Effects Of Ice Nucleation And Crystal Habits On The Dynamics Of Arctic Mixed Phase Clouds

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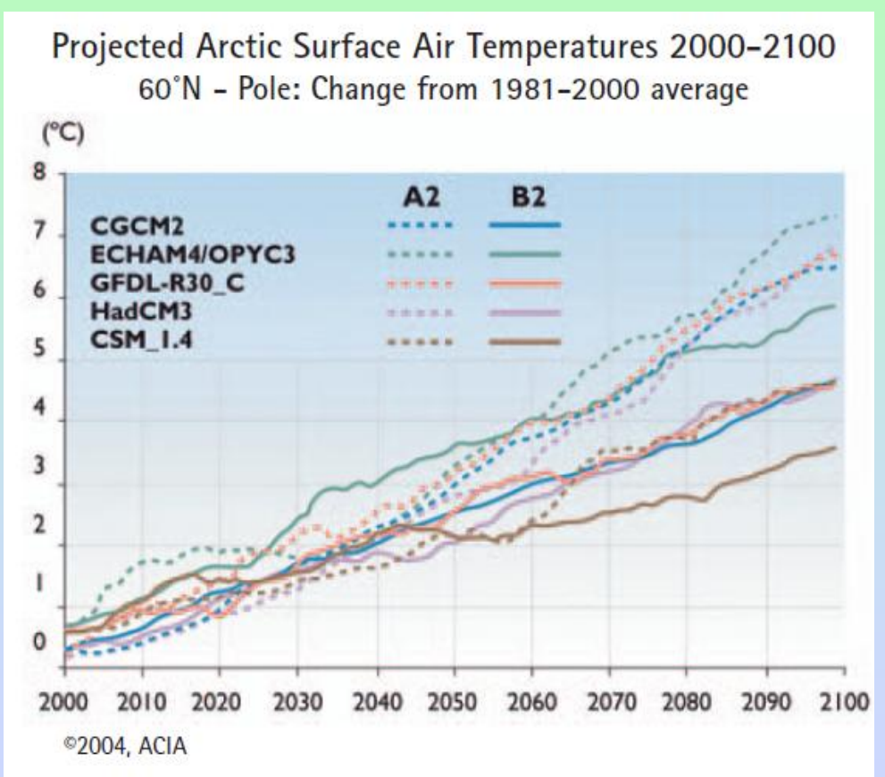
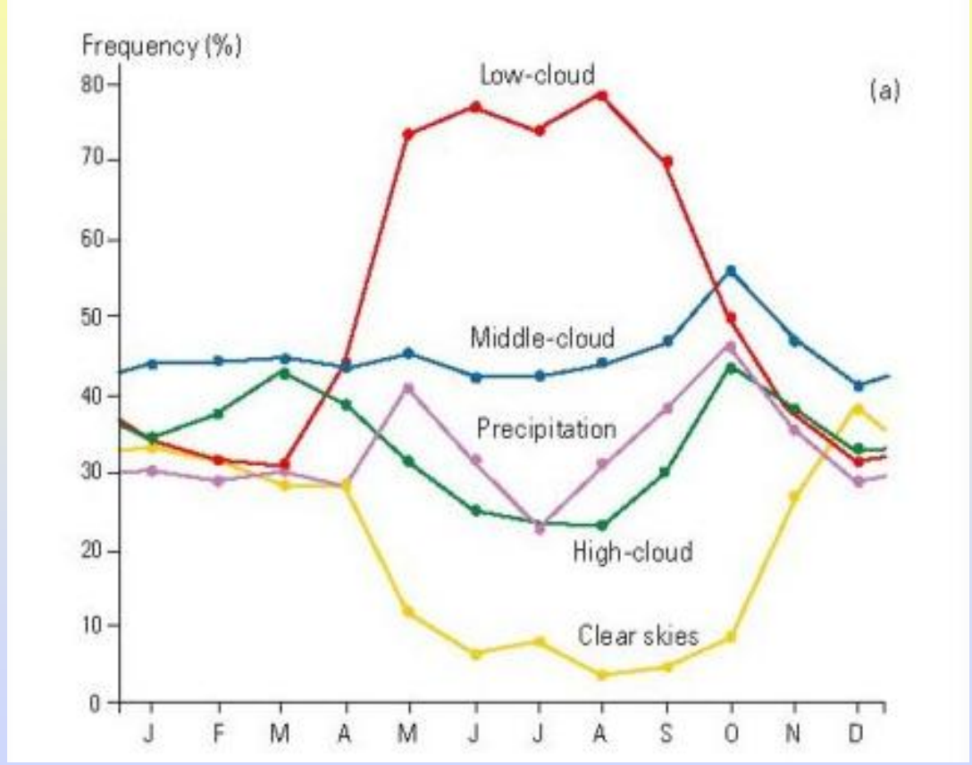
Future Arctic Climate Predictions



