The Formation of Snow Crystals

New Mexico
Supercomputing Challenge
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Team #34
The Down to Earth School

Team Members:

- Simone Hill

Teachers:

- Shanon Muehlhausen
- Maia Chaney

Project Mentors:

- Maia Chaney
- Shanon Muehlhausen

Executive Summary:

Have you ever noticed that there are different shapes and styles of snow crystals? My project is about how these different types of snow crystals are formed.

The types of crystals are: solid prisms, how columns, needles, dendrites, sectored plates, thin plates, solid plates, columns, and plates. These crystals are formed depending on mainly two variables: supersaturation and atmospheric temperature. Supersaturation is the number of grams of water molecules in one cubic meter. Atmospheric temperature is the temperature of the atmosphere at different altitudes, so depending on how high in altitude it is measured, it may vary.

My model is a computational snow crystal guide. It allows the observer it choose a snow crystal picture and it imports it. Then it set the supersaturation and temperature. Then it runs the formation of the crystal shown in the picture.

Table of Contents:

Introduction and Background Research:

In my project I am studying how the different types of snow crystals are formed. Snow crystals are formed by deposition, going from a gaseous state directly into a solid state, onto a particle of dust or pollen. The dust particle floats through the atmosphere toward the ground and water vapor molecules freeze onto it. There can be between 0 and $3.333 * 10^{22}$ water molecules per gram per cubic meter. To form snow crystals there is between 0 and $1 * 10^{23}$ water molecules or 0 to 0.3 grams in a cubic meter in the atmosphere. The equation used to find these numbers was solved using Avogadro's number.

There are many different types of snow crystals. There are: Solid Prisms, Hollow Columns, Needles, Dendrites, Sectored Plates, Thin Plates, Solid Plates, Columns, and Plates.

Dendrite means tree or tree-like so dendrites are plate-like crystals with branches and side-branches. These are the most commonly imagined snow crystals when people think of snow crystals.

Hollow columns are hexagonal columns with cone-shaped hollow areas at their ends. They're very small. The two hollow regions in either end are symmetrical to each other. Sometimes the ends grow over and enclose the hollow parts forming bubbles in the ice.

Needles are thin columnar ice crystals. They sometimes look like small white hairs. They are formed when the temperature is twenty-three degrees Fahrenheit.

Sectored plates have very prominent ridges extending toward each adjacent facet from the center. The simplest sectored plates are hexagonal crystals that are divided into six equal pieces. [1] More complex specimens show prominent ridges on broad, flat branches. [1]

Solid prisms are the simplest geometry of snow crystals. Snow crystal facets are rarely flat, being more typically decorated with various indents, ridges, or other features. [1] Depending on how fast they grow they can be from thin plates to slender hexagonal columns.

Thin plates are wide and thin hexagonal crystals which are a type of simple prism. They can have very complex designs on their facets. These are what dendrites begin as before developing the branches and side-branches.

Solid plates are crystals very similar to thin plates. They are thicker than thin plates and their facets are not as ornately decorated. These crystals are developed earlier than dendrites because they don't have to develop as long or complex.

Columns are hexagonal, slender, long crystals that look a lot like unsharpened wooden pencils. Columns are also a type of simple prism as well as solid and thin plates. Columns are small and moderately common.

I have collected information from a chart about when the snow crystals form; as in how supersaturated it is and what temperature it is when they form. I have used that information in the code in my model. I have recreated the graph more accurately with precise amounts.

