependent on
  – Molecular spacing and crystal structure - similar to ice is best
  – Temperature – Activation is more likely as temperature decreases

• Ice nuclei concentration increases as temperature decreases

Ice Nucleation

• Significance?
  – Cloud will not necessarily glaciate at temperatures below 0°C
  – Want snow (or even rain in many cases)? Need ice!

  – If temperatures in cloud are
    • -4°C or warmer  VERY LITTLE chance of ice
    • -10°C  60% chance of ice
    • -12°C  70% chance of ice
    • -15°C  90% chance of ice
    • 20°C  VERY GOOD chance of ice

Ice nuclei increase by an order of magnitude for every 4°C drop in temperature

Wallace and Hobbs (1977)

– Warm

– Cold

Ice nuclei

Ice nuclei increase by an order of magnitude for every 4°C drop in temperature
Ice Multiplication

- Still have a few problems
  - There are still very few ice nuclei even at cold temperatures
  - Ice particle concentrations greatly exceed ice nuclei concentrations in most mixed phase clouds
  - How do we get so much ice?
- Ice multiplication – creation of large numbers of ice particles through
  - Mechanical fracturing of ice crystals during evaporation
  - Shattering of large drops during freezing
  - Splintering of ice during riming (Hallet-Mossop Process)

Deposition (WBF Process)

- Saturation vapor pressure for ice is lower than that for water
- Air is near saturation for water, but is supersaturated for ice
- Ice crystals/snowflakes grow by vapor deposition
- Cloud droplets may lose mass to evaporation

Deposition (WBF Process)

Habit is a function of temperature and supersaturation with respect to ice

More Habit Diagrams

“A review of over 70 years of ice crystal studies reveals a bewildering variety of habit diagrams” - Bailey and Hallett (2009)

Classification Systems

Magono and Lee (1966), Pruppacher and Klett (1997), Bailey and Hallett (2009), Snowcrystals.com
“While aesthetically appealing and offering a striking subject for photography, the fact is that most ice crystals are defective and irregular in shape.” - Bailey and Hallett (2009)

Reality

Accretion

• Growth of a hydrometeor by collision with supercooled cloud drops that freeze on contact
  • Graupel – Heavily rimed snow particles
    – 3 types: cone, hexagonal, lump

Accretion

• Favored by
  – Warmer temperatures (more cloud liquid water, less ice)
  – Maritime clouds (fewer, but bigger, cloud droplets)
  – Strong vertical motion (larger cloud droplets lofted, less time for droplet cooling and ice nuclei activation)

Accretion

• Bigger particles
  • Impact on precipitation rate is probably small
    – May impact crystal transport and fallout across mountain barriers
    – May affect mass loss from sublimation/evaporation below cloud base

Aggregation

• Ice particles colliding and adhering with each other
  • Can occur if their fall speeds are different
  • Adhering is a function of crystal type and temperature
    – Dendrites tend to adhere because they become entwined
    – Plates and columns tend to rebound
    – Crystal surfaces become stickier above –5°C

Aggregation
Yesterday's Aggregates (1148)

Growth, Transport, & Fallout

- Growth, fallspeed, transport, and terrain scale affect precip rate and distribution
- Typical fall speeds
  - Small ice particles: \(< 1 \text{ m/s}\)
  - Snow: \(\sim 1 \text{ m/s}\)
  - Graupel: \(\sim 3 \text{ m/s}\)
  - Rain \(\sim 7 \text{ ms}^{-1}\)

Hobbs et al. (1973), Houze (2012), Garrett et al. (2012)

Discussion

What evidence is there that these microphysical processes operate in the Tirol?

Do you have a "microphysical experience" you could share with the group?

References