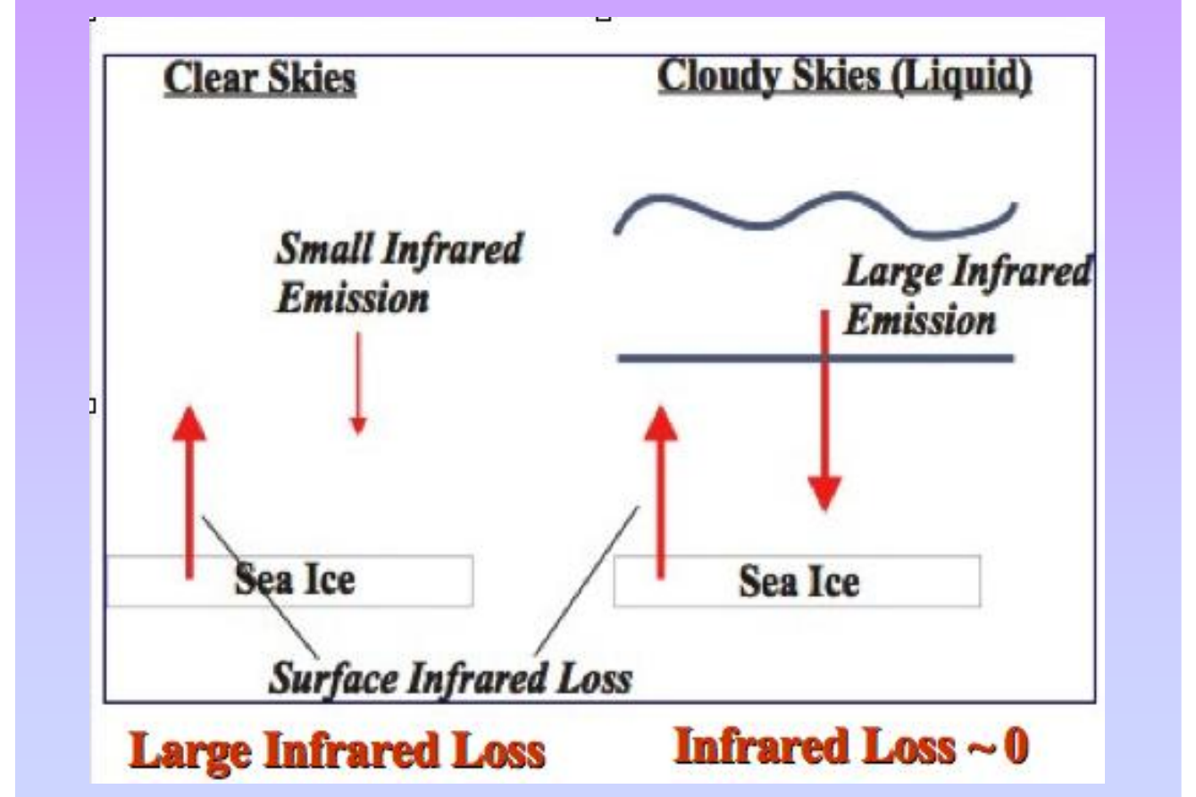
Global Climate Model Predictions are highly scattered in the Arctic even for the same emission scenario (A2 or B2).

Annual Arctic Cloud Cover



Low clouds are frequently observed in the Arctic atmosphere.

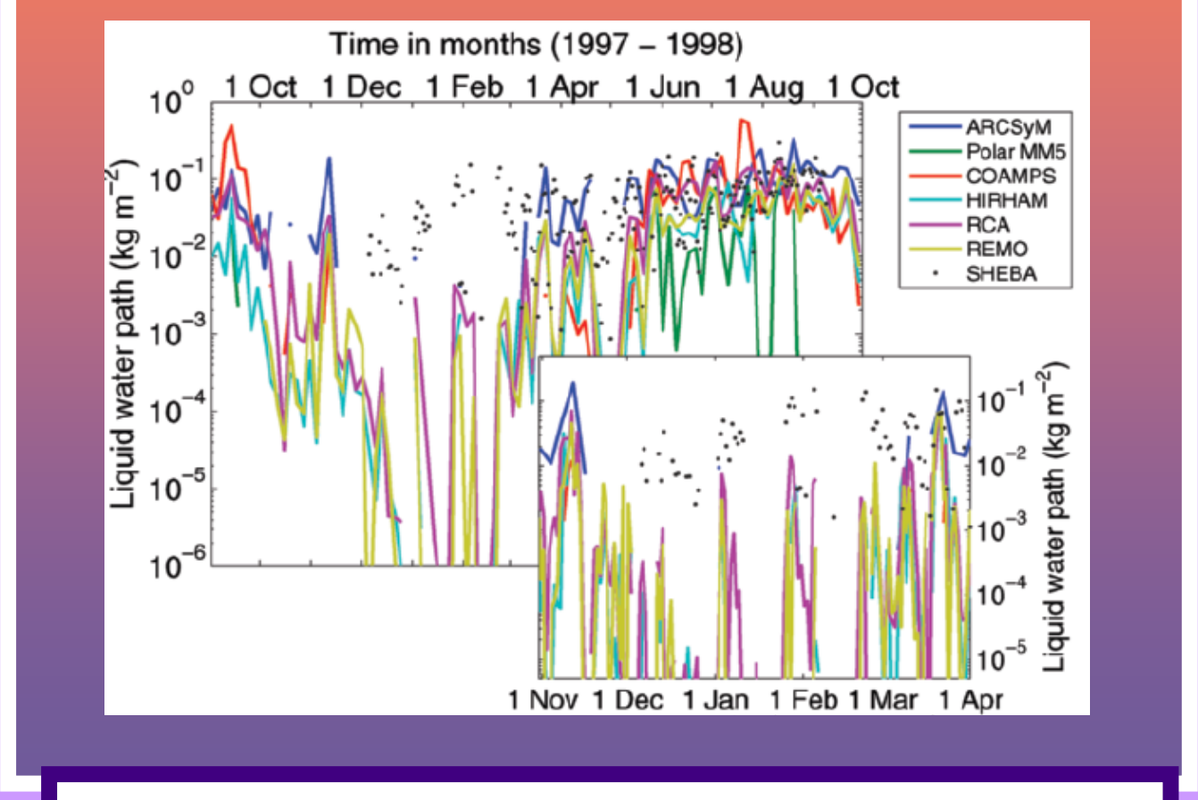
Influence of Low Clouds in Arctic



Low clouds decrease the loss of Infrared Radiation. Increased heating may lead to melting of sea ice; a change in albedo.

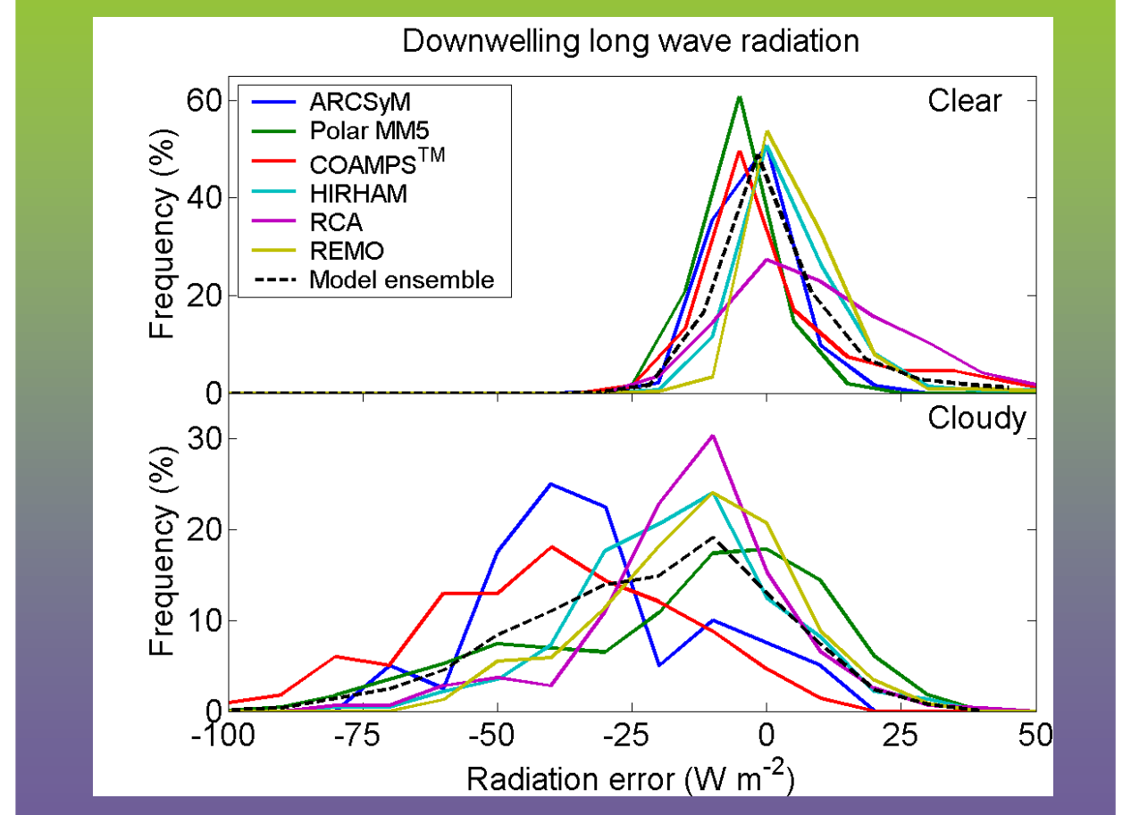
Accurate Parameterization of Arctic Clouds
ARE NECESSARY TO
Improve Arctic Climate Predictions

Regional Model Simulations of Arctic Clouds



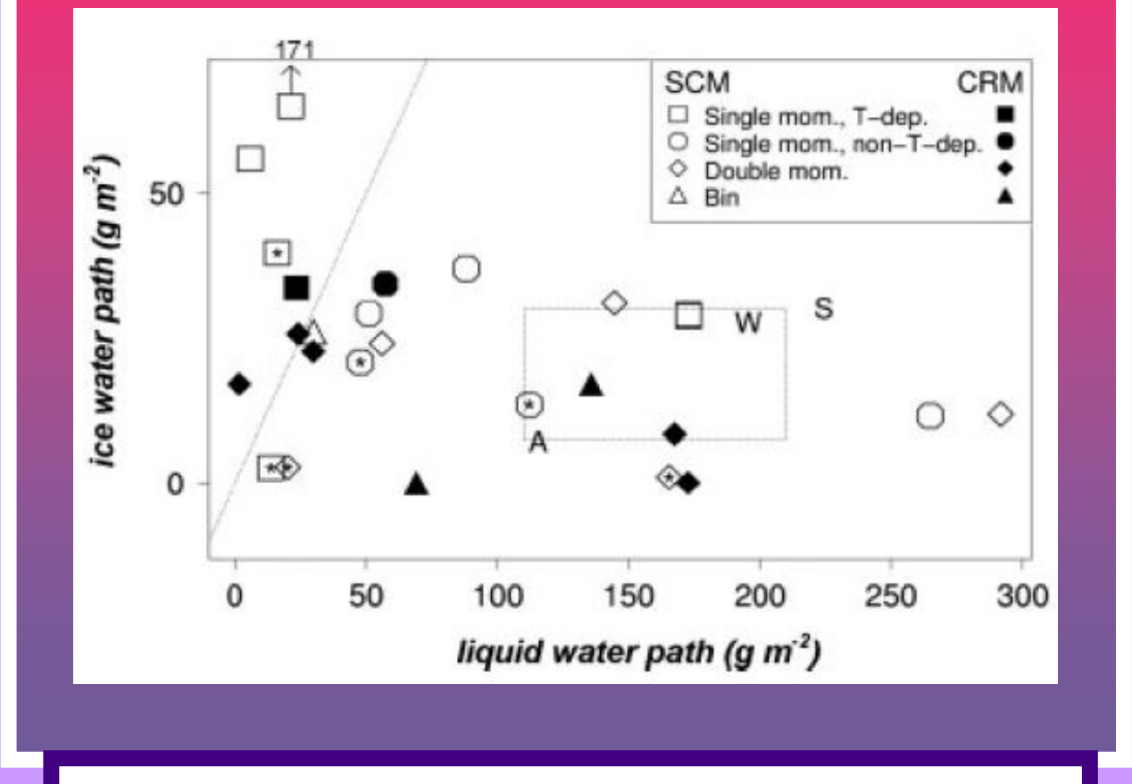
Both Ice and Liquid water contents of Arctic Clouds are poorly simulated in cold season, when both ice and liquid are present in clouds.

Radiation Error in Models



When clouds are present, radiation error increases in models due to the lack of predicted water.

Partitionin of Ice and Liquid Water in Models



Models Partition Liquid Water and Ice highly differently.

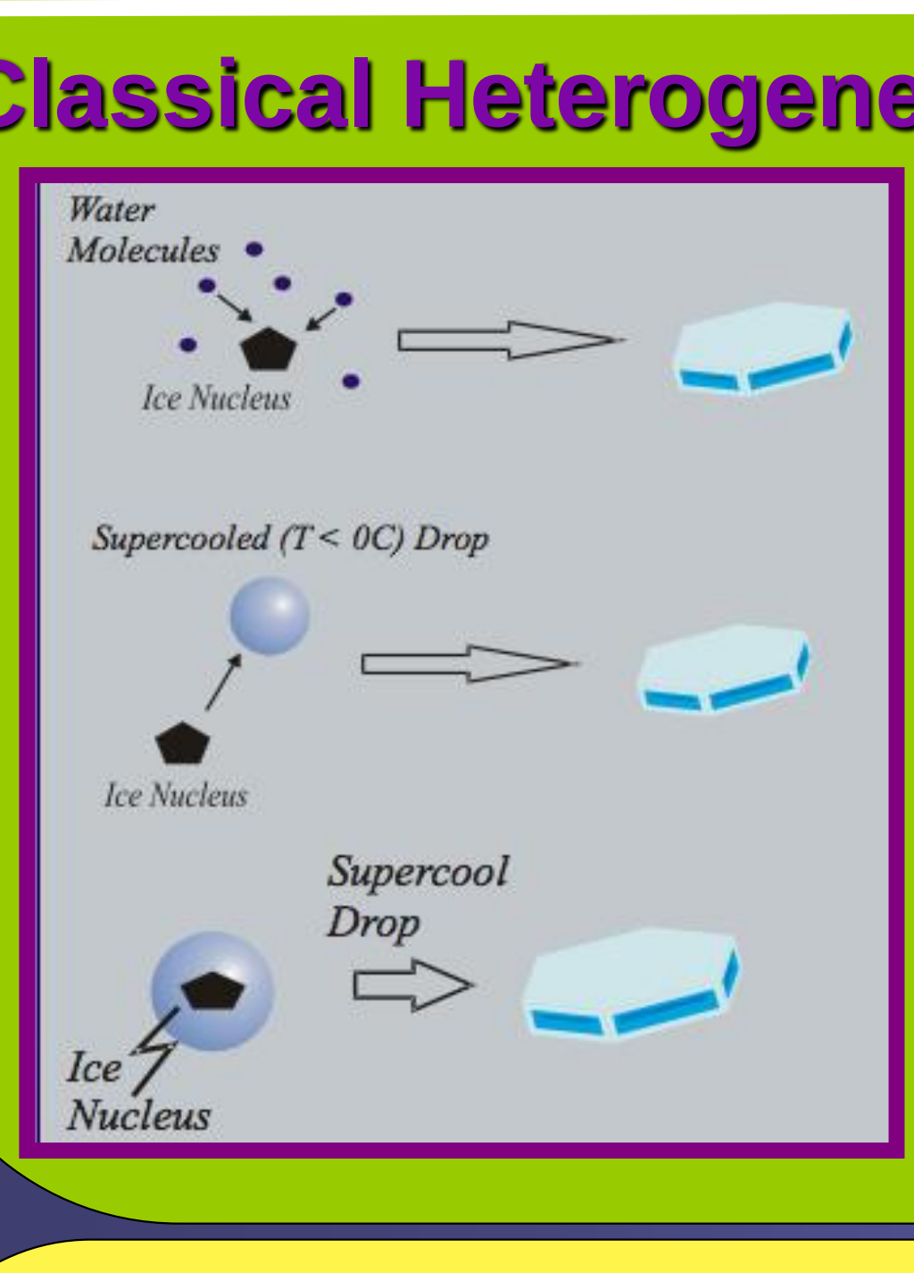
Differences in Model Results has been linked to

Uncertainties related to Ice Nucleation and Ice Crystal Shapes

Ice Nucleation Mechanisms

Ice can form homogeneously and heterogeneously.
Homogeneous nucleation is the freezing of liquid water drops, and takes place at very low temperatures, much lower than the cases we're interested in.
Heterogeneous nucleation is the formation of ice with an aiding medium, named as an Ice Forming Nucleus (IN).

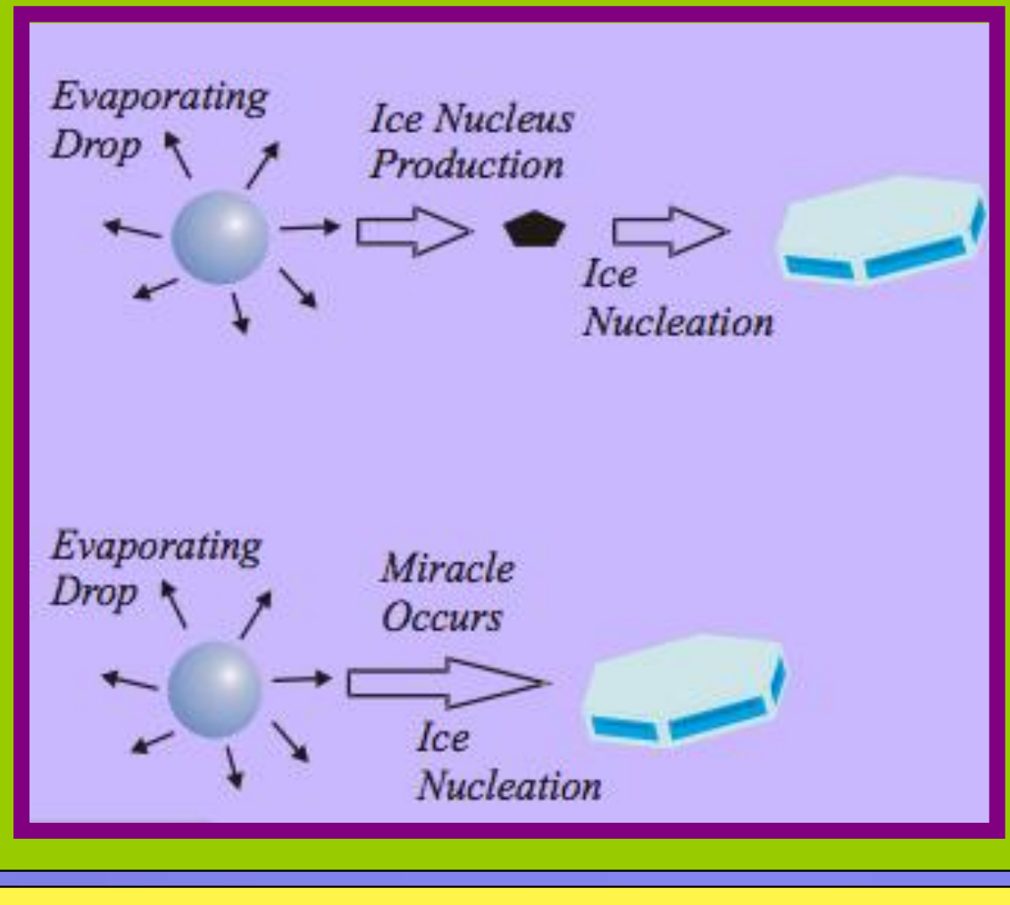
Classical Heterogeneous Ice Nucleation Mechanisms:



- **Deposition / Condensation Nucleation**
  Vapor deposition /liquid water condensation followed by freezing on an ice nucleus (IN).
- **Contact Freezing**
  Freezing of a liquid water drop upon contact with an ice forming nucleus (IN).
- **Immersion Freezing**
  Ice forming nucleus (IN) is immersed in the water drop, and in time freezing takes place

Alternative Ice Nucleation Mechanisms:

These mechanisms are proposed to match the observed ice concentrations.



- Evaporation IN
  As droplets evaporate a fraction of them leave an ice forming nucleus behind, which takes part in ice formation
- Evaporation Freezing
  A fraction of the evaporating droplets freeze and form ice

Uncertainties Related to Ice Nucleation:

Parameterization of ice nucleation mechanisms involve the number of ice forming nuclei: NOT WELL KNOWN

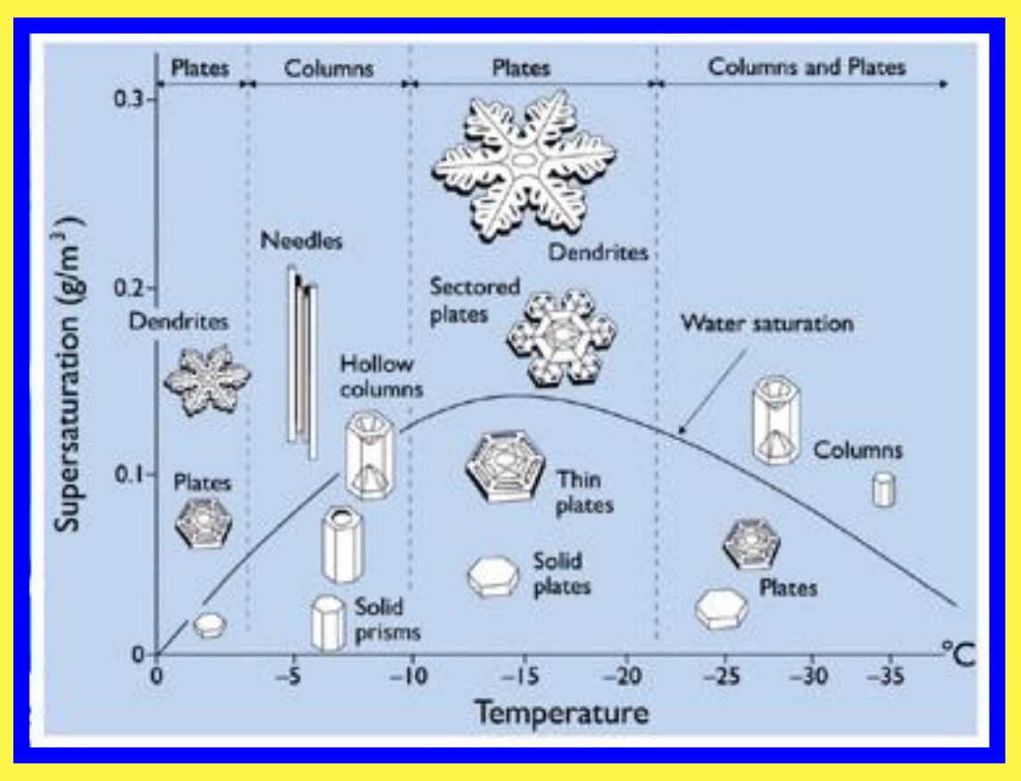
Laboratory measurements of ice nucleation is possible, but natural ice measurements are scarce.

Alternative Ice nucleation mechanisms are not well-understood

Ice Crystal Shapes

Ice Crystal shapes are primarily dependent on Temperature and secondarily on environmental water vapor Supersaturation

Classification of Ice Crystal Shapes



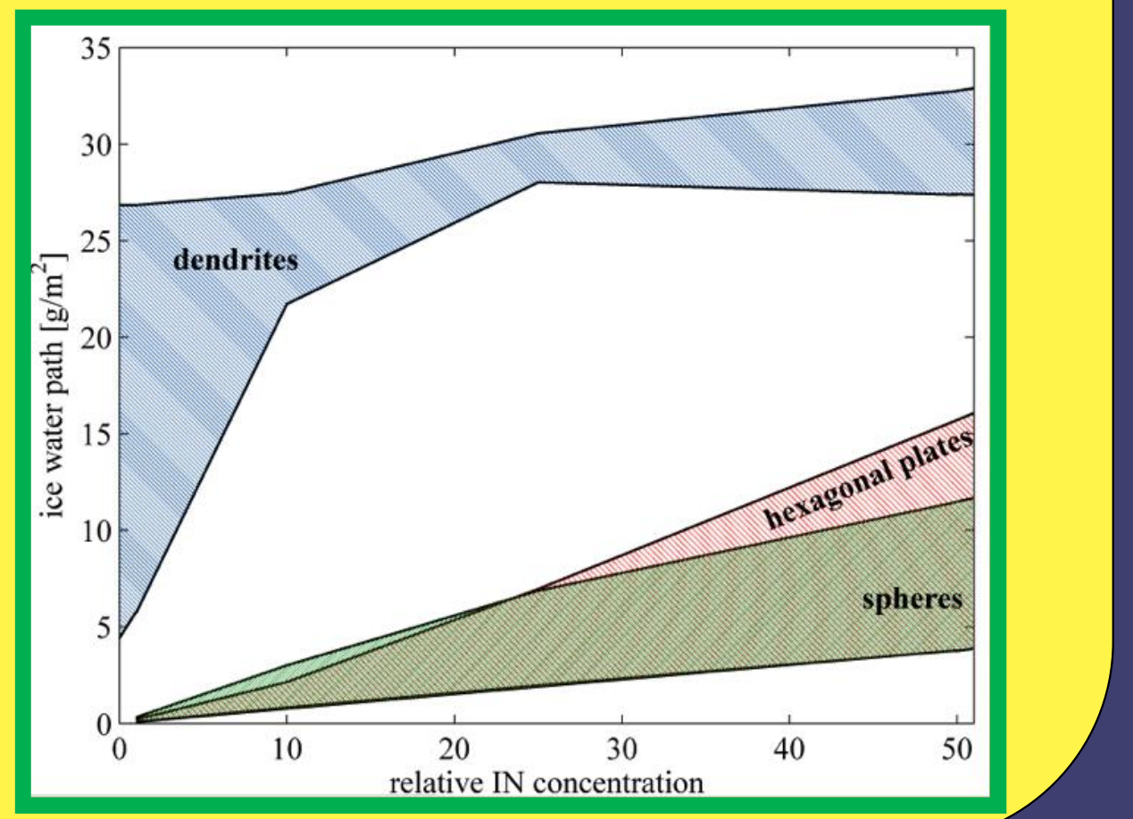
Primary Shapes are temperature dependent, and ice evolves as either a plate like or a columnar crystal.

When supersaturation is high, growth along edges take place; and plate like ice grows from its edges ending up with arms (Dendrites).

Nature does not always obey this classification.
Shapes are defined in models using mass and velocity relationships obtained through in-situ measurements

Uncertainties Related to Ice Crystal Shapes

- **Spheres are commonly used in models.**
- **Wide range of available crystal shapes lead to wide range of water paths.**
- **Use of spheres can lead to underestimation of ice in clouds.**



Methods & Analysis

MODEL SETUP			
RAMS 2D ERM			
HORIZONTAL	60 m	VERTICAL	30 m
Domain Size	10 km x 3 km		
Timestep	1 s	Simulation	12 h
Lateral Boundary	Cyclic	Top Boundary	Raleigh Damping
Bottom Boundary	Ocean Surface with Fixed fluxes		
SGS Turbulence	Deardorff (1980)	IR Radiation	Fu and Liou (1996)

- Simulations of Arctic Mixed-Phase Clouds
- Separate Simulations Using
  - Different Nucleation Mechanisms
  - Different Ice Crystal Shapes
- Dynamical Analysis & Feedbacks Among Processes