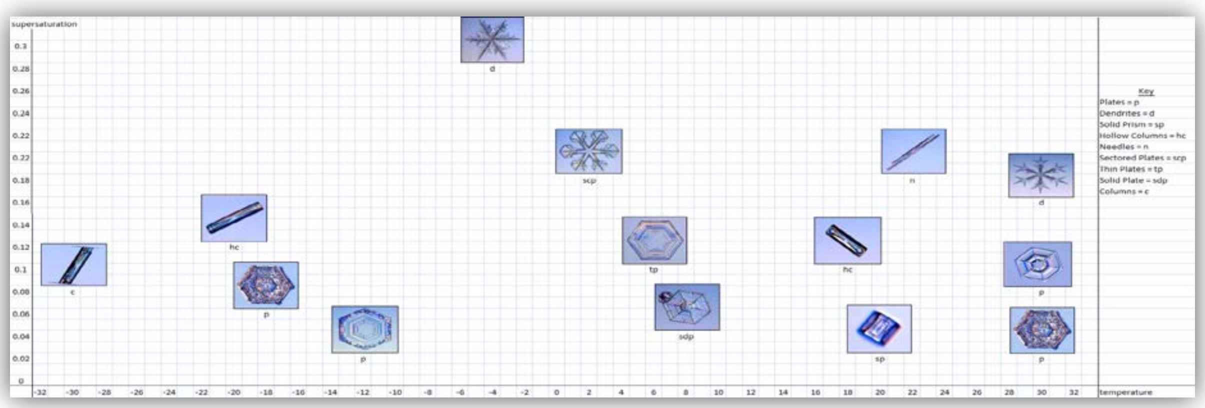


Figure1. Snow Crystal Formation

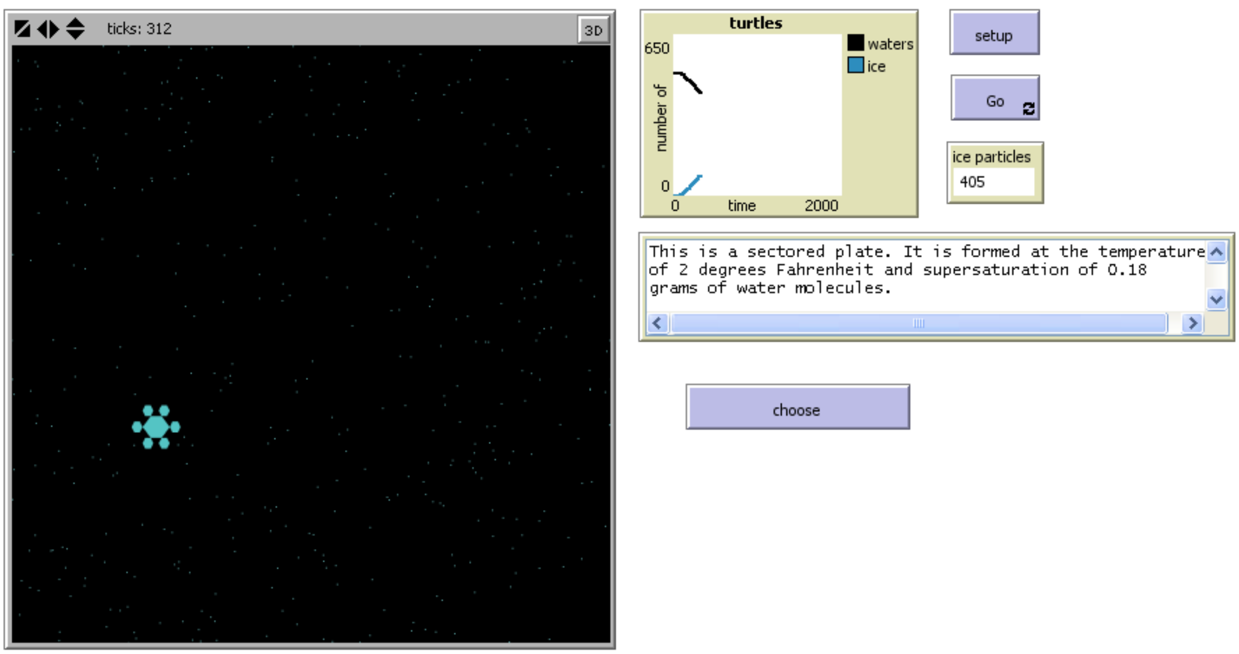
(Snow crystal images from http://www.its.caltech.edu/~atomic/snowcrystals/class/class.htm)

Problem Definition:

The problem I am trying to solve is; what causes the formation of the different types of snow crystals? The main variables that cause the formation of the different types are supersaturation and atmospheric temperature. We will be using these variables in our model and project to help to answer our question.

