# SOLUTION for: Group Assignment 1.1, Friday, Sep 6, 2024

Modelling, Uncertainty, and Data for Engineers

TU Delft

# Handout for: Group Assignment 1.1, Friday, Sep 6, 2024

Modelling, Uncertainty, and Data for Engineers

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# Introduction

Our overall goal is to build a model to predict when the ice breaks apart and win >$200,000!!!

To help achieve this goal, the following slides contain:

**Part I: Overview of the Nenana Ice Classic** (how the betting competition works)

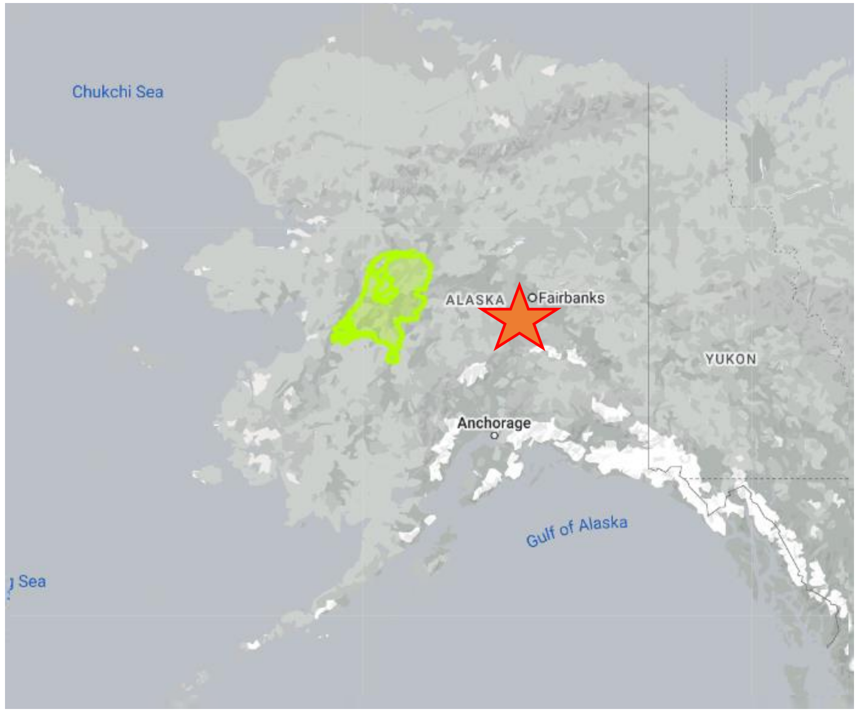
**Part II: Illustration of available data and physical processes**

**Part III: Description of Tasks to Complete MUDE Group Assignment 1.1**

*Spend a few minutes scanning through Part I and Part II to see what is there, but otherwise they are meant to be a reference while you work through the Tasks in Part III.*

Part I: Overview of the Nenana Ice Classic

# Nenana Alaska Ice Classic




Last year's winnings: $210,155

# Nenana Ice Classic

- Each year you can bet on the day and time the river ice in the Tanana River, Alaska will break apart along the waterfront of the town Nenana (the town is called Nenana because it is located just upstream from the confluence of this tributary with the Tanana River)
- A tripod is constructed on the ice during the first weekend in March. Break-up time is determined as follows: "*The Tripod is setup with a unique pulley and clock system that stops the clock once the tripod has moved downstream by 100 ft.*" (see next page)
- You can buy a ticket for $3 and place a bet between Feb 1 and April 5. Our goal is to create a model to predict the ice break-up and WIN!!!
- Visit the website for more information, or to view a live webcam of the river nenanaakiceclassic.com

# What do the tripod, tower and mechanism look like?

RIVAHMAN,THURSDAY, APRIL 22, 2010. Retrieved Sep 7, 2023.
https://rivahman.blogspot.com/2010/04/nenana-ice-classic.html

The elegant antique timing contraption of the Nenana Ice Classic awaits the moment of breakup on the Tanana River. One rope trips the siren. One rope trips the cleaver, which cuts the main rope, setting the tripod free as the fourth rope pulls the pin on the clock. (Dermot Cole / Alaska Dispatch News) 2017. Retrieved Sep 7, 2023.

https://www.adn.com/opinions/2017/05/01/this-antique-engineering-marvel-records-spring-breakup-in-alaska-like-clockwork/

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# Part II: Illustration of available data and physical processes (organized by scale)

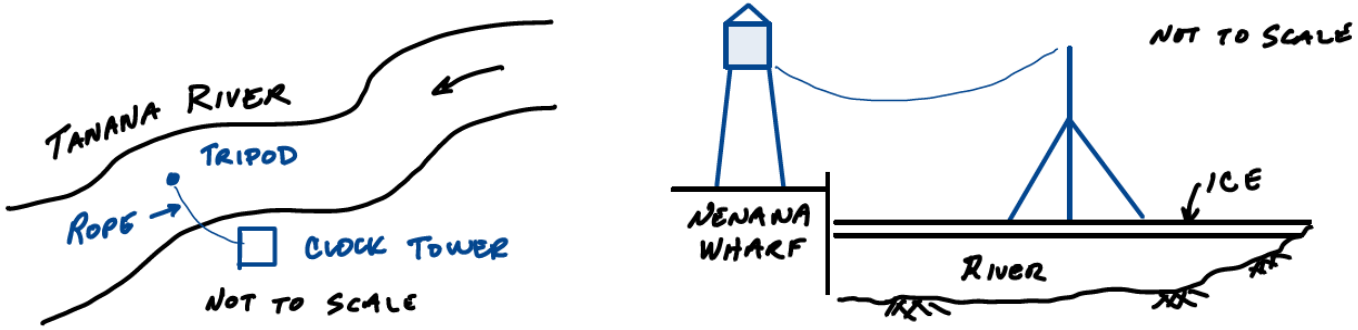
| Scale | Physical Process | Variable | Symbol | Units |
|---|---|---|---|---|
| Local | River discharge | Monthly average discharge | $Q_{month}$ | m3/s |
| | | Water level at freeze-up | $H_F$ | m |
| | | Water level at break-up | $H_B$ | m |
| | Ice thickness | Ice thickness | t | m |
| | Ice deformation / melting | River temperature | $T_r$ | °C |
| Watershed | River discharge | Average spring precipitation | $P_{AM}$ | mm |
| | | Glacial reduce | $V_G$ | $m^3$ |
| | Ice thickness | Average winter temperature | $T_{DJM}$ | °C |
| | Snow cover / solar radiation | Average winter precipitation | $P_{DJFM}$ | mm |
| | Ice deformation / melting | Monthly average temperature | $T_{month}$ | °C |
| Regional | Ice thickness | Accumulated degree-days frost | ADDF | °C |
| | Snow cover / solar radiation | Cloud coverage | $CC_{month}$ | % |
| | | Sun hours | $t_{sun}$ | h |
| | Ice deformation / melting | Heat wave days per month | $HWd_{month}$ | d |
| | | Accumulated degree-days thaw | ADDT | °C |
| Large (Global) | Pacific Ocean surface temperature | ENSO effect in February-May | $ENSO_{FMAM}$ | °C |
| | | PDO effect in February-May | $ENSO_{FMAM}$ | °C |

# Local Elements: Key System Components

The setup of the tripod and clock is interesting and should be included in your model. This setup directly determines the definition of ice break-up: a rope is attached from the tripod to a clock on the riverbank. When the rope is pulled tight it stops the clock; this time is used to determine the winning guess of the breakup day and time (down to the minute).

As such, these components could be interesting to include in a model:

- River
- Ice
- Tripod
- Rope




Diagrams illustrate their positions and orientations relative to each other

# Local Scale: Nenana Waterfront

| Physical Process | Variable | Symbol | Units |
|---|---|---|---|
| River discharge | Monthly average discharge | $Q_{month}$ | m3/s |
| | Water level at freeze-up | $H_F$ | m |
| | Water level at break-up | $H_B$ | m |
| Ice thickness | Ice thickness | t | m |
| Ice deformation / melting | River temperature | $T_r$ | °C |

Image source: https://www.google.com/url?sa=i&url=https%3A%2F%2Fen.wikipedia.org%2Fwiki%2FNenana_Ice_Classic&psig=AOvVaw3tnHXKo9OPR3-LQdijw42w&ust=1694170505343000&source=images&cd=vfe&opi=89978449&ved=0CBAQjRxqFwoTCICe9omrmIEDFQAAAAAdAAAAABAE

# Watershed Scale

| Physical Process | Variable | Symbol | Units |
|---|---|---|---|
| River discharge | Average spring precipitation | $P_{AM}$ | mm |
| | Glacial reduce | $V_G$ | m3 |
| Ice thickness | Average winter temperature | $T_{DJM}$ | °C |
| Snow cover / solar radiation | Average winter precipitation | $P_{DJFM}$ | mm |
| Ice deformation / melting | Monthly average temperature | $T_{month}$ | °C |

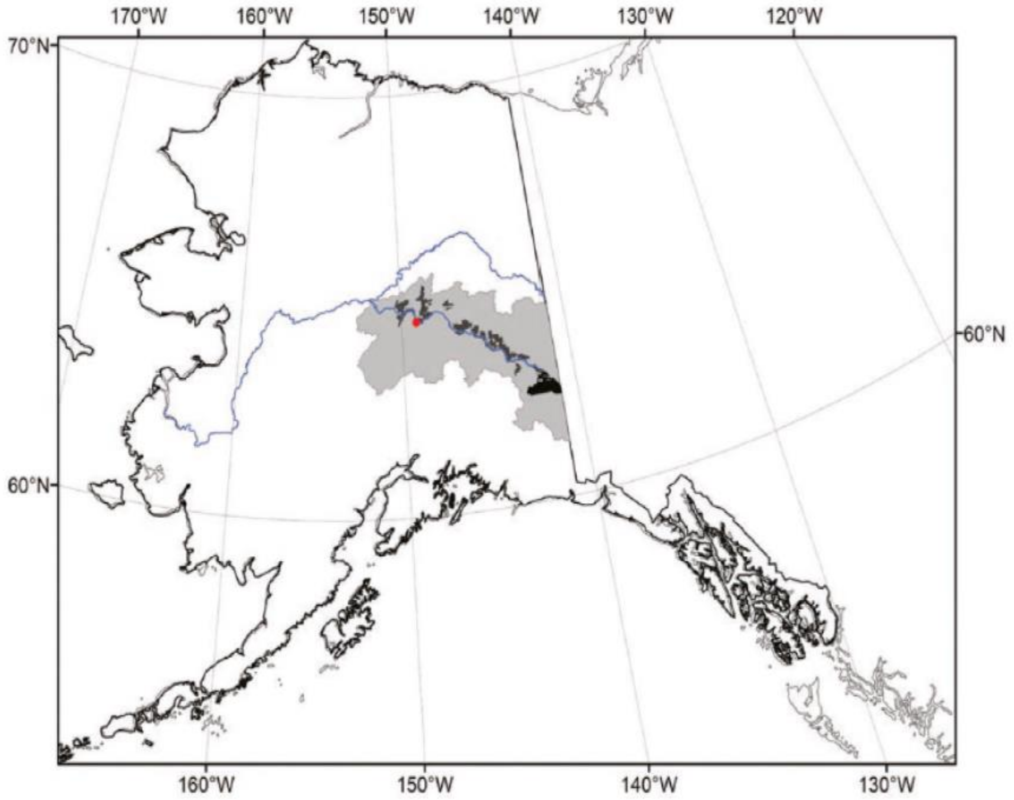



Figure 1.2: Location of Tanana river basin (grey), Yukon and Tanana river (blue) and Nenana (red dot) (edit by Terwogt, 2021, from original figure by Pattison et al., 2018).

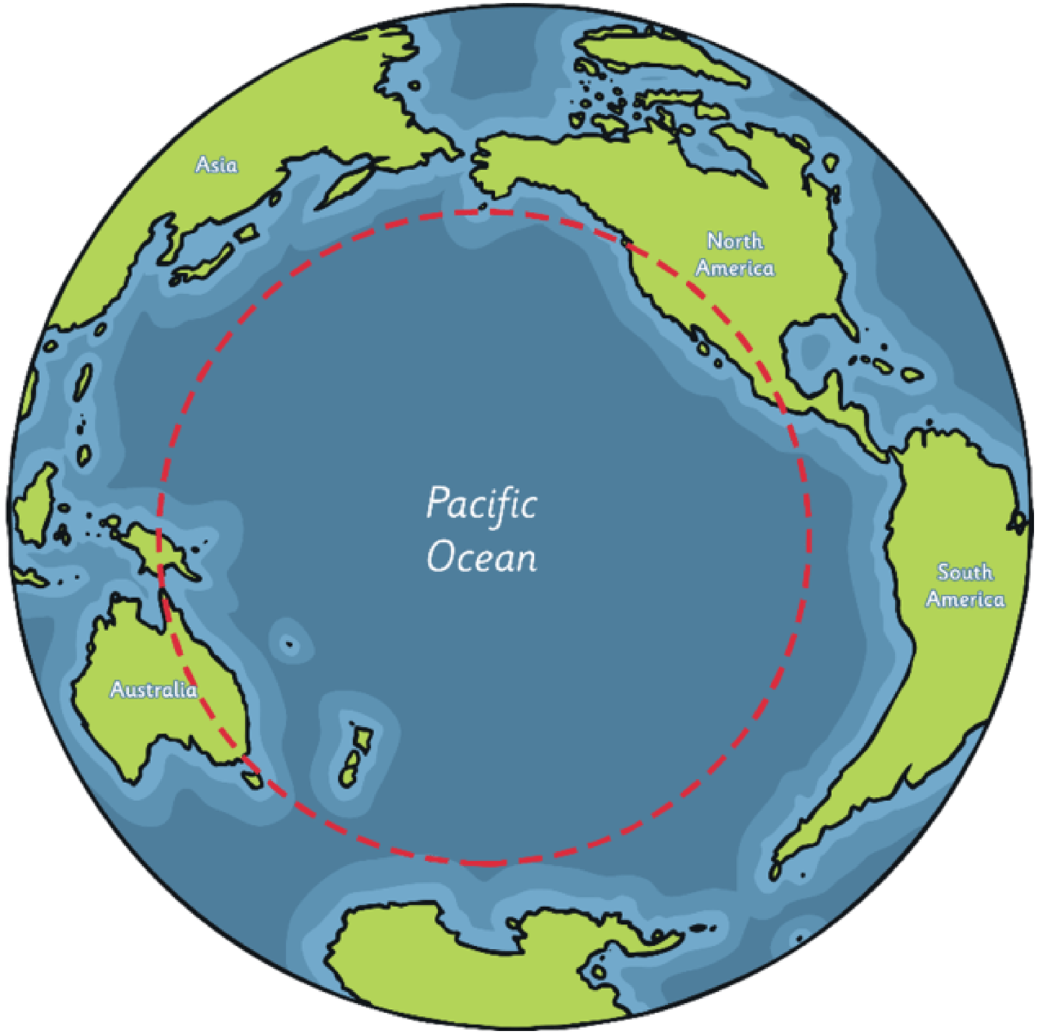
# Regional Scale

| Physical Process | Variable | Symbol | Units |
|---|---|---|---|
| Ice thickness | Accumulated degree -days frost | ADDF | °C |
| Snow cover / solar radiation | Cloud coverage | $CC_{month}$ | % |
| | Sun hours | tsun | h |
| Ice deformation / melting | Heat wave days per month | $HWd_{month}$ | d |
| | Accumulated degree -days thaw | ADDT | °C |


Image source: https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.britannica.com%2Fplace%2FAlaska&psig=AOvVaw1AvtDd25Wq1B4mNgEmI9H5&ust=1694170043967000&source=images&cd=vfe&opi=89978449&ved=0CBAQjRxqFwoTCKC-762pmIEDFQAAAAAdAAAAABAE

# Large Scale (Global)

| Physical Process | Variable | Symbol | Units |
|---|---|---|---|
| Pacific Ocean surface temperature | ENSO effect in February-May | $ENSO_{FMAM}$ | °C |
| | PDO effect in February-May | $ENSO_{FMAM}$ | °C |

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# Task 1: Model classification and decisions (warm-up)

Consider the 4 descriptions of models on the next page, then complete the following tasks:

- Classify the models using the 4 categories from the textbook
- Rank each according to the corners of the triangle diagram (place dot on triangle): complexity, accuracy, affordability (for affordability, consider money and/or computation time)
- Decisions: which simplifications have been made? (4 types)
- Which GoF measures could you use, and on which variables? (refer to those in the textbook, but don't worry if you can't think of much for this one – it's harder to do when you can't see the results)
- Which model do you think would be the most useful for helping us win the Ice Classic bet? Why?

*Try splitting into pairs within your group and each choose a model to consider, then after a few minutes regroup and explain your results to each other. It is OK if you don't get through all 4 models.*

# Task 1: Four Example Models

These models have been arranged in order of large to small scale and can be considered as one of many tools that could be used to inform your prediction for break-up day and time in the Nenana Ice Classic. Each model may have more than one "sub-model" that you can consider.

1) From a global climate model considering ENSO (sea-surface temperatures in the South Pacific Ocean) and Alaska temperatures (a) determine the heat exchange of the system which leads to (b) precipitation (c) river discharge and (d) ice melting rate.
2) Consider the heat of the sun, cloud coverage and the snow/ice cover at a regional scale (whole Alaska for instance) to (a) determine the heat absorption of the ground and/or snow/ice. Then (b) determine the rate of ice melting in the river from the river temperature and discharge due to snowmelt and rainfall.
3) Consider river water discharge and river water temperature (a) to determine ice melting rate in the river within 1 km upstream of Nenana, which is used to (b) predict deformation and movement of ice downstream and (c) the tension in the rope until it reaches a point that the clock is stopped.
4) Given a velocity of ice moving downstream (slowly) as it melts and deforms (as a plastic continuum), (b) calculate the rope tension as in model 3 above. The velocity is derived from (a) past measurements that are represented with a probability distribution.

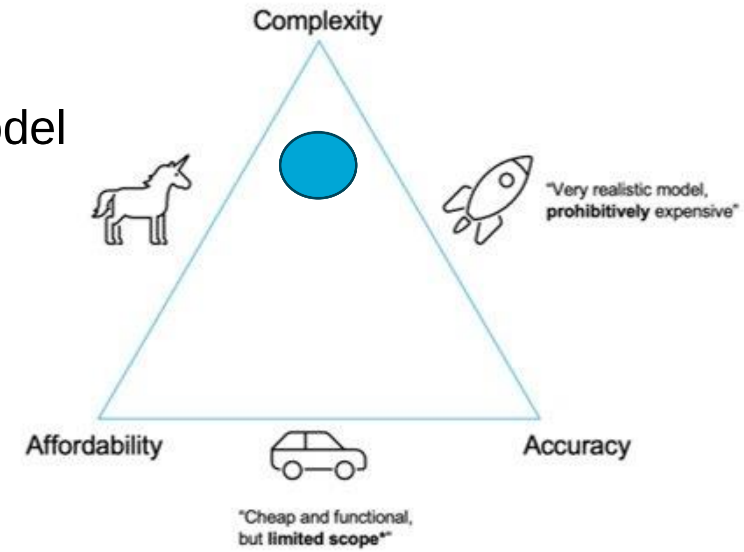
# Task 1 Solutions #1

While the Global Climate model may have small components that are mechanistic, it is phenomenological: based on atmospheric physics with some inference from observations. Accuracy is low because the Earth is discretized into cells using finite element/volume/difference methods. Complexity is high due to the numerical issues in setting up and running the model. Stochastic elements might be included for represent some uncertainty, but this tends to complicate things, so it is often accounted for by running a large set of simulations and evaluating the variation in the output of this "ensemble." Heat exchange: mechanistic possible (diffusion equation), more likely phenomenological, static, and deterministic. River discharge might be data-driven or phenomenological; to simplify river geometry, non-linear effects and time-dependent aspects would likely be excluded. Ice melting rate: phenomenological, time-invariant, static.

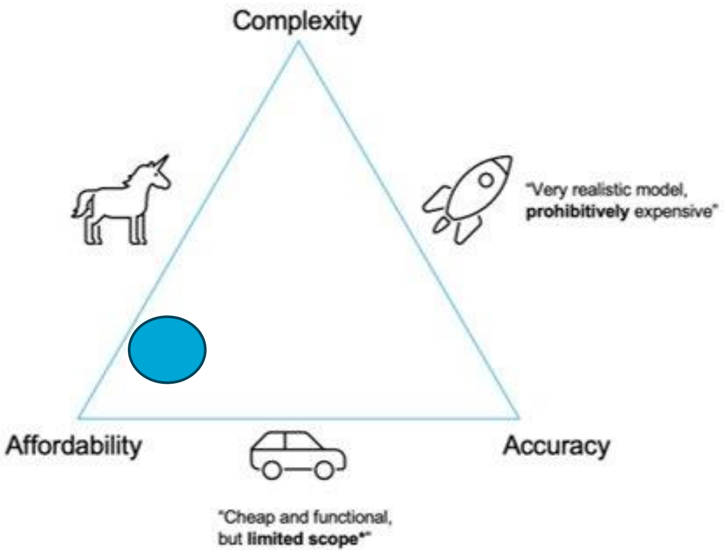
GoF: comparing error metrics and $R^2$ for each stage with data.

Depending on your perspective as a 1) creator or 2) user of the model, the assessment of cost and complexity varies:

Perspective 1:
Setting up the model




Perspective 2:
Using the model



# Task 1 Solutions #2

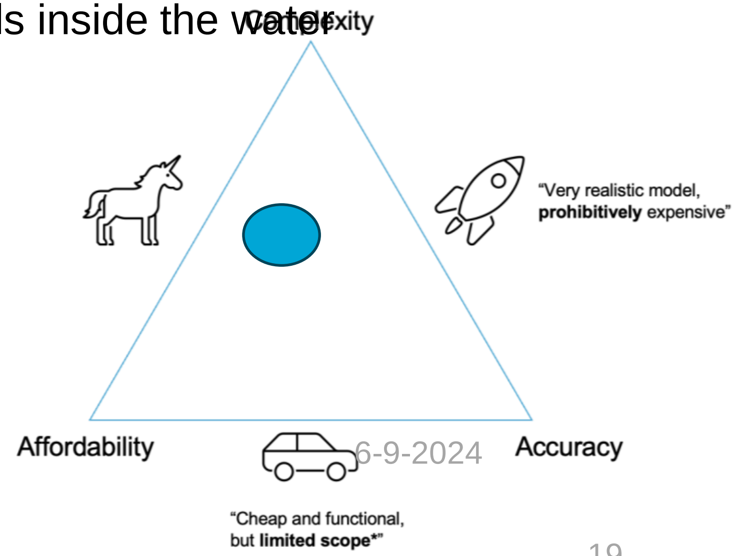
Heat of the sun can be found deterministically using mechanistic models, and cyclical variation due to daily, seasonal, etc, cycles could be included. This would be complex, but perhaps a stochastic model could simplify it. Snow/ice cover could be found from historical data and predicted stochastically or with regression (mechanistic and time-invariant, static and non-linear), which can be used in a mechanistic model to determine river temperature and rate of ice melting in the river (time-invariant, deterministic, can be simplified as static). River discharge has a lot of data, an could probably be more complex with a non-linear and possibly dynamic model.

The ice melting rate model can be simplified as static because we assume that temperatures do not change rapidly, while for the river discharge model the dynamic choice is better as a sudden input of rainfall following a rainstorm and ice or snowmelt after a heat wave can occur more easily.

Simplifications: again, no mechanics of the river interacting with the tripod or rope are included (it breaks when the ice  completely melts, which is not  always necessarily the case). It considers that ice melts at the same temperature uniformly but there are differences depending on the chemicals inside the water (for example salt or other sediment).

Recommended GoF: $R^2$ for heat absorption, RMSE for ice melting rate,

rbias for river discharge



# Task 1 Solutions #3

Discharge and temperature will almost certainly be from data, which could be modeled stochastically with distributions. The model of ice melting in the river (a, b) could be mechanistic (e.g., mass and heat capacity of ice, heat energy of incoming water), but more likely this would be phenomenological, perhaps with a dimensionless type analysis, since the river geometry is complex.The tension in the rope would be found using a mechanistic model, as well as the catenary shape; it is definitely non-linear.

c. The rope tension can almost certainly be considered a static case because the loading rate on the rope will be very slow as the ice slowly melts, unless there is an abrupt change to the river flow (or local breakage of ice blocks) so that it would be considered as an impulse load.

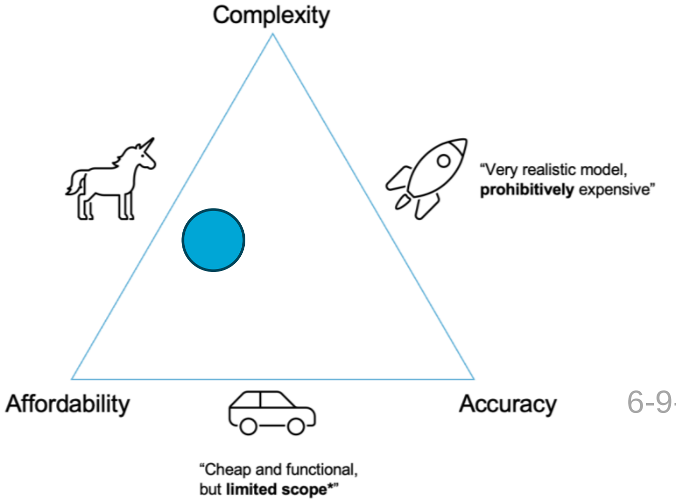
Simplifications: no model of large-scale phenomena considered (neglect heat exchange and mass transfer processes)

A big limitation with this approach is that there doesn't seem to be any measurements of ice movement downstream over a period of time close to the break-up date for prior years. Perhaps we should collect this information while watching the webcam this year :)

Recommended GoF: $R^2$ for ice movement.

RMSE or other error measures should be used to compare observations

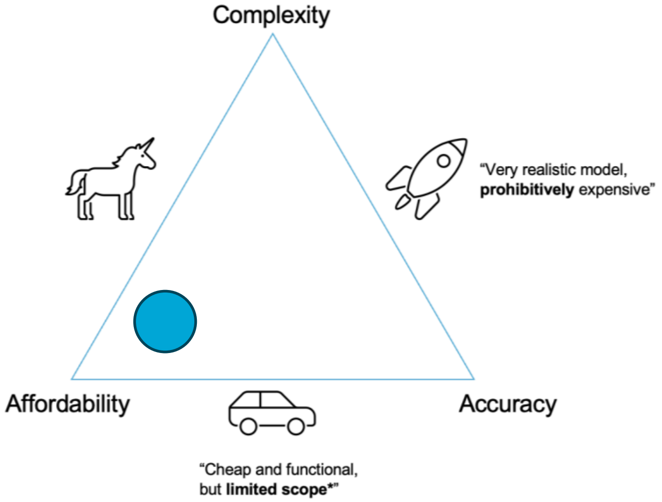
of ice deformation for the other models



# Task 1 Solutions #4

See previous answer. Here the decision is obviously made to abandon the complicated mechanistic and phenomenological models about ice deformation and simply quantify the probability of reasonable values. In terms of the triangle, this loses accuracy, but makes the model much less complex and more affordable.

Recommended GoF: q-q plot (not yet covered) and $R^2$ for observations of ice displacement

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# Task 1 Solution for "which model is best?"

"There is not a definitive answer otherwise we wouldn't be here now."

- A. Stamou, MUDE TA, Delft

- Good discussions in class
- Difficult to identify GoF without seeing more details of the model (also why solution is not detailed)
- Many answers are subjective; depends on your assumptions/perspective
  (e.g., Ex 1: are you setting up the model, or using the results?)

# Task 2: Modelling Ice Breakup

- Consider the following set of slides that introduce two important aspects of river ice:
  1. Ice thickness, and
  2. River ice break-up mechanisms

- Next, look at the data analysis that follows, which captures our previous attempts to evaluate these processes for the Nenana Ice Classic:
  A. Overview of temperature, discharge and ice thickness data
  B. Exploration of ice thickness data and break-up day
  C. Exploration of discharge data and break-up day

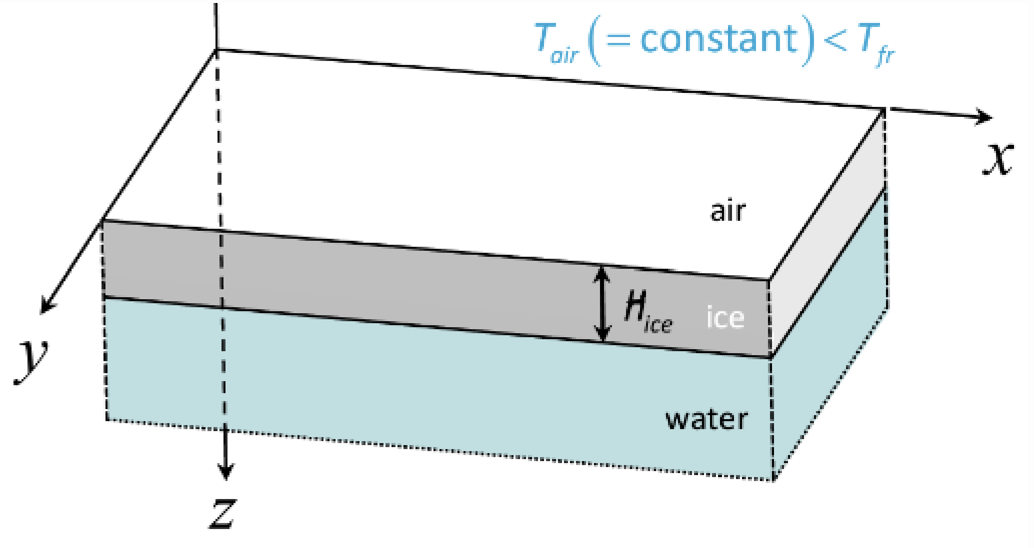
Finally, imagine it is April 1, 2025: make a prediction using the information provided on the last slides of this Task.

>>> <u>There are some “ice experts” in each classroom to help you interpret the data and reason through the prediction</u>

Model: Ice Thickness

# Task 2: Modelling Ice Breakup

To model the ice growth, you could use the Ashton model, which aims to determine how an ice layer grows as a function of time, given the constraint that the temperature of air is constant, smaller than the freezing temperature and everywhere the same.




$$\frac{dh}{dt} = \left(\frac{1}{\rho_{ice} L}\right)\left(\frac{T_{water} - T}{\frac{h}{k_{ice}} + \frac{1}{H_{ia}}}\right)$$

- $h$ = ice thickness
- $t$ = time
- $\rho_{ice}$ = ice density
- $L_{ice}$ = ice fusion heat
- $T_{water}$ = temperature at the ice-water interface
- $T$ = air temperature
- $k_{ice}$ = ice thermal conductivity
- $H_{ia}$ = bulk heat transfer coefficient (air-ice)

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# Task 2: Modelling Ice Breakup

*Beltaos (1984) Threshold between mechanical and thermal breakup of river ice cove*

Excerpt from Abstract

*Extreme ice-jam flood events in rivers occur during a type of breakup that is partly governed by the mechanical properties of the ice cover, and known as “mechanical”. By contrast, thermal breakups are preceded by advanced thermal decay of the ice and can only produce insignificant, if any, jamming…It is shown that there is a site-specific rise in water level above the freeze-up elevation, which delineates mechanical from thermal events. The threshold value is approximately proportional to the thickness of the ice cover, and also depends on local river morphology and hydraulics*

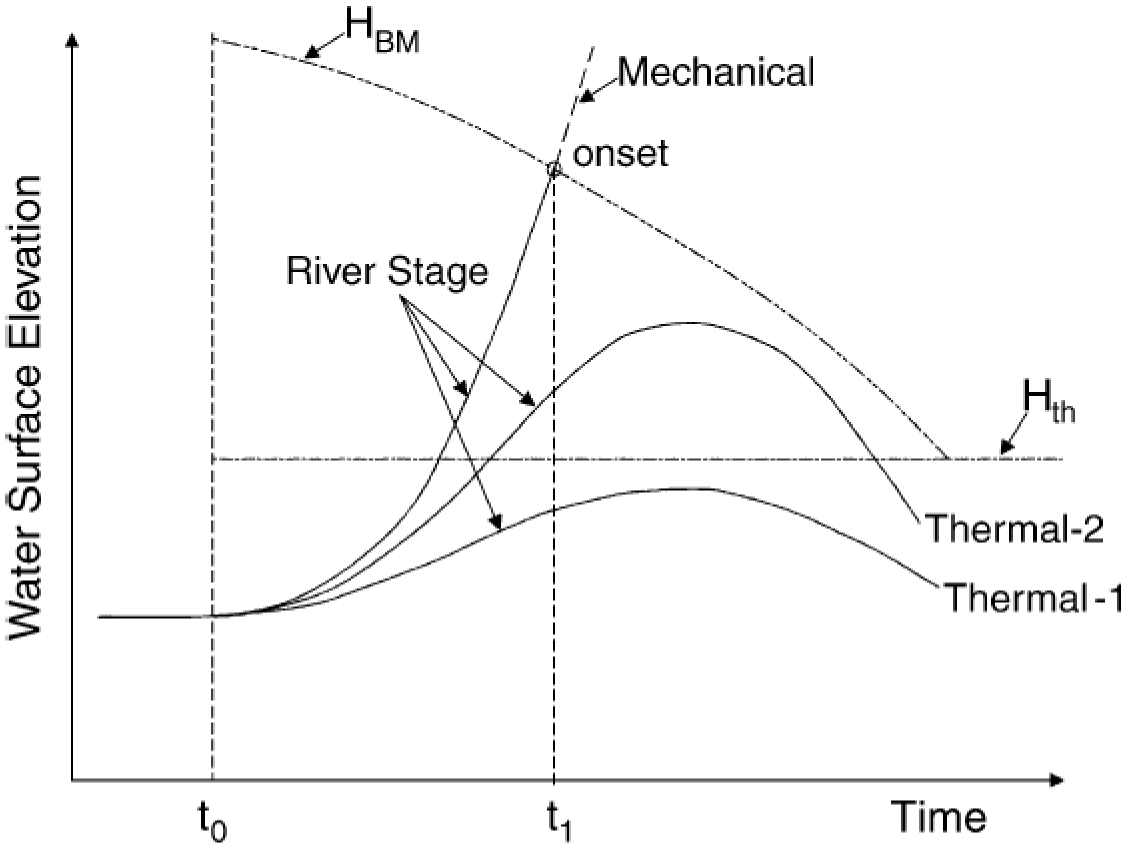


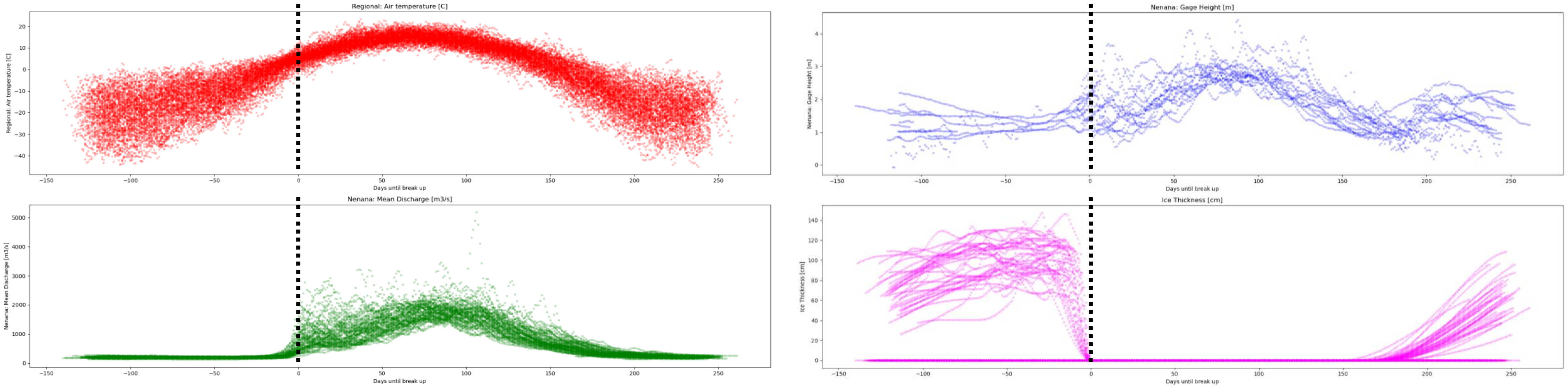

Fig. 8. Illustration of different types of breakup events that may result from different river stage hydrographs.

- If the river rises rapidly, a *mechanical breakup* occurs
- If the river rises slowly, or does not exceed some threshold, a *thermal breakup* occurs

Data: Ice Thickness, Temperature, Discharge

# Task 2: Modelling Ice Breakup

- Historical data, normalized such that actual breakup day is at 0

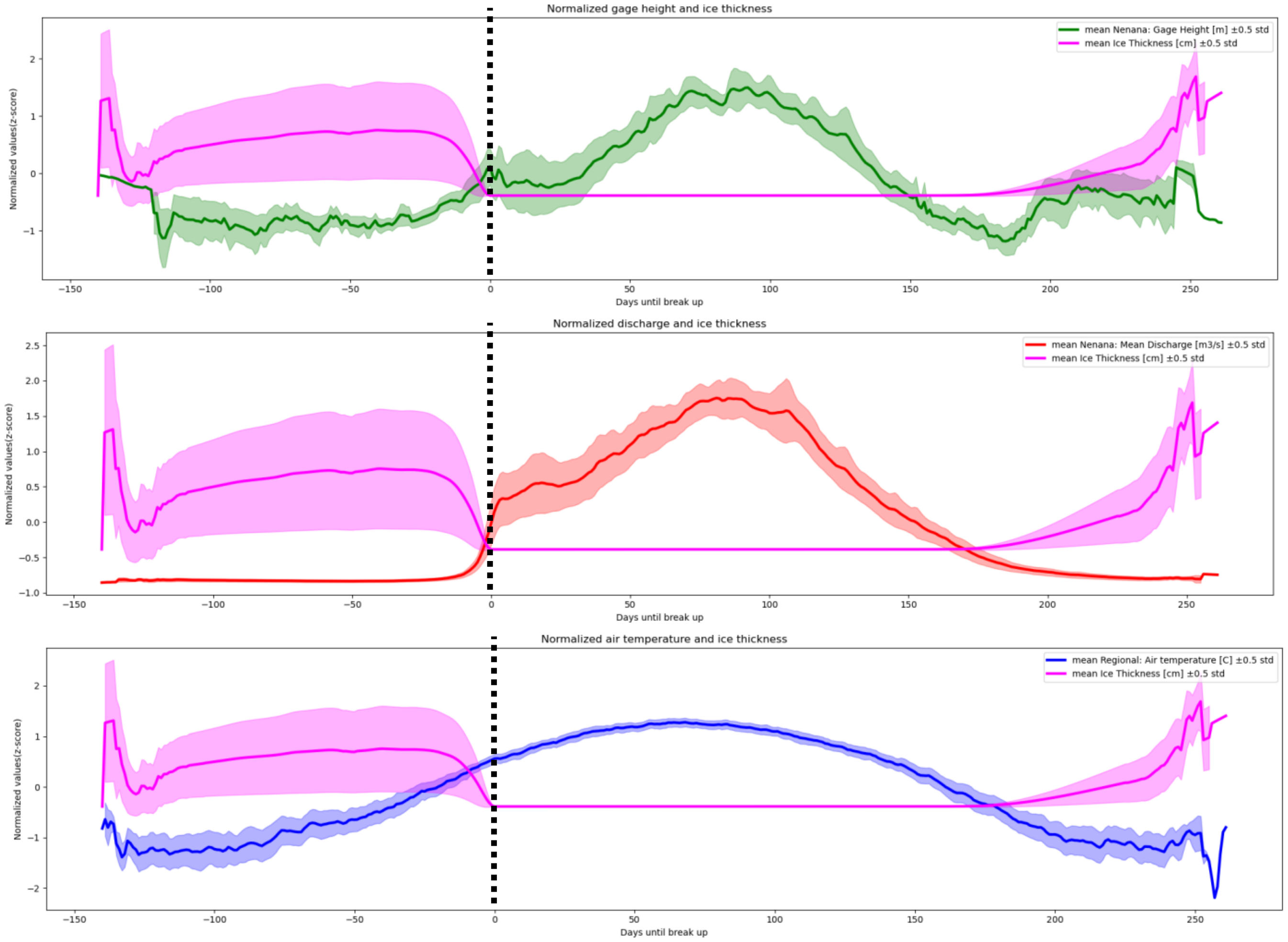



*Note that "Gage Height" is measured directly (next to the Ice Classic tower) and is a point measurement, whereas discharge is inferred from this value and representative of the eriver along that reach.*

Data: Ice Thickness, Temperature, Discharge

# Task 2: Modelling Ice Breakup

- Key variables plotted with ice thickness
- Colored bands indicate one standard deviation of historic data
- Ice thickness is a combination of physical observations, combined with the Ashton model to and an interpolation method to fill in the days with no data

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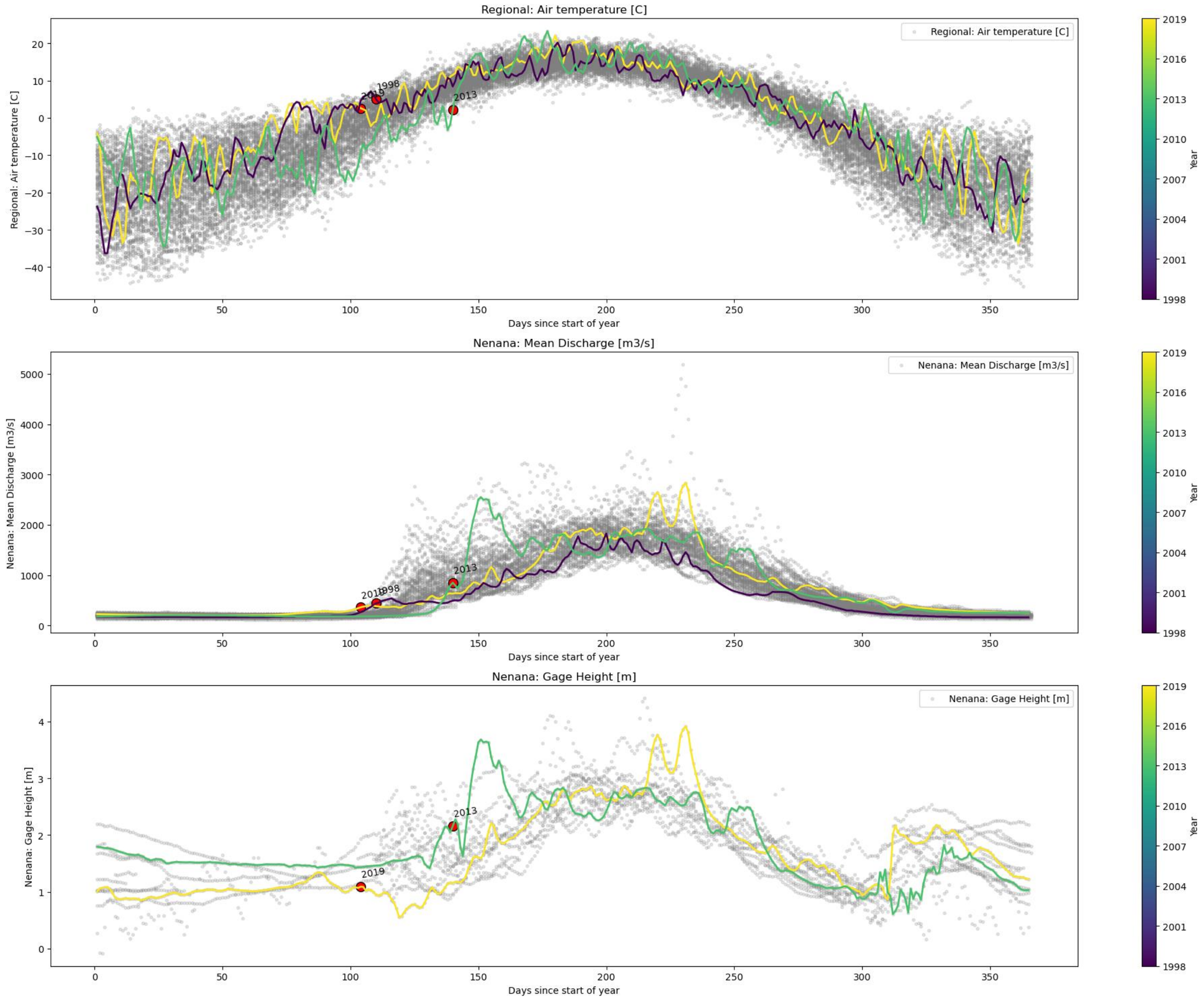
Data: Ice Thickness, Temperature, Discharge

# Task 2: Modelling Ice Breakup

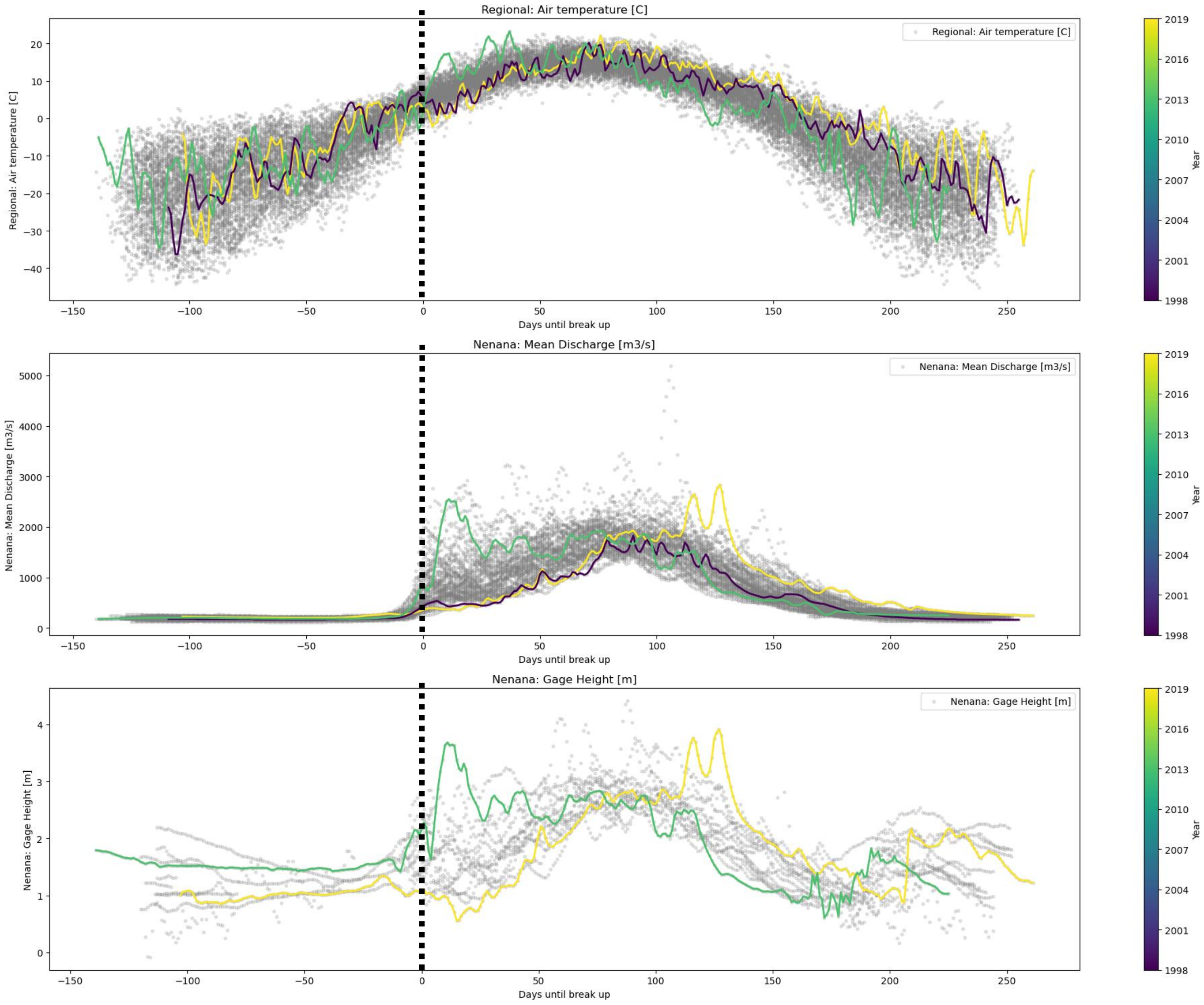
- Historic data with several years highlighted: 1998, 2013, 2019
- Horizontal axis is absolute days since start of year



**Data: Ice Thickness, Temperature, Discharge**

# Task 2: Modelling Ice Breakup

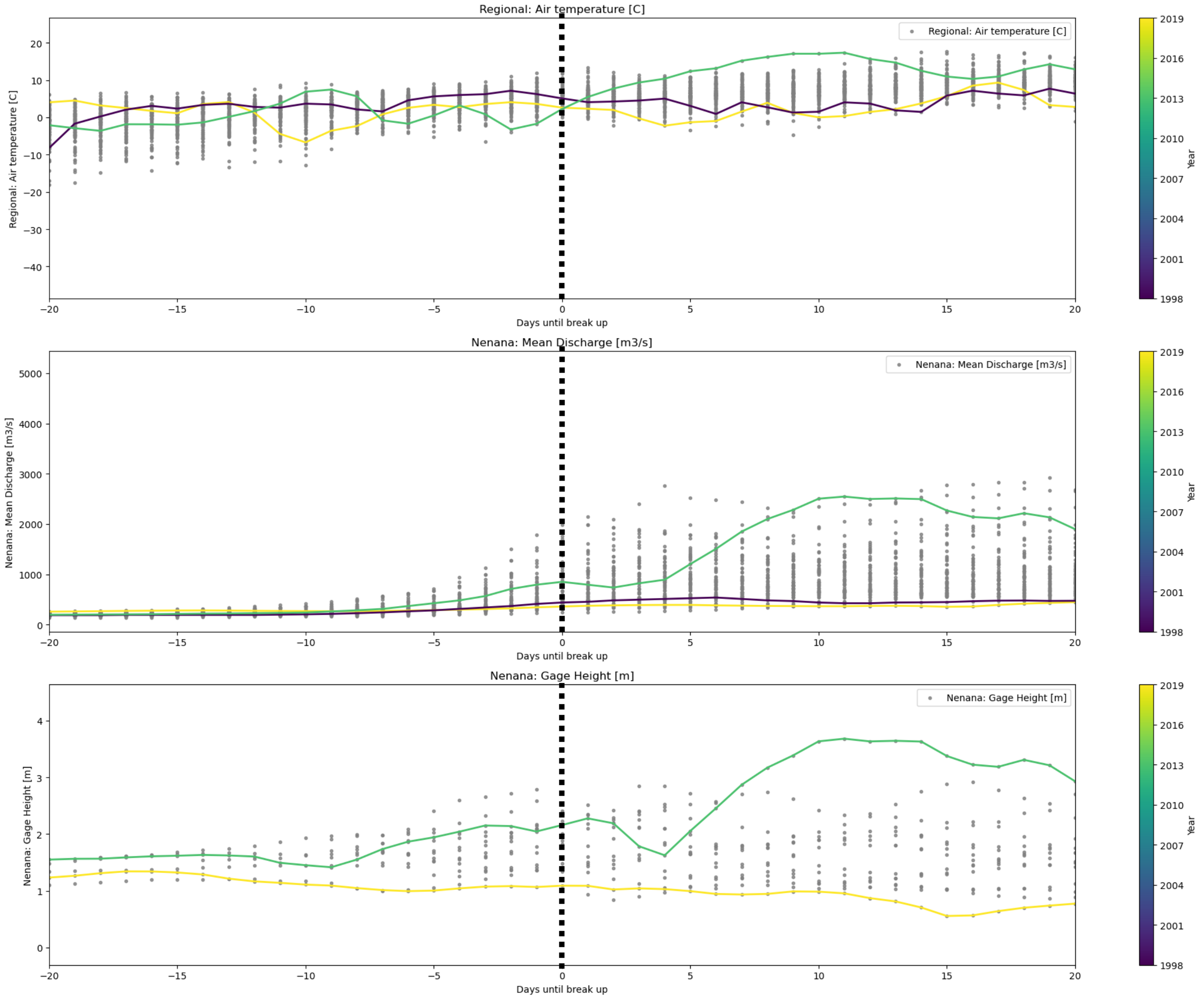
- Historic data with several years highlighted: 1998, 2013, 2019
- Horizontal axis is normalized such that actual breakup day is at 0



Data: Ice Thickness, Temperature, Discharge

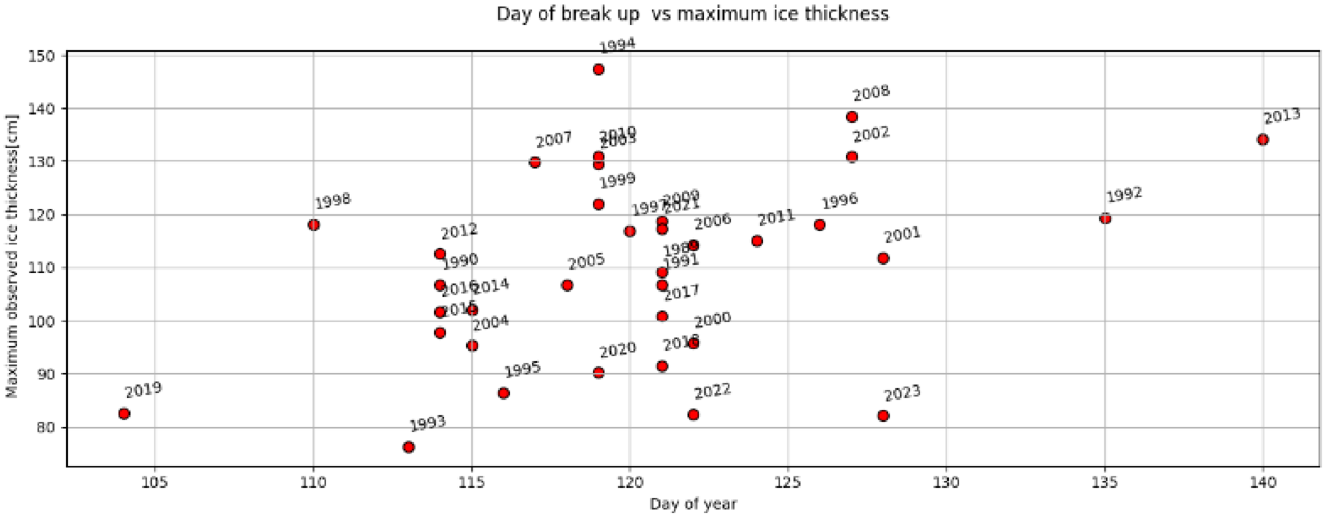
# Task 2: Modelling Ice Breakup

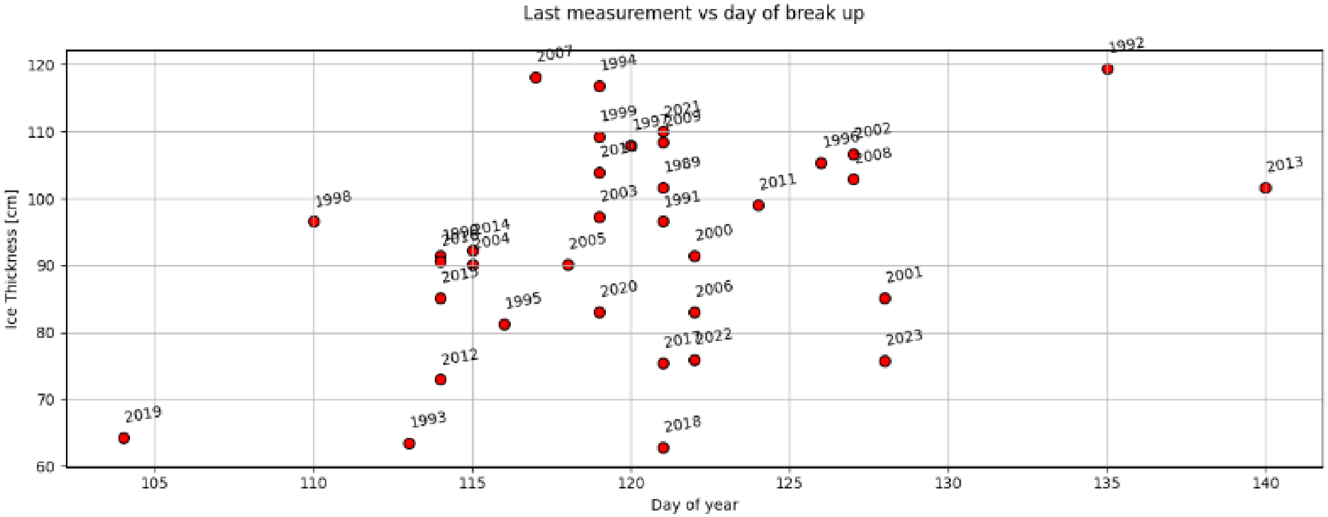
- Same as previous slide, but these are zoomed-in around the break-up date (+/-20 days)



# Task 2: Modelling Ice Breakup

- Maximum ice thickness and Last Measured ice thickness (y-axes) plotted against actual breakup day of that year

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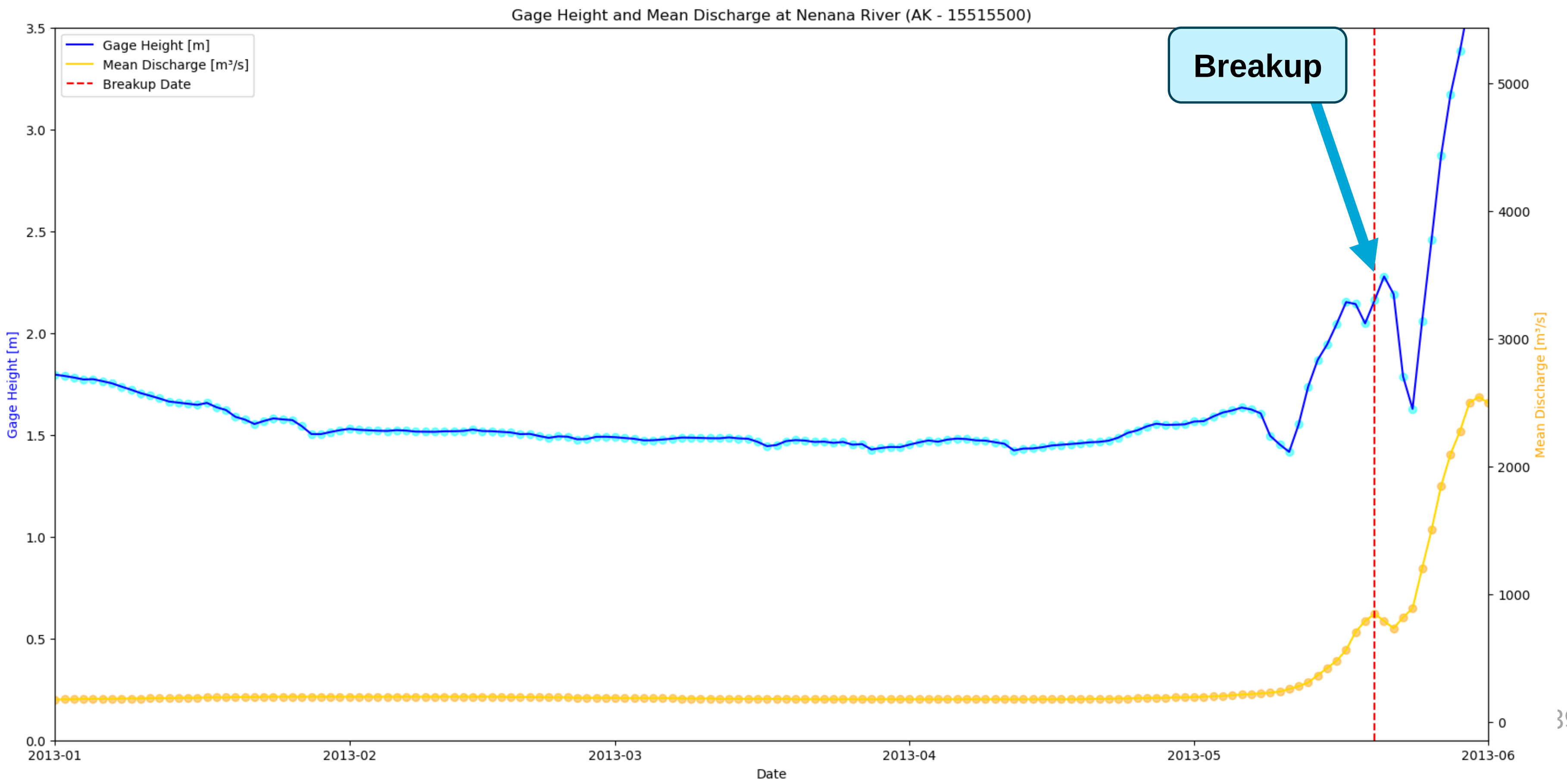
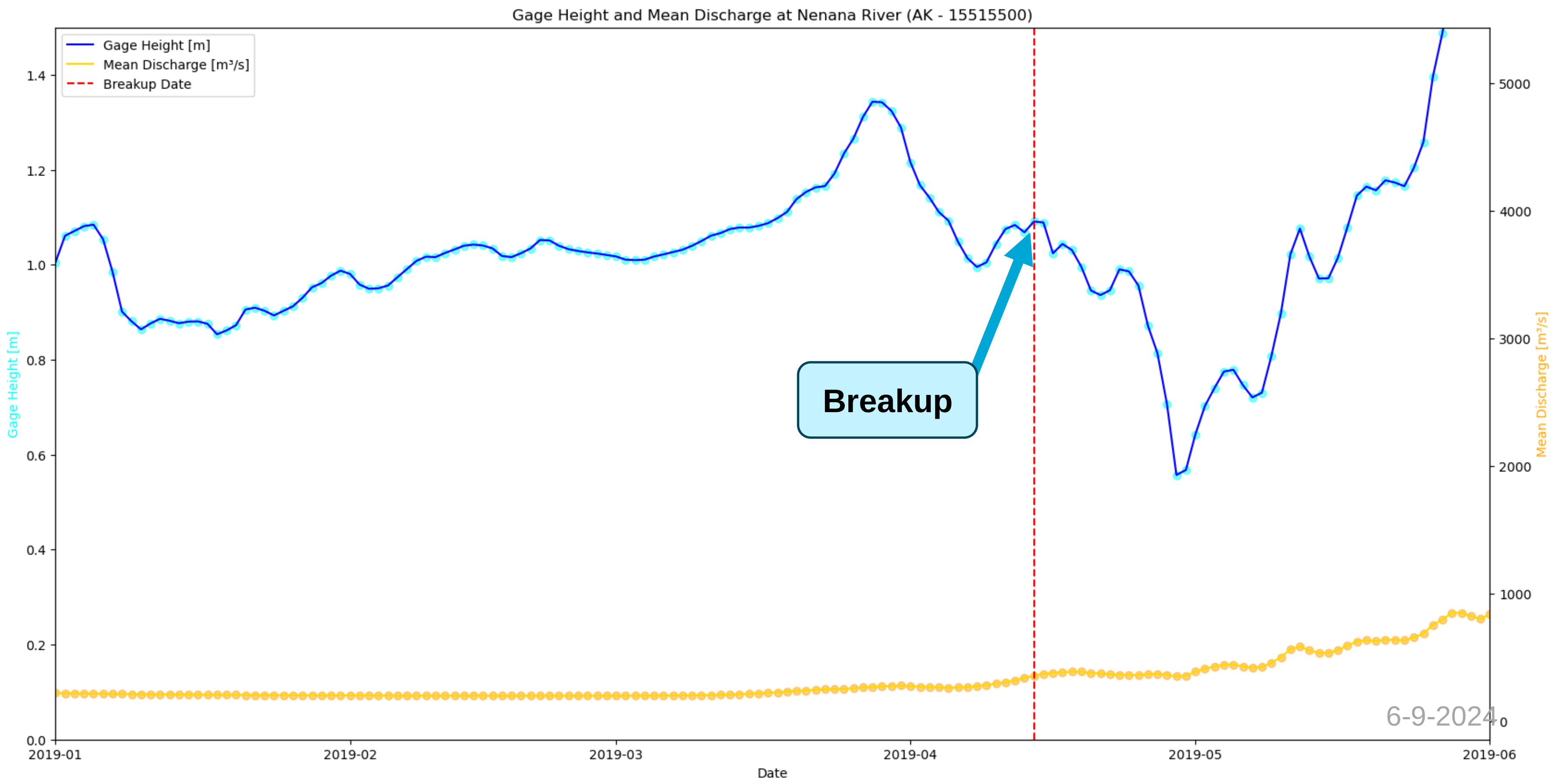
# Task 2: Modelling Ice Breakup

- Discharge and Gage Height (height of river surface elevation) prior to breakup in 2013
- River is clearly rising when breakup occurs → indicates Mechanical Breakup Mechanism



# Task 2: Modelling Ice Breakup

- Discharge and Gage Height (height of river surface elevation) prior to breakup in 2019
- Compared to previous slide, river level is low; no significant increase → indicates Thermal Breakup Mechanism

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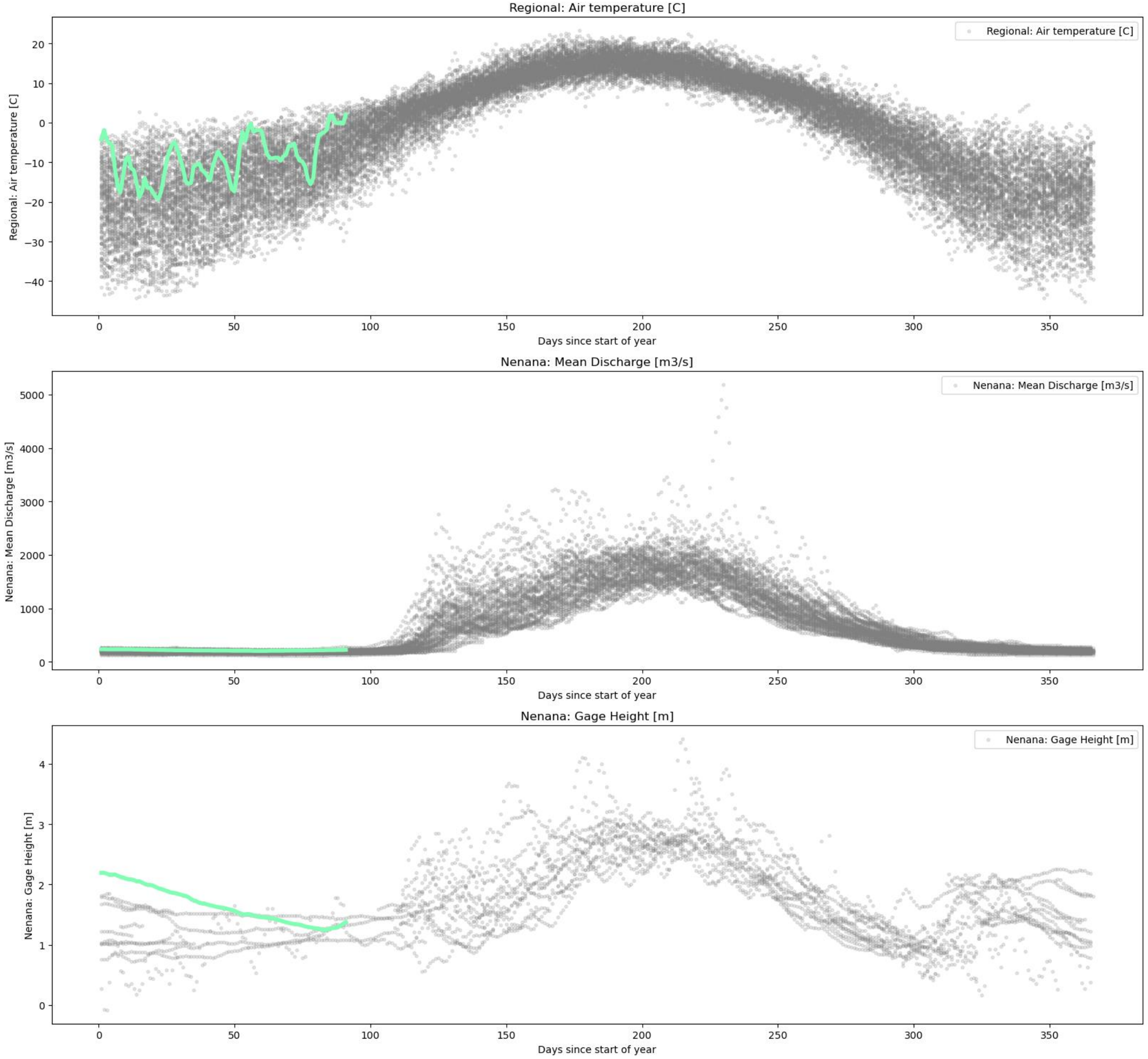
Hypothetical Information for 2025

# Task 2: Modelling Ice Breakup

- Hypothetical situation, April1st 2025,

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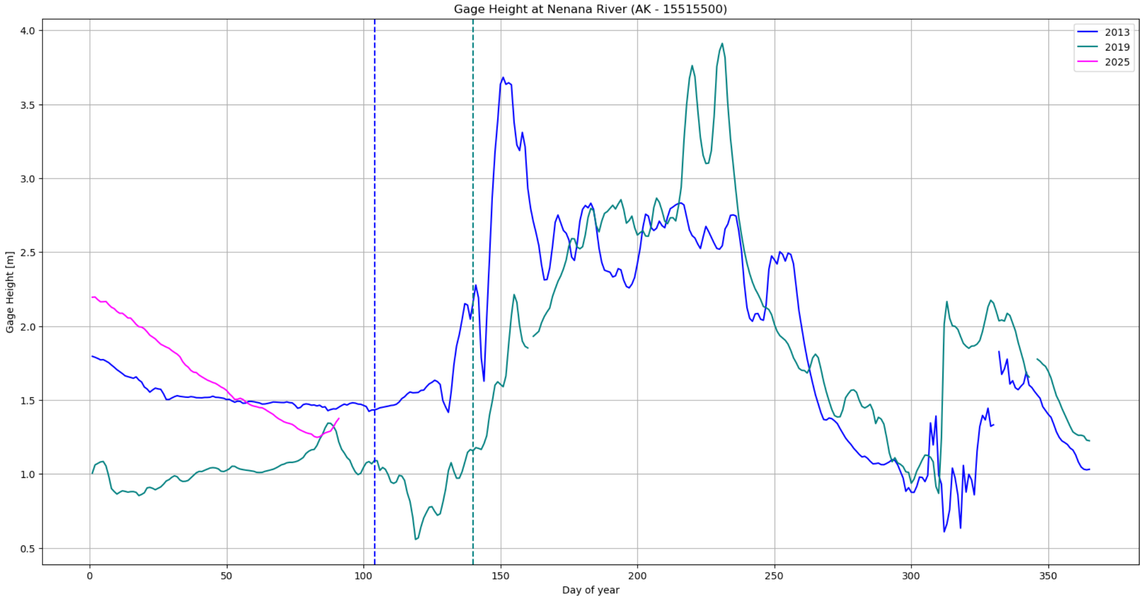
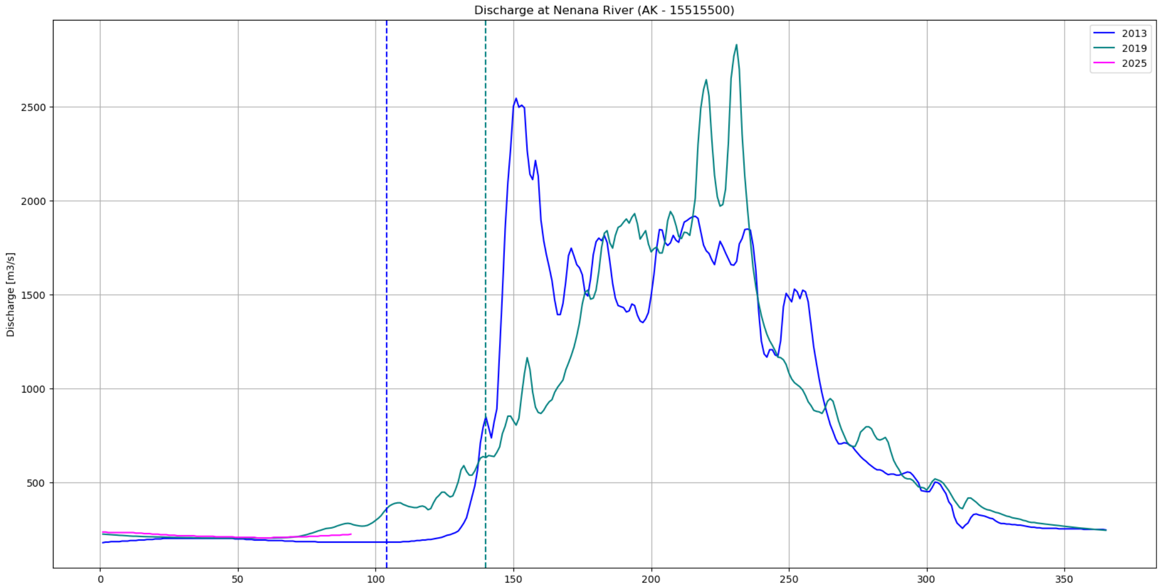
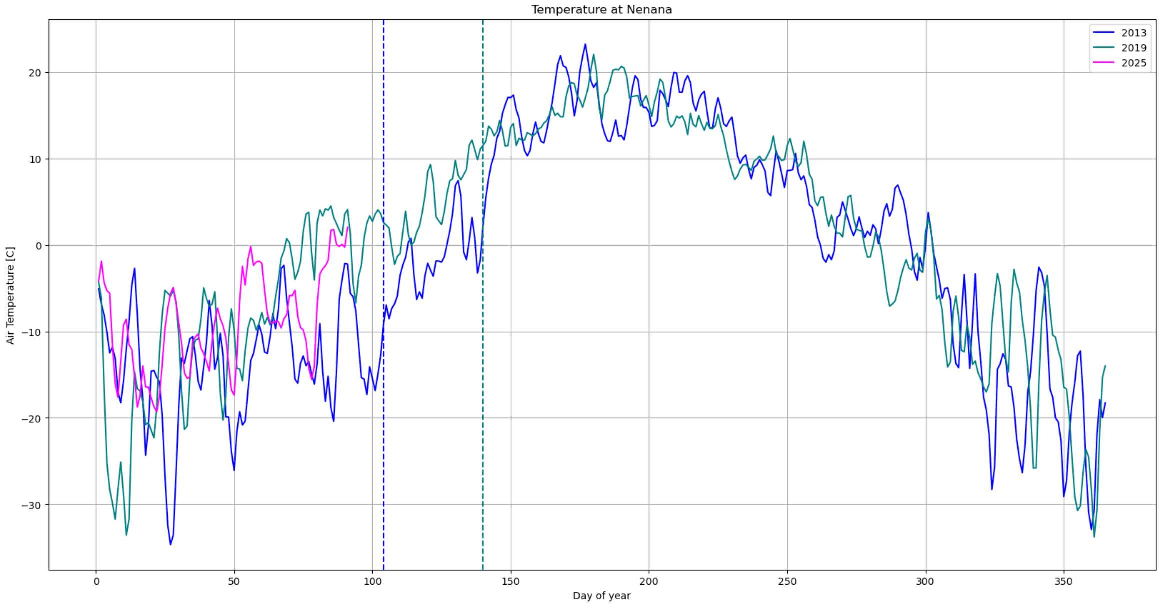
Hypothetical Information for 2025

# Task 2: Modelling Ice Breakup

- Hypothetical situation, April 2025 (red line)
- Compared with 2013, 2019
  (breakup indicated in dashed lines during those years)

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Hypothetical Information for 2025

# Task 2: Modelling Ice Breakup

*Using the information on the previous slides…*

Imagine its April 1, 2025 and you need to submit your prediction/ticket for the Nenana Ice Classic:

- In addition to the hypothetical information on the slides immediately before this one, you observe that:
  - There was more snow than average
  - The 10-day forecast indicates there will be an average temperature of -2 C, but there are 2 days which could rise above 0 C during the daylight hours
  - The most recent ice measurement is 1.1 m, but the maximum measurement (a couple weeks ago) was 1.4 m

**Task 3: Make a Prediction for the 2025 competition!**

>>> There are some "ice experts" in each classroom to help you interpret the data and reason through the prediction

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# Task 2: Solution

- There is a huge variety of answers, so only a brief outline will be illustrated here.

Some key observations to have made from the figures:

- 2013 and 2019 are illustrated on the figures and they are each the *latest* and *earliest* breakup days recorded
- There is clearly a difference with the temperature profile for each of those year; although both sets of observations vary in the weeks preceding breakup, the variation is within the observations from all years, and the temperature of 2019 (the earlier year) is on average much higher. In fact, there seems to be several days above 0 C directly preceding breakup.
- Discharge and ice thickness seem to have big influence on breakup date as well. The ice thickness plots indicate that there could be a trend (low thickness → early breakup), but there is a lot of scatter in the middle area of the plot, indicating other processes could play a big role.

The answer? Recognizing that the hypothetical conditions described for 2025 are similar to 2013 and choosing a day similar to that would be sufficient. Also good to note that 2013 is extremely late in May, so maybe on the earlier side is better – how about…..May 12!?

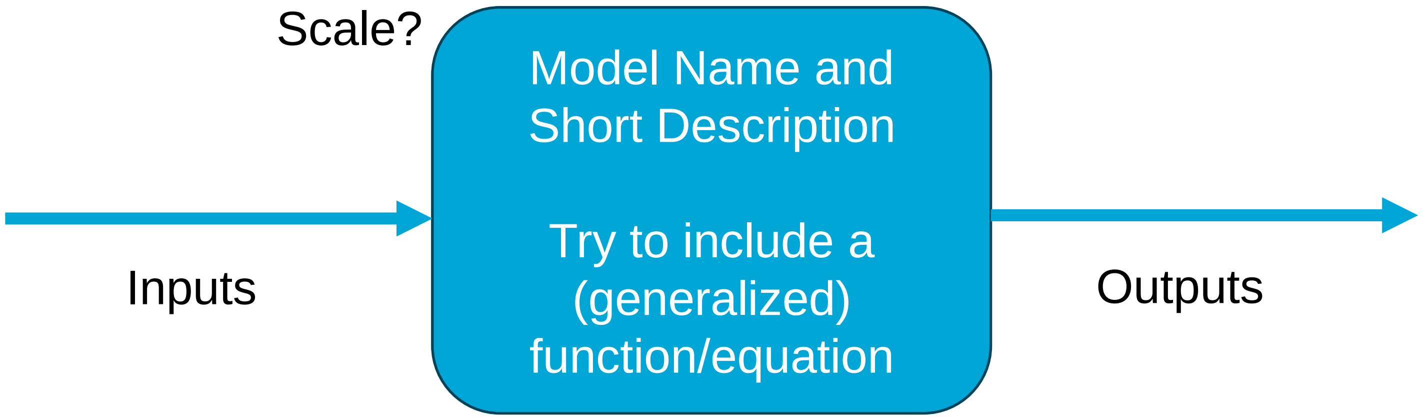
# Task 3: Improving the Model

- Now that you are familiar with the data that is available and have already been given a hint of some key relationships, we want you to give a recommendation on how we can better predict when breakup occurs.
- For this task: *describe a model of a specific physical process or variable of interest that can be used to better predict the* ***day*** *of ice breakup. Imagine that there are no restrictions on complexity or cost.*
- *Include:*
  - Short description of the model, as well as a generalized equation (if possible)
  - A diagram of the model (see template on next page). If your model is complex, you can break it down into sub-models (using several instances of the diagram)
  - A description of the model Classification, Decisions, Inputs/outputs
- Finally, reflect for a few minutes and answer this:

*Identify the least feasible part of your model in terms of cost/complexity/accuracy. What are the primary limitations?*

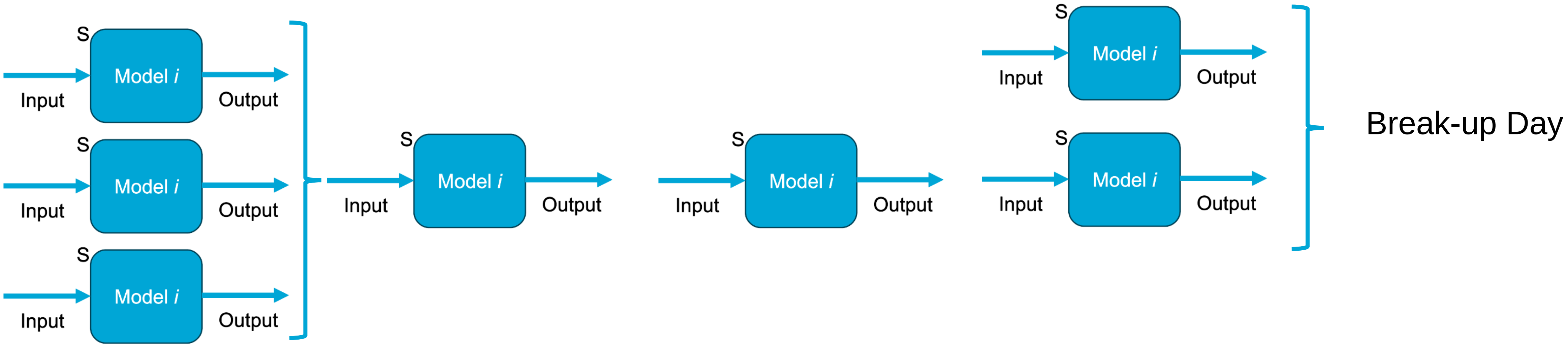
# Task 3: Improving the Model

- You can use this template to represent your model, or sub-components of your model
- Specify classification and decisions
- Try to illustrate the entire system from Global to Local by putting together multiple models (connecting inputs/outputs) … see next page



# Task 3: Improving the Model

- Here is a suggestion for how you might be able to Illustrate the subcomponents of your model

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# Task 2: Solution

- There is a huge variety of answers, so only a brief outline will be illustrated here.
- Most groups recognized the importance of discharge and ice thickness and found really interesting ways to connect observable variables to these, which are at the core of the prediction model. Some were more complex than others, and ranged in scale from global to regional, but all incorporated interesting aspects of hydrology, climate, weather, etc (solar radiation, for example, was a nice one, as it has complex relationship with snow/ice melting, both on the river and upstream in the watershed).

Some key points to keep in mind/recognize:

- Ideally one would “observe” the discharge and ice thickness at breakup to identify a critical threshold of discharge that may cause the ice to break, given the current ice thickness (i.e., critical discharge increases with increasing ice thickness). This is a great idea; however, it is much more difficult to do in practice:
  - It is impossible to measure ice thickness during breakup: check out this video to understand why. Also, at some point before breakup occurs it becomes unsafe to measure the ice thickness. You can get around this issue by using the Ashton model to estimate ice thickness (extrapolate from last measurements)
  - There will be “scatter” in the relationship between discharge and ice thickness, it is not a perfect 1:1 relationship
  - To make the bet, we are making a prediction (extrapolating). We need to predict discharge and thickness, both of which are heavily dependent on weather, which is very difficult to predict accurately, especially when we need to look several weeks in advance! This makes the ice classic a very challenging (but interesting) modelling problem.