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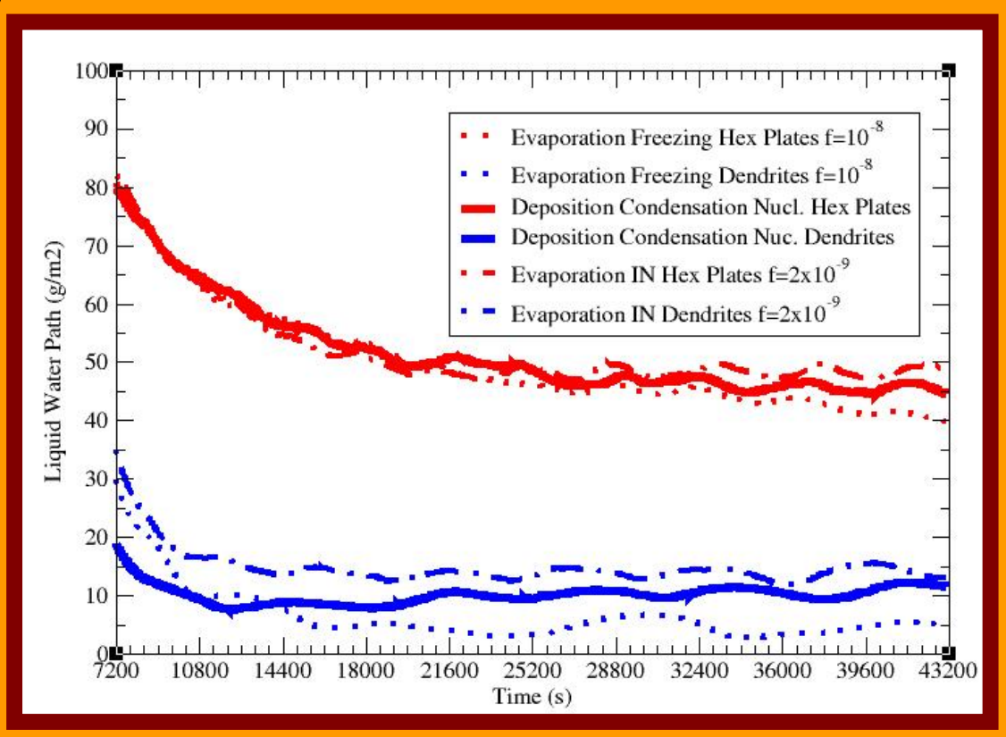
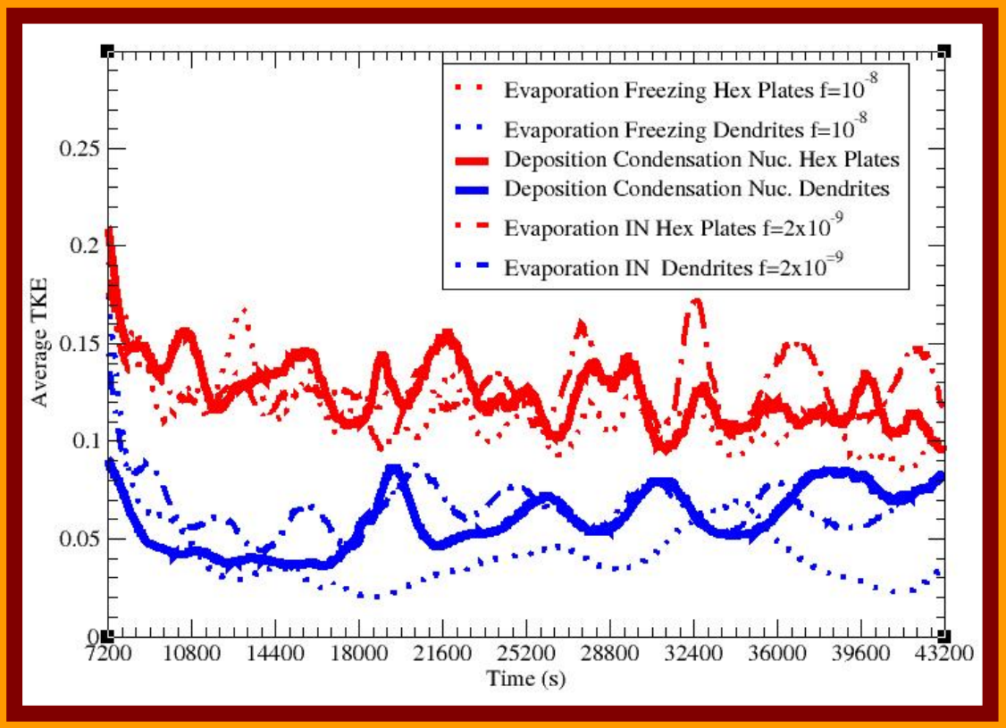
Results



Liquid Water Path: Domain averaged and vertically integrated amount of liquid water from surface to cloud top.

Influence of Crystal Shapes on Liquid Water Paths are GREATER compared to the Influence of Ice Nucleation Mechanisms.



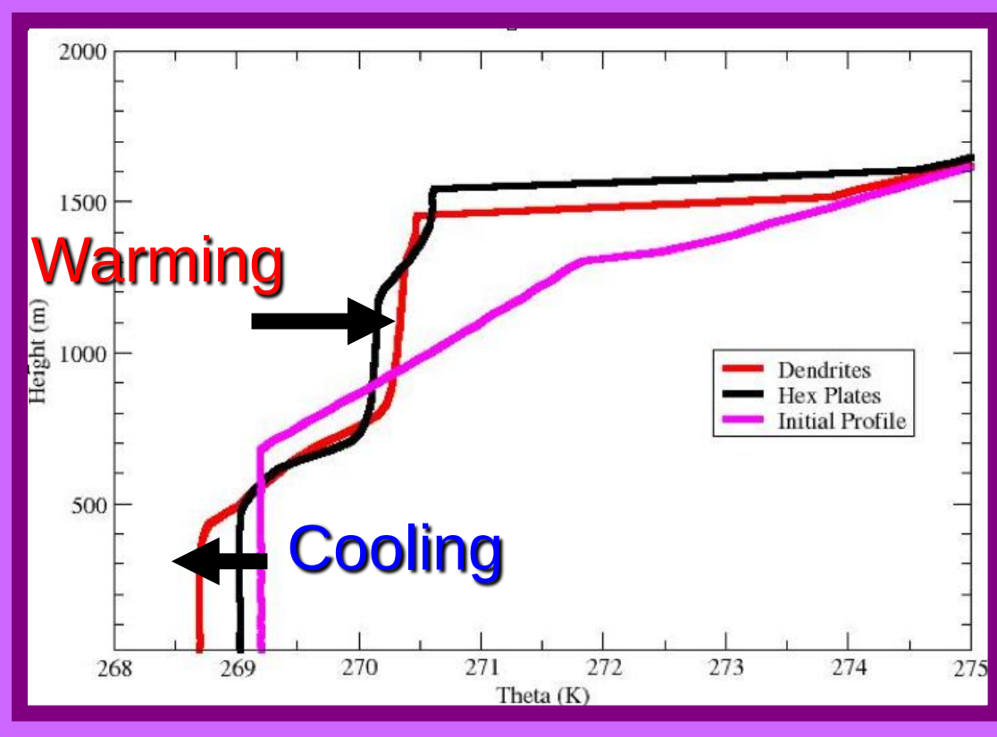
Turbulent Kinetic Energy: A measure of strength of circulations from surface to cloud top.

Simulations that produce Less Liquid Water yield less Turbulent Kinetic Energy.

TKE is influenced by the following processes:

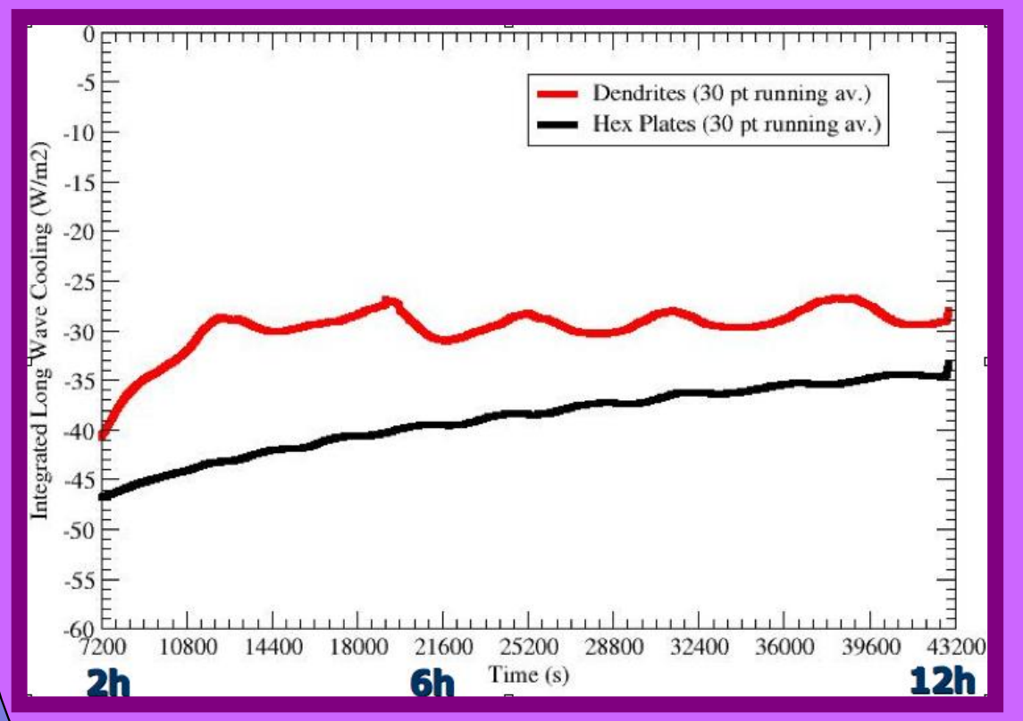
- **Cloud Base Stabilization:** Latent Heating (Cooling) through Ice Production (Precipitation) in Cloud (Below Cloud). Warmer air overlying colder air, shuts off circulations.
- **Radiate Cooling at Cloud Top:** Due to the presence of Liquid Water. Produces vertical motions (cold air sinks).

Cloud Base Stabilization: Potential Temperature at 6th hour of deposition condensation nucleation simulations with **Dendrites (Red)** and **Hexagonal Plates (Black)**



Stronger Stabilization with Dendrites:
- Dendrites fall slowly
- More time for ice growth, more in cloud latent heat release
- More ice precipitation, some of the ice sublimates below cloud base, latent cooling
- Reduced Circulations, Weaker TKE

Radiative Cooling: Domain averaged and vertically integrated radiative cooling from surface to cloud top.



Weaker Radiative Cooling with Dendrites:
- Dendrites fall slowly
- More time for ice growth
- At T<0 ºC Ice growth at the expense of liquid water drops
- More liquid is consumed
- Less cloud top radiative cooling
- Weaker Circulations (TKE)