Precipitation Systems and Microphysical Processes

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Precipitation Systems

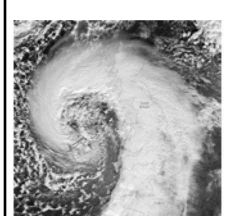
Generating Clouds and Precipitation

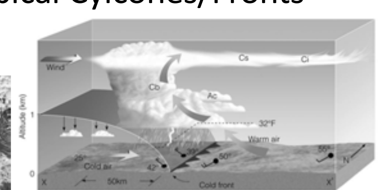
- Clouds form when water vapor in the atmosphere condenses into cloud droplets or ice crystals
  - Requires air to become supersaturated through evaporation or cooling
  - Ascent and associated adiabatic expansion and cooling is the primary (but not only) mechanism for generating supersaturation in precipitating 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

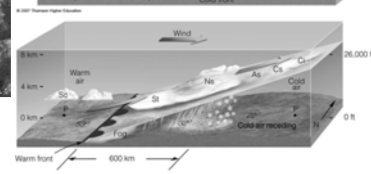
Group Discussion

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

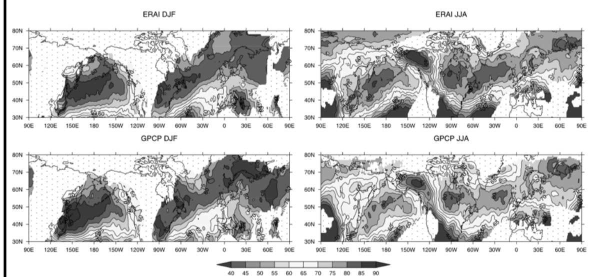
Extratropical Cylcones/Fronts





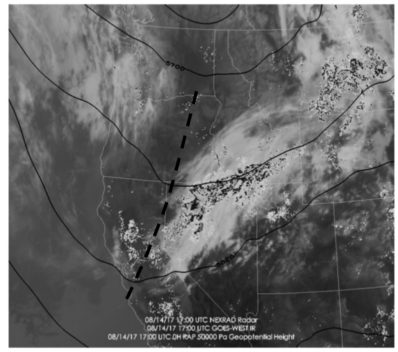


Cyclone Contribution



Source: Hawcroft et al. (2012), http://onlinelibrary.wiley.com/doi/10.1029/2012GL053866/abstract

Large-scale forcing



Convection

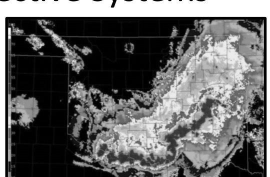
- Vertical motions due to an imbalance of forces in the vertical
- Precipitating clouds generated by rising parcels that are warmer than their environment, resulting in an updraft
- Key ingredients
  - Instability, moisture, & lift

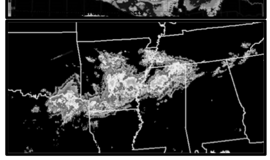
Convection

https://www.youtube.com/watch?v=Pv9thuWwofI

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

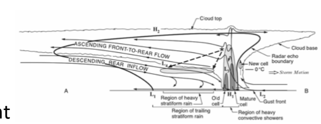




Trapp (2013)

Mesoscale Convective Systems

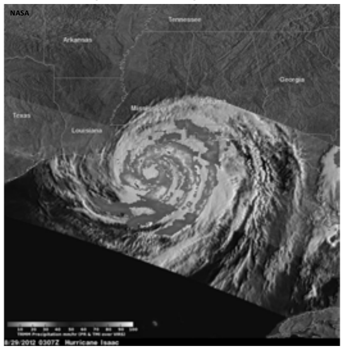
- Hydrometeor detrainment and transport from convective line and “layer lifting” important in precipitation dynamics of the stratiform region
- Example is of a convective-line MCS (a.k.a. squall line)



Convective Line

Houze et al. (1989), Houze (2004)

Tropical Cyclones



Orographic

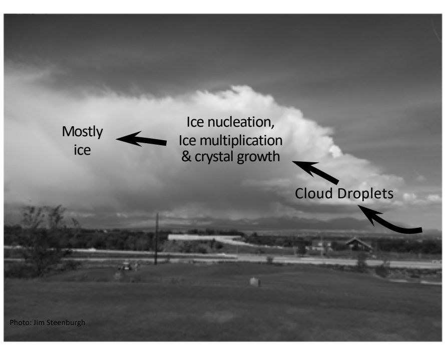
Steenburgh (2014)

Microphysical Processes

Microphysical Processes

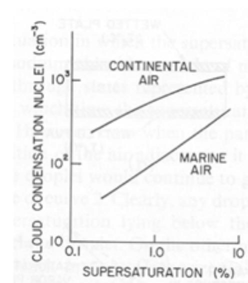
- Cloud droplet formation
  – CCN and droplet size spectra
- Warm cloud processes
  – Collision-coalescence
- Mixed-phase processes
  – Ice nucleation
  – Ice multiplication
  – Depositional growth (a.k.a., the Bergeron-Findeisen Process)
  – Accretional growth
  – Aggregation