Description of Method Used to Solve Our Problem:

In my model I have each type of crystal with a breed and shape to match. The types are listed in the introduction. I also have breeds for the dust particle, the water vapor molecules, and the ice particles. Each breed is set to be a certain shape depending on what the breed is.



The dust particle moves around randomly as if being blown in the wind. The water molecules start at the top of the screen and move their way towards the bottom. When the water molecules collide with the dust particle they turn into ice by changing their breed to "ice" and setting their color white. Once the water molecules have frozen, they move around with the dust particle as if frozen to it. As the number of ice particles increases the dust particle gets larger and changes its shape. Once the number of ice particles reaches four-hundred five, the dust particle will turn into the type of crystal that forms at that specific temperature and supersaturation.

The model has two buttons; the "setup" button is one of the buttons; the other is the "go" button. The "setup" button call a series of commands that include: clearing the screen, creating the turtles, setting their color, size, shape, and coordinates, and then it calls a different procedure called "choose." The "choose" procedure tells the computer to choose a random number between zero and twelve and depending on what number it is, tells it to set the temperature, supersaturation and the picture. The "go" button imports the chosen picture from the procedure "choose" and then runs the formation of the crystals.

In my model there is a graph that monitors the number of ice particles and water molecules. There is also an output system that when the snow crystal is completely formed tells a little bit about that crystal type. It tells what kind of crystal it is and at what temperature and supersaturation it was formed at.

I validated my model by making sure that when the supersaturation and temperature are set to amounts that create a certain crystal, it creates that crystal. The amount of supersaturation and the temperature chosen for the specific crystals are from a chart that I researched and recreated.

Results:

I successfully created a model that is a computational snow crystal guide. My model allows the observer to choose a random snow crystal image and it will set the supersaturation and atmospheric temperature that creates that crystal type. Then it runs the formation and once the snow crystal is fully developed, the model stops; then it outputs what type of crystal it is and at what temperature it was created. During the formation a graph plots the amounts of water molecules and ice particles. As the dust particle collects more ice particles it changes its shape and color slightly.

My Future Plans:

My future plans are to make the model scan an image and recognize what type of crystal it is and then run the formation of it. I would also like to try to discover something about snow crystals. I would like to continue with the idea of snow crystal formation.

My Significant Achievement:

My significant achievement was creating the beginnings of computational guide to snow crystals. I hope to use the knowledge I have gained by completing this project in future endeavors.

Acknowledgements:

I want to give a great big thanks to my teachers and project mentors, Maia Chaney and Shanon Muehlhausen, for all of the support and help provided by them. Also thank you John Paul Gonzales for helping me a lot on our model and helping us to fix it. A thank you to Harry and Dale Henderson for the help and tips on programming our model. A huge thank you to Maya Eilert for assisting with my webpage.

Bibliography:

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Appendix 1 Model Code:

```
Globals[
  ices
  temperature
  supersaturation
  filename
]
Breed[dusts dust]
Breed[waters water]
Breed[ice a-ice]
Breed[columns column]
Breed[dendrites dendrite]
Breed[plates plate]
Breed[solid-plates solid-plate]
Breed[hollow-columns hollow-column]
Breed[prisms prism]
Breed[needles needle]
Breed[thin-plates thin-plate]
Breed[solid-prisms solid-prism]
Breed[sectored-plates sectored-plate]

Ice-own[
  target
  icf]
Dusts-own[in]
sectored-plates-own[in]
solid-prisms-own[in]
hollow-columns-own[in]
needles-own[in]
dendrites-own[in]
thin-plates-own[in]
columns-own[in]
plates-own[in]
solid-plates-own[in]




To setup
  __clear-all-and-reset-ticks
  set-default-shape waters "dot"
  set-default-shape dusts "dust"
  set-default-shape ice "dot"
  set-default-shape columns "column"
  set-default-shape dendrites "dendrite"
  set-default-shape plates "plate"
  set-default-shape solid-plates "solid-plate"
  set-default-shape hollow-columns "hollow-column"
```

```
 set-default-shape prisms "prism"
 set-default-shape needles "needles"
 set-default-shape thin-plates "thin-plate"
 set-default-shape solid-prisms "solid-prism"
 set-default-shape sectored-plates "sectored-plate"
 reset-ticks
 create-dusts 1
 [

  set size 2
  set color orange + 3
 ]

 create-waters 500

 [
  setxy random-xcor 16
  set size .22
  set color cyan + 1
  set heading 180
 ]

End

To choose
 if filename = 0
 [
  set temperature 2
  set supersaturation 0.18
 ]

 if filename = 1
 [set filename "snow1.jpg"
  set temperature 18
  set supersaturation 0.1]

 if filename = 2
 [set filename "snow2.jpg"
  set temperature 22
  set supersaturation 0.18]

 if filename = 3
 [set filename "snow3.jpg"
  set temperature 8
  set supersaturation 0.04]

 if filename = 4
 [set filename "snow4.jpg"
  set temperature 30
  set supersaturation 0.08]
```

```
 if filename = 5
[set filename "snow5.jpg"
  set temperature -20
  set supersaturation 0.12]

 if filename = 6
[set filename "snow6.jpg"
  set temperature 30
  set supersaturation 0.16]

 if filename = 7
[set filename "snow7.jpg"
  set temperature 20
  set supersaturation 0.02]

 if filename = 8
[set filename "snow8.jpg"
  set temperature 6
  set supersaturation 0.1]

 if filename = 9
[set filename "snow9.jpg"
  set temperature -30
  set supersaturation 0.08]

 if filename = 10
[set filename "snow10.jpg"
  set temperature -18
  set supersaturation 0.06]

 if filename = 11
[set filename "snow11.jpg"
  set temperature 4
  set supersaturation 0.28]

 if filename = 12
[set filename "snow12.jpg"
  set temperature -12
  set supersaturation 0.02]
end


To make-crystal

   set ices count turtles with [breed = ice] * 5


  ask dusts[
    set in count turtles-here with [breed = ice] * 5
```

```
]

ask ice [
  set icf count turtles-here with [breed = ice]]



ask waters
[
  right random 20
  forward random 2
  right random 25
  forward random 2
  left random 15
  if any? turtles-here with [breed = dusts]
    [
      set breed ice
      set color white
      set target one-of dusts
    ]
]


ask dusts
[
  forward random 2
  right random 30
  forward random 2
]

ask columns
 [
  forward random 2
  right random 30
  forward random 2
]

ask dendrites
 [
  forward random 2
  right random 30
  forward random 2
]

ask plates
 [
  forward random 2
  right random 30
  forward random 2
```

```
]

ask solid-plates
 [
  forward random 2
  right random 30
  forward random 2
]

ask hollow-columns
 [
  forward random 2
  right random 30
  forward random 2
]

ask prisms
 [
  forward random 2
  right random 30
  forward random 2
]

ask needles
 [
  forward random 2
  right random 30
  forward random 2
]

ask thin-plates
 [
  forward random 2
  right random 30
  forward random 2
]

ask solid-prisms
 [
  forward random 2
  right random 30
  forward random 2
]

ask sectored-plates
 [
  forward random 2
  right random 30
  forward random 2
]
```

```
 ask ice with [color = white]
 [
  move-to target
  set heading random 360
 ]

   ask dusts
 [ if in = 50
  [set shape "dustw50"
    set size 2
  ]
  if in = 150
  [set shape "dustw150"
    set size 2]
  if in = 200
  [set shape "dustw200"
    set size 5]
  if in = 275
  [set size 3
    set shape "hex"
    set color cyan
  ]
  if in = 405 and temperature = 30 and supersaturation = 0.08