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

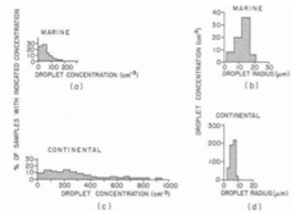


Wallace and Hobbs (1977)

Size Spectra

Marine

Continental



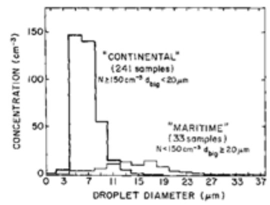
- Continental clouds frequently feature
  - Large cloud droplet number concentrations & smaller cloud droplets
- Maritime clouds frequently feature
  - Smaller cloud droplet number concentrations & larger cloud droplets

Wallace and Hobbs (1977)

Size Spectra

Cloud droplet spectra

Storm Peak Lab
Steamboat, CO



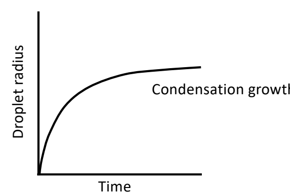
- In continental areas, however, there are large intra- and inter-storm variations depending on aerosol characteristics
  - Maritime size spectra are rare, but possible
- Significance: Impacts hydrometeor growth (more later)

Hindman et al. (1994)

Warm Cloud Processes

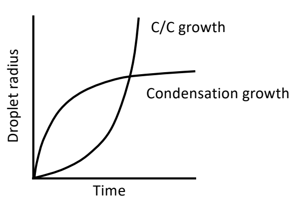
- "Warm Cloud"
  - Clouds that lie entirely below the 0°C level or consistent entirely of liquid water
- Mechanisms for warm cloud hydrometeor growth
  - Condensation
  - Collision-coalescence

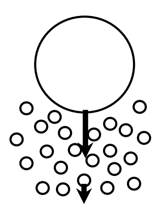
Condensation



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

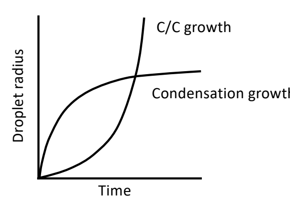
Collision–Coalescence

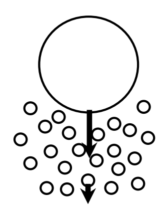




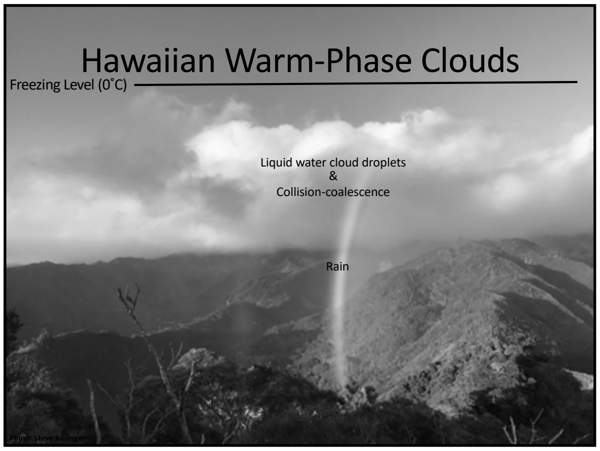
- Growth of small droplets into raindrops is achieved by *collision-coalescence*
- Fall velocity of droplet increases with size
- Larger particles sweep out smaller cloud droplets and grow
- Becomes more efficient as radius increases
- Turbulence may contribute to this growth mechanism

Warm Cloud Processes





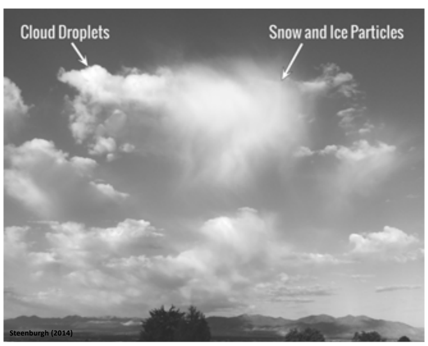
- Cloud droplet growth initially dominated by condensation
- Growth into raindrops dominated by collision-coalescence
-
- Most effective in maritime clouds due to presence of larger cloud droplets (due to fewer CCN)



Mixed-Phase Cloud Processes

- Glaciation
  - Ice nucleation & multiplication
- Depositional growth
- Accretion
- Aggregation

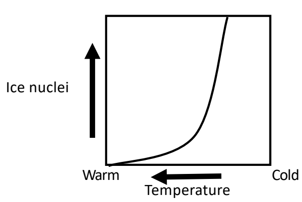
Glaciating Cloud Example



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



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

Wallace and Hobbs (1977)

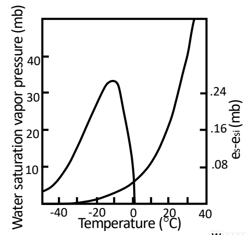
Ice Nucleation

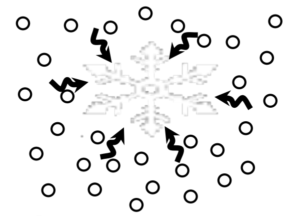
- Significance?
  - Cloud will not necessarily glaciate at temperatures below 0°C
  - Want snow (or even rain in many cases)? Need ice!
  - If temperatures in cloud are
    - -4°C or warmer VERY LITTLE chance of ice
    - -10°C 60% chance of ice
    - -12°C 70% chance of ice
    - -15°C 90% chance of ice
    - 20°C VERY GOOD chance of ice

Ice 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)

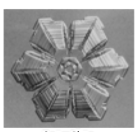




Wegener–Bergeron–Findeisen Process

- 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

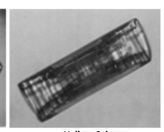
Deposition (WBF Process)



Sector Plate

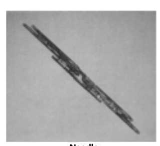
Stellar Dendrite

Dendritic Sector Plate



Hollow Column

Habits – types of ice crystal shapes created by vapor deposition

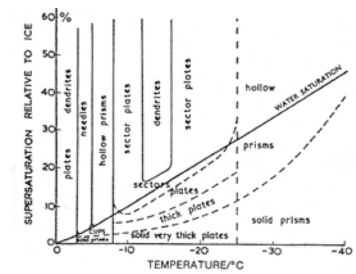


Needle

Snowcrystals.com

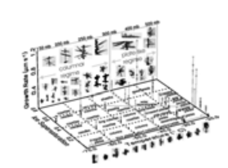
Deposition (WBF Process)

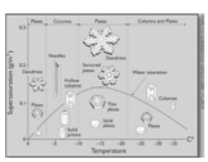
Habit is a function of temperature and supersaturation with respect to ice

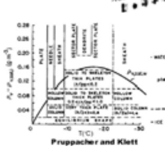


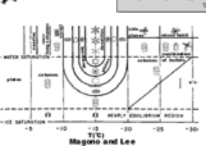
Snowcrystals.com

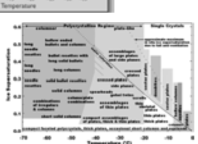
More Habit Diagrams











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

Magono and Lee (1966), Pruppacher and Klett (1997), Bailey and Hallett (2009), Snowcrystals.com

Classification Systems

Magono And Lee

International

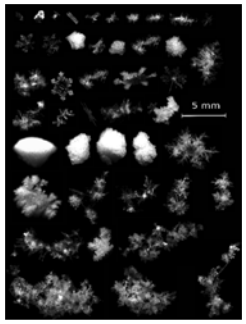
Nakaya

Magono and Lee (1966), storyofsnow.com, snowcrystals.com

Reality

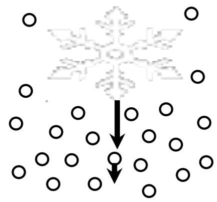
"While aesthetically appealing and offering a striking subject for photography, the fact is that most ice crystals are defective and irregular in shape"

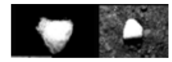
- Bailey and Hallett (2009)



Bailey and Hallett (2009), Garrett et al. (2012)

Accretion





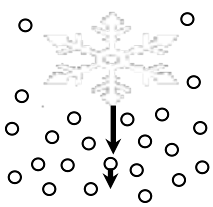
Graupel (UCLA)

Hexagonal Lump Cone

Magono and Lee (1966)

- 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



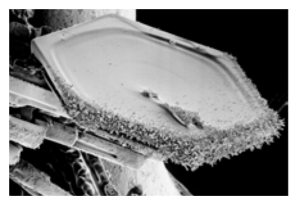
Graupel (UCLA)

Hexagonal Lump Cone

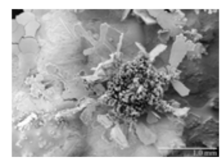
Magono and Lee (1966)

- 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)

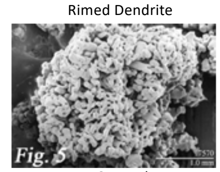
Accretion



Rimed Plate



Rimed Dendrite



Graupel

USDA Beltsville Agricultural Research Center

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

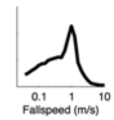
Aggregation

- 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

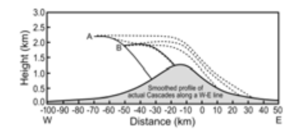
Yesterday's Aggregates (1148)

Growth, Transport, & Fallout

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



Fallspeed of particles @ Alta



Solid Lines = Heavily Rimed Particles
Dashed Lines = Lightly Rimed Particles

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?

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