  [set breed plates
        output-type "This is a plate. It is formed at the temperature \nof 30 degrees Fahrenheit and supersaturation of 0.08 \n of water molecules."
        set size 3]

  if in = 405 and temperature = 30 and supersaturation = 0.16
  [set breed dendrites
        output-type "This is a dendrite. It is formed at the temperature \nof 30 degrees Fahrenheit and supersaturation of 0.16 \ngrams of water molecules."
        set size 3]

   if in = 405 and temperature = 20 and supersaturation = 0.02
  [set breed solid-prisms
        output-type "This is a solid prism. It is formed at the temperature \nof 20 degrees Fahrenheit and supersaturation of 0.02 \ngrams of water molecules."
        set size 3]

   if in = 405 and temperature = 18 and supersaturation = 0.10
  [set breed hollow-columns
        output-type "This is a hollow column. It is formed at the temperature \nof 18 degrees Fahrenheit and supersaturation of 0.10 \ngrams of water molecules."
        set size 5]

   if in = 405 and temperature = 22 and supersaturation = 0.18
  [set breed needles
```

```
        output-type "These are needles. They are formed at the temperature \nof 22 degrees
Fahrenheit and supersaturation of 0.18 \ngrams of water molecules."
        set size 3]

   if in = 405 and temperature = 4 and supersaturation = 0.28
  [set breed dendrites
        output-type "This is a dendrite. It is formed at the temperature \nof 4 degrees Fahrenheit and
supersaturation of 0.28 \ngrams of water molecules."
        set size 3]

   if in = 405 and temperature = 2 and supersaturation = 0.18
  [set breed sectored-plates
        output-type "This is a sectored plate. It is formed at the temperature \nof 2 degrees
Fahrenheit and supersaturation of 0.18 \ngrams of water molecules."
        set size 3
        set color cyan]

   if in = 405 and temperature = 6 and supersaturation = 0.10
  [set breed thin-plates
        output-type "This is a thin plate. It is formed at the temperature \nof 6 degrees Fahrenheit
and supersaturation of 0.10 \ngrams of water molecules."
        set size 3]

   if in = 405 and temperature = 8 and supersaturation = 0.04
  [set breed solid-plates
        output-type "This is a solid plate. It is formed at the temperature \nof 8 degrees Fahrenheit
and supersaturation of 0.04 \ngrams of water molecules."
        set size 3]

   if in = 405 and temperature = -30 and supersaturation = 0.08
  [set breed columns
        output-type "This is a column. It is formed at the temperature \nof -30 degrees Fahrenheit
and supersaturation of 0.08 \ngrams of water molecules."
        set size 5]

   if in = 405 and temperature = -18 and supersaturation = 0.06
  [set breed plates
        output-type "This is a plate. It is formed at the temperature \nof -18 degrees Fahrenheit and
supersaturation of 0.06 \ngrams of water molecules."
        set size 3]

    if in = 405 and temperature = -12 and supersaturation = 0.02
  [set breed plates
        output-type "This is a plate. It is formed at the temperature \nof -12 degrees Fahrenheit and
supersaturation of 0.02 \ngrams of water molecules."
        set size 3]

    if in = 405 and temperature = 30 and supersaturation = 0.02
  [set breed plates
```

```
        output-type "This is a plate. It is formed at the temperature \nof 30 degrees Fahrenheit and supersaturation of 0.02 \ngrams of water molecules."
        set size 3]

   if in = 405 and temperature = -20 and supersaturation = 0.12
  [set breed hollow-columns
        output-type "This is a hollow column. It is formed at the temperature  \nof -20 degrees Fahrenheit and supersaturation of 0.12 \ngrams of water molecules."
        set size 5]


  if in = 405 and temperature != -20 and temperature != 30 and temperature != -12 and temperature != -18 and temperature != -30 and temperature != 8 and temperature != 6 and temperature != 2 and temperature != 4 and temperature != 22 and temperature != 18 and temperature != 20  and supersaturation != 0.08 and supersaturation != 0.16 and supersaturation != 0.02 and supersaturation != 0.10 and supersaturation != 0.18 and supersaturation != 0.28 and supersaturation != 0.04 and supersaturation != 0.06 and supersaturation != 0.12
  [set shape "hex"
   set size 4
   set color cyan
   ]

 ]
 tick
 if ices >= 405
 [stop
  reset-ticks]
end
```

Appendix 2 Snow Crystal Chart: