

Example 2: Using a Unique Application to Motivate STEM Topics

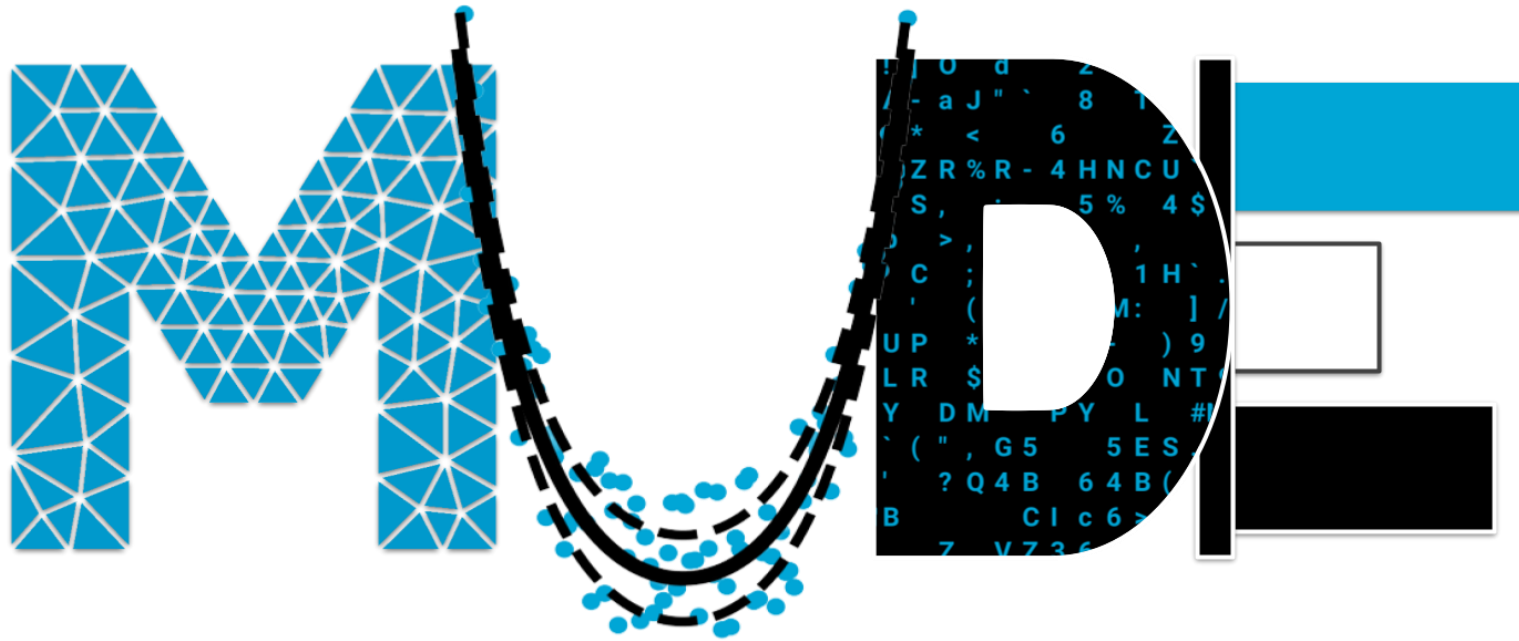
This example is a PDF that illustrates a group activity that I designed at the start of my course that covers fundamentals of modelling, uncertainty and data for civil and environmental engineers and earth scientists. Engineering students often appreciate when a connection is made between theoretical content and real world applications, but this is challenging with 300 students, all of whom come from different backgrounds and are interested in different branches of engineering. One way I have addressed this is to find something fun and interesting for all students: money!

The Nenana Ice Classic is a betting competition in Alaska that has been going on for over 100 years: anyone can make a bet on the precise month, day, minute and hour when the ice in the frozen river will break apart, signalling the arrival of Spring---and win more than \$300,000! The historical record is a very unique data set, and is especially motivating because students can quickly see that climate change may be playing a role in when breakup occurs. It is easy to motivate students to see how learning complex topics like probability theory, numerical modelling and programming can be useful.

The Ice Classic is used several times over the 16 week course, and the pages that follow illustrate only the first encounter students have with it, when it is used to introduce students working in groups to basic concepts of modelling and data analysis. The file is the "solution" to the assignment, so the answers are included in the pages for each task as they are introduced.

The documents provided here are explicitly shared here as part of the portfolio of Robert Lanzafame. We are currently working on finalizing the open source licenses, so please contact Robert at R.C.Lanzafame@tudelft.nl if you are interested in using them.

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



Modelling, Uncertainty, and Data for Engineers

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



Modelling, Uncertainty, and Data for Engineers

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)

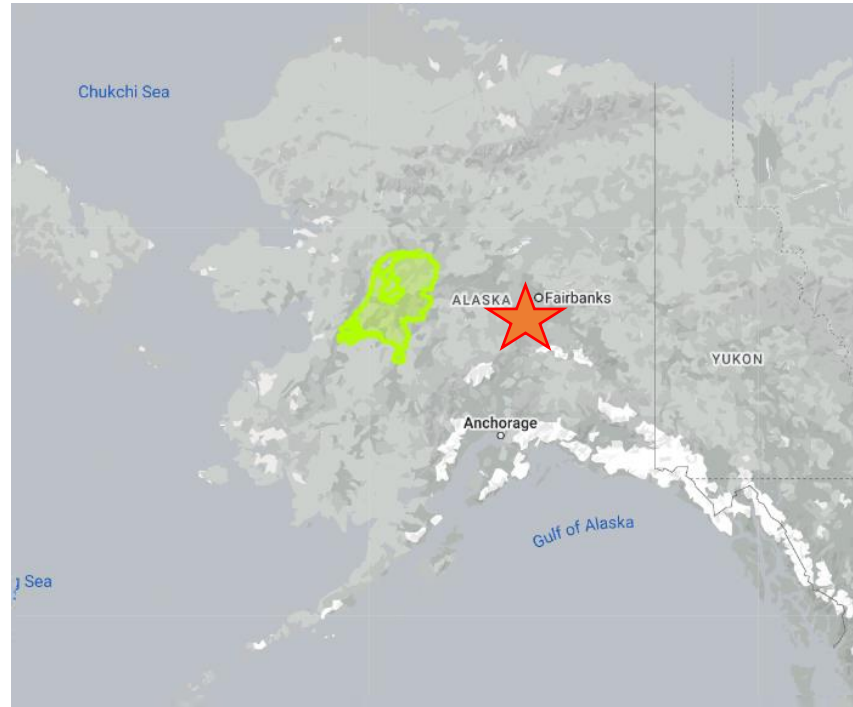
Part II: Illustration of available data and physical processes

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



9/6/2024

Last year's winnings: \$210,155



CLASSIC - \$3.00
DATE APRIL 5, 2018
MONTH 5
DAY 14
HOUR 6
MINUTE 28
CIRCLE ONE
AM PM
Name YOUR NAME
Mailing Address YOUR ADDRESS
City _____ State _____ Zip _____
Ph. # _____
Permit No. 000002

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/>

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

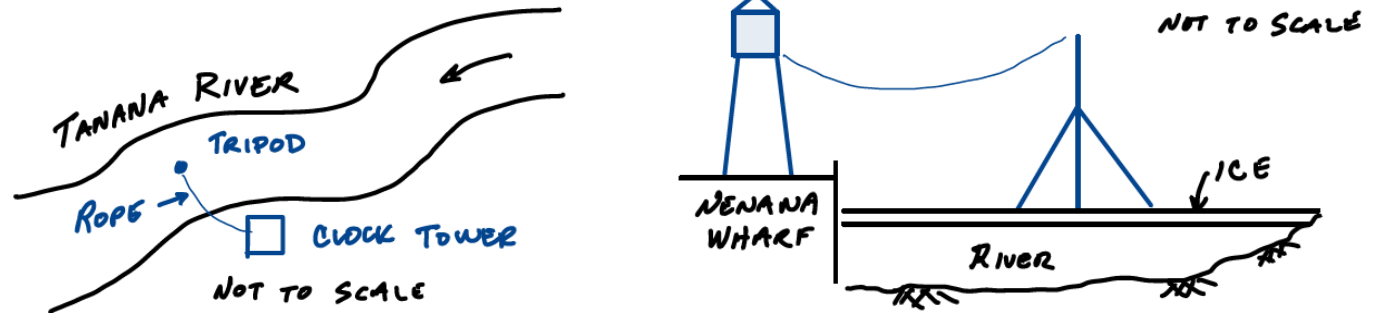
Scale	Physical Process	Variable	Symbol	Units
Local	River discharge	Monthly average discharge	Q_{month}	m ³ /s
		Water level at freeze-up	H_F	m
		Water level at break-up	H_B	m
	Ice thickness	Ice thickness	t	m
	Ice deformation / melting	River temperature	T_r	°C
Watershed	River discharge	Average spring 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}	m ³ /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

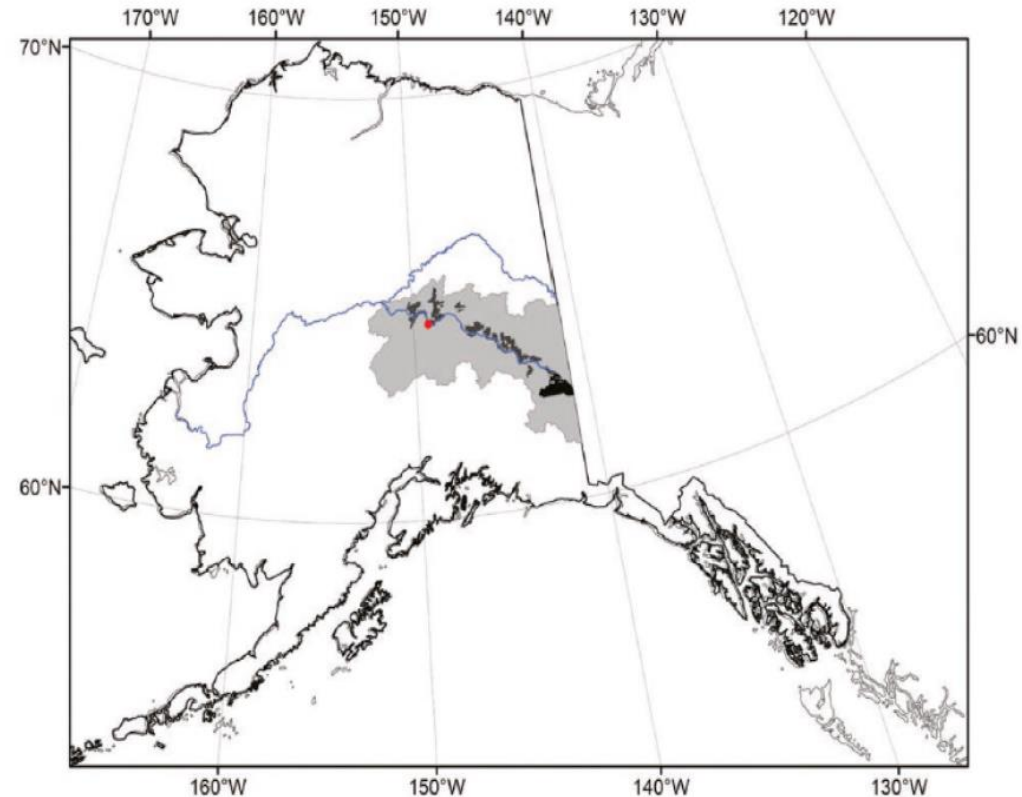


Figure 1.2: Location of Tanana river basin (grey), Yukon and Tanana river (blue) and Nenana (red dot) (edit by Terwogt, 2021, from original figure by Pattison et al., 2018).

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	$ENSO_{FMAM}$	$^{\circ}C$
	PDO effect in February-May	$ENSO_{FMAM}$	$^{\circ}C$

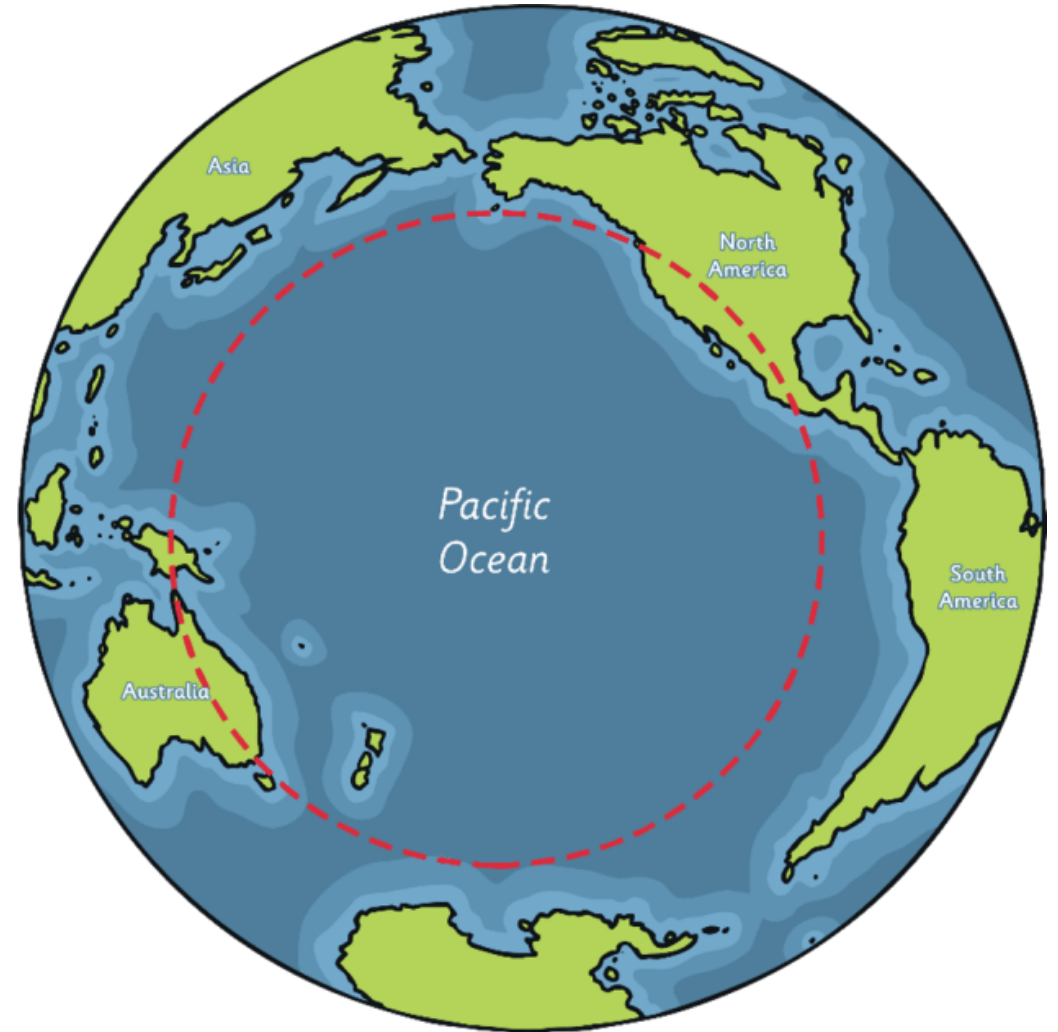


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Task 1: Model classification and decisions (warm-up)

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.

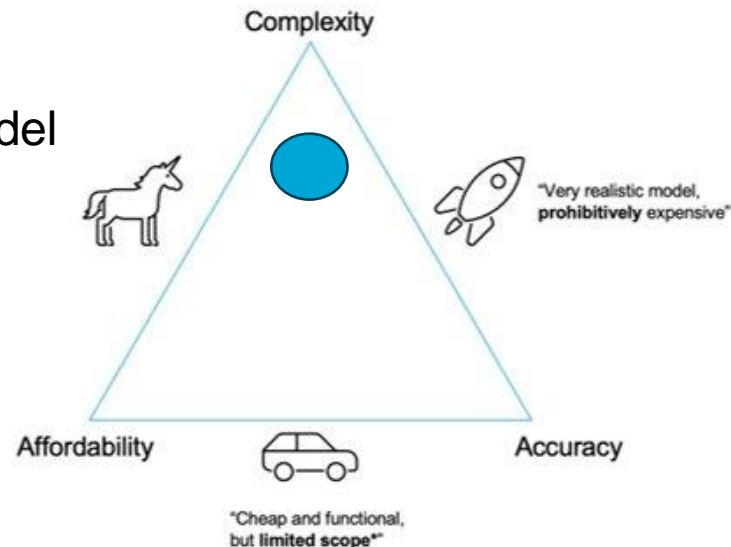
Task 1 Solutions #1

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 to 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.

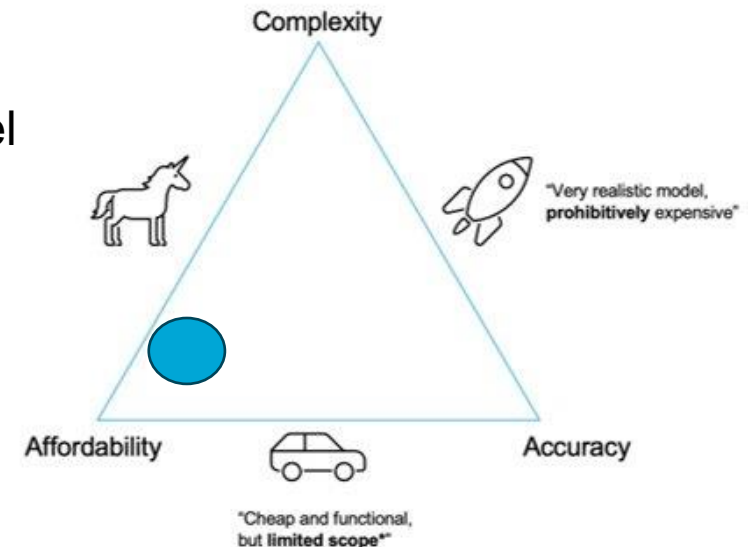
GoF: comparing error metrics and R^2 for each stage with data.

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



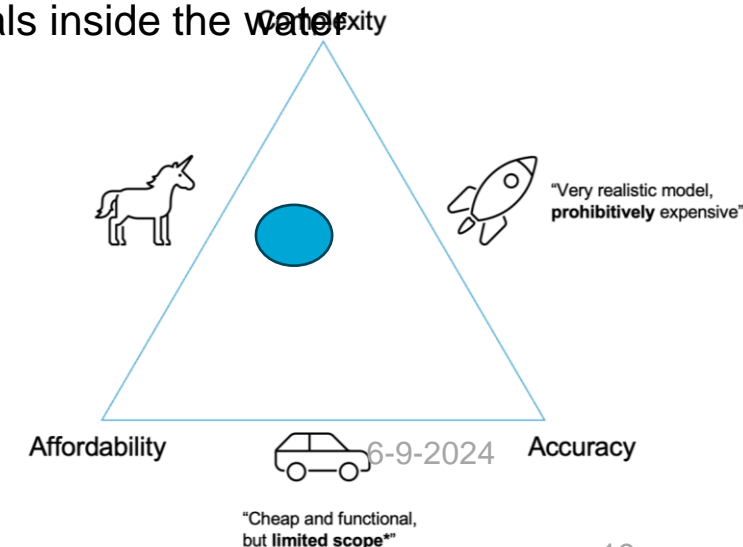
Task 1 Solutions #2

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, and 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, bias 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.

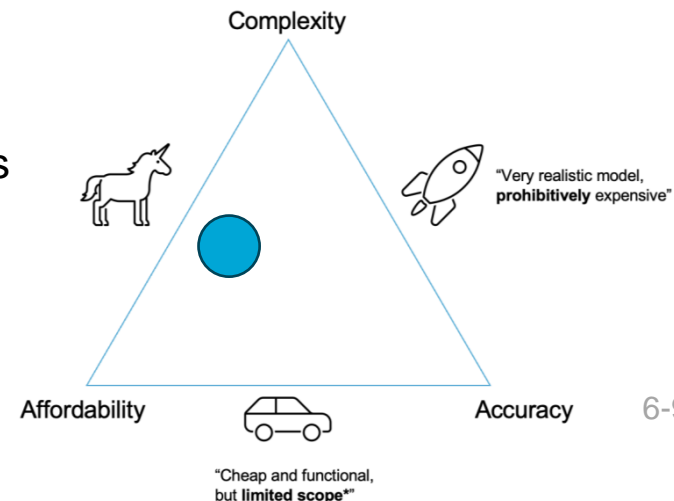
c. The rope tension can almost certainly be considered a static case because the loading rate on the rope will be very slow as the ice slowly melts, unless there is an abrupt change to the river flow (or local breakage of ice blocks) so that it would be considered as an impulse load.

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.

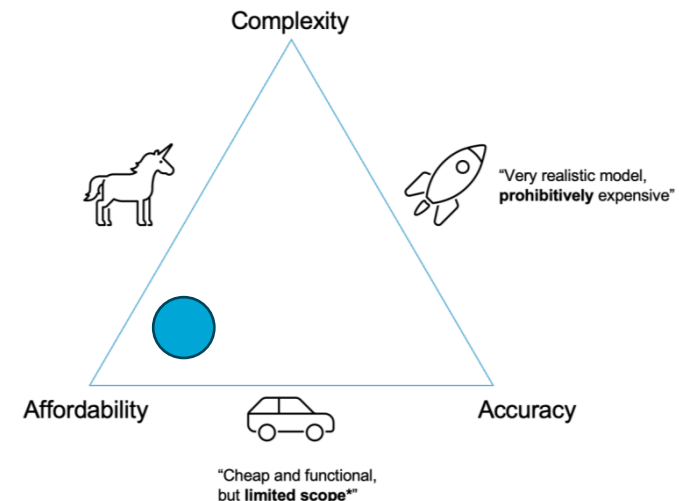
RMSE or other error measures should be used to compare observations of ice deformation for the other models



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



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

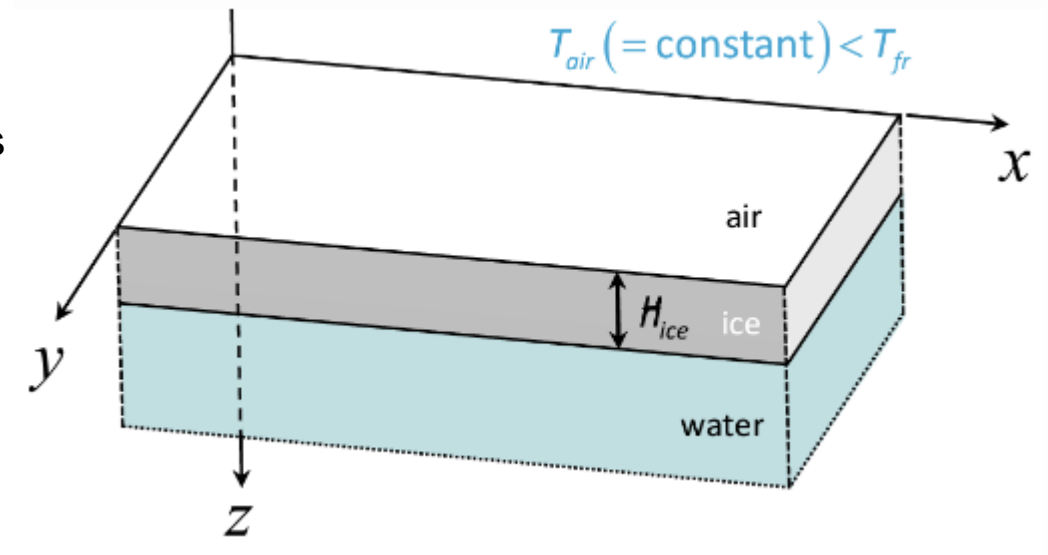
Finally, imagine it is April 1, 2025: make a prediction using the information provided on the last slides of this Task.

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
- ρ_{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)



Task 2: Modelling Ice Breakup

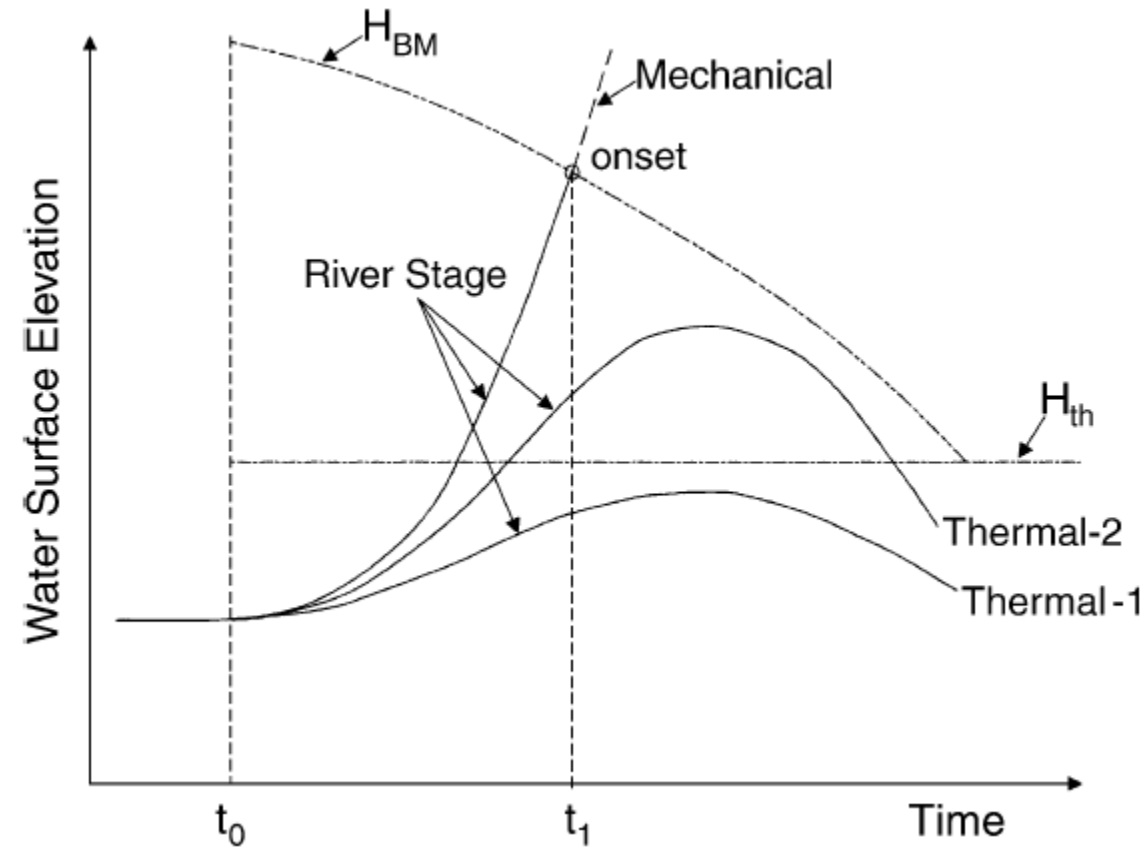
Beltaos (1984) Threshold between mechanical and thermal breakup of river ice cover

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

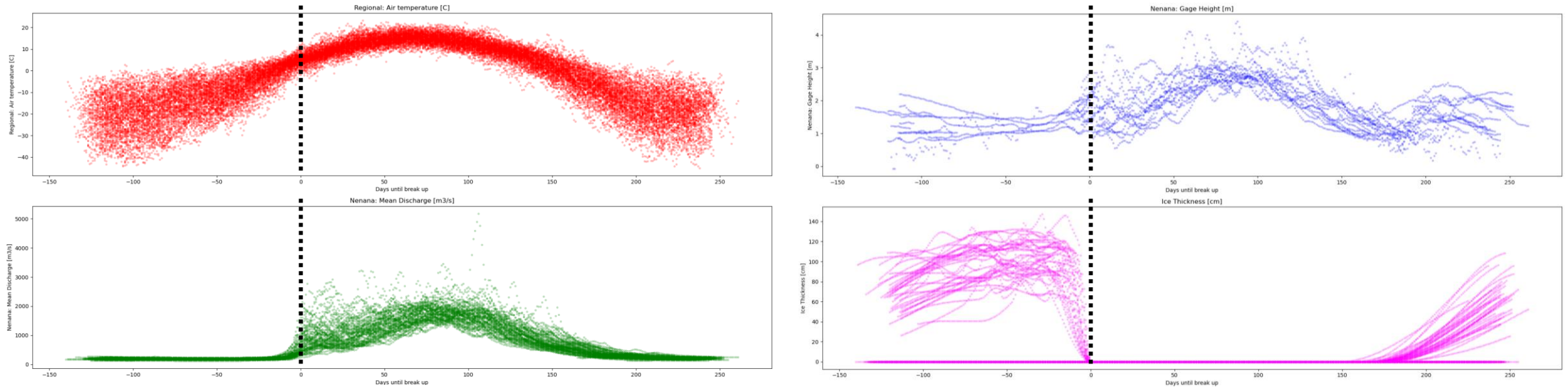
Fig. 8. Illustration of different types of breakup events that may result from different river stage hydrographs.

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



Task 2: Modelling Ice Breakup

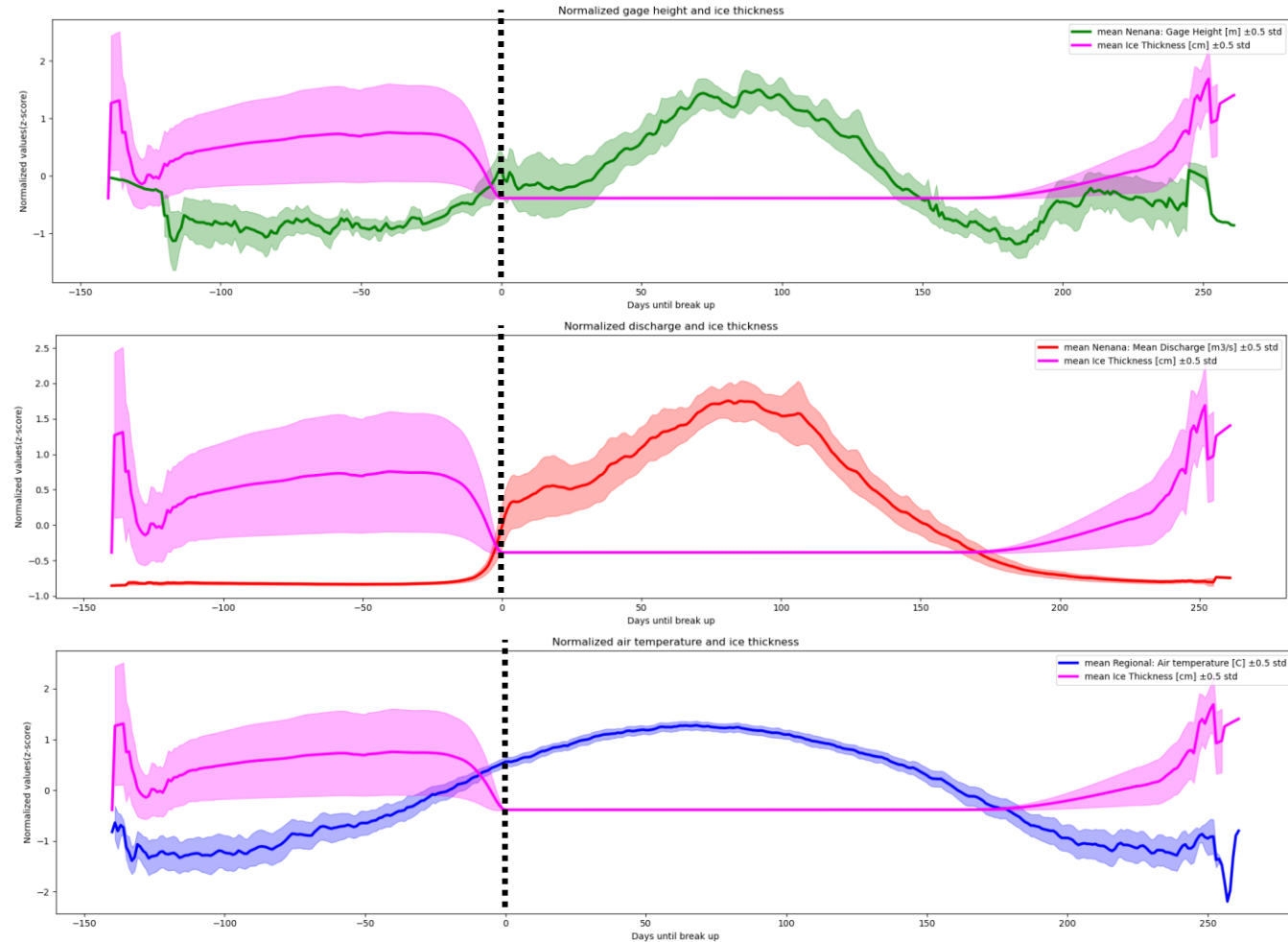
- Historical data, normalized such that actual breakup day is at 0



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 river along that reach.

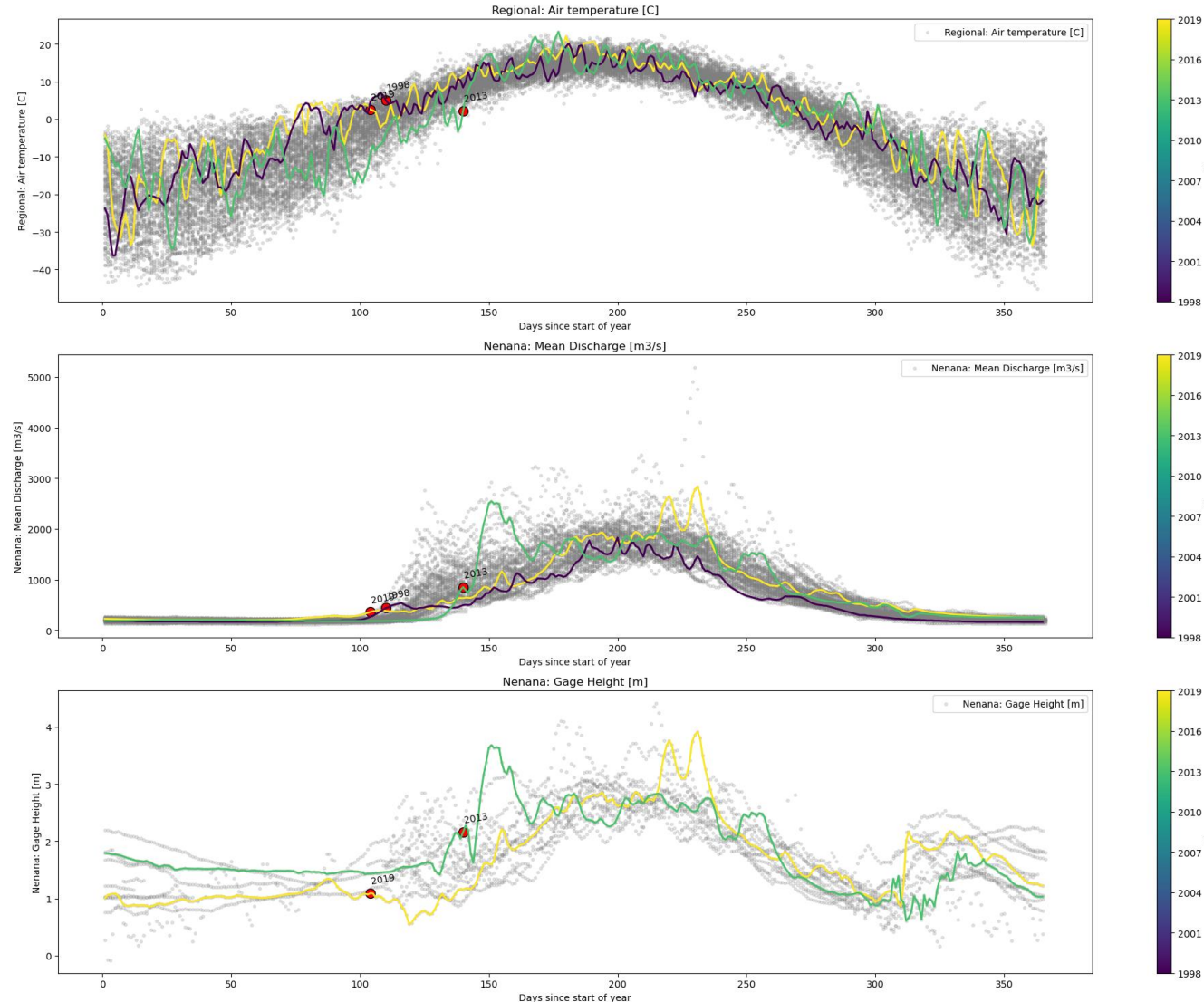
Task 2: Modelling Ice Breakup

- 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



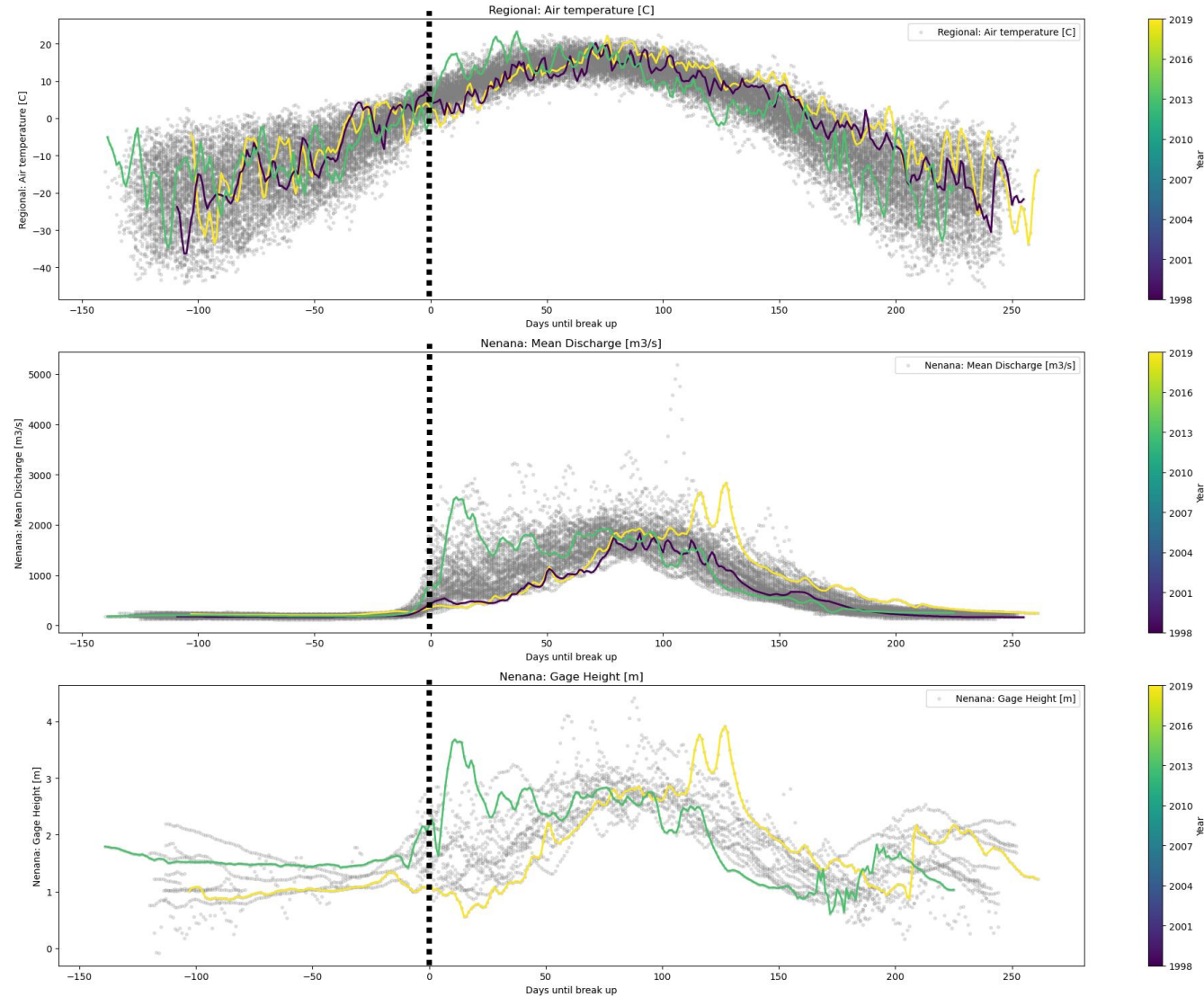
Task 2: Modelling Ice Breakup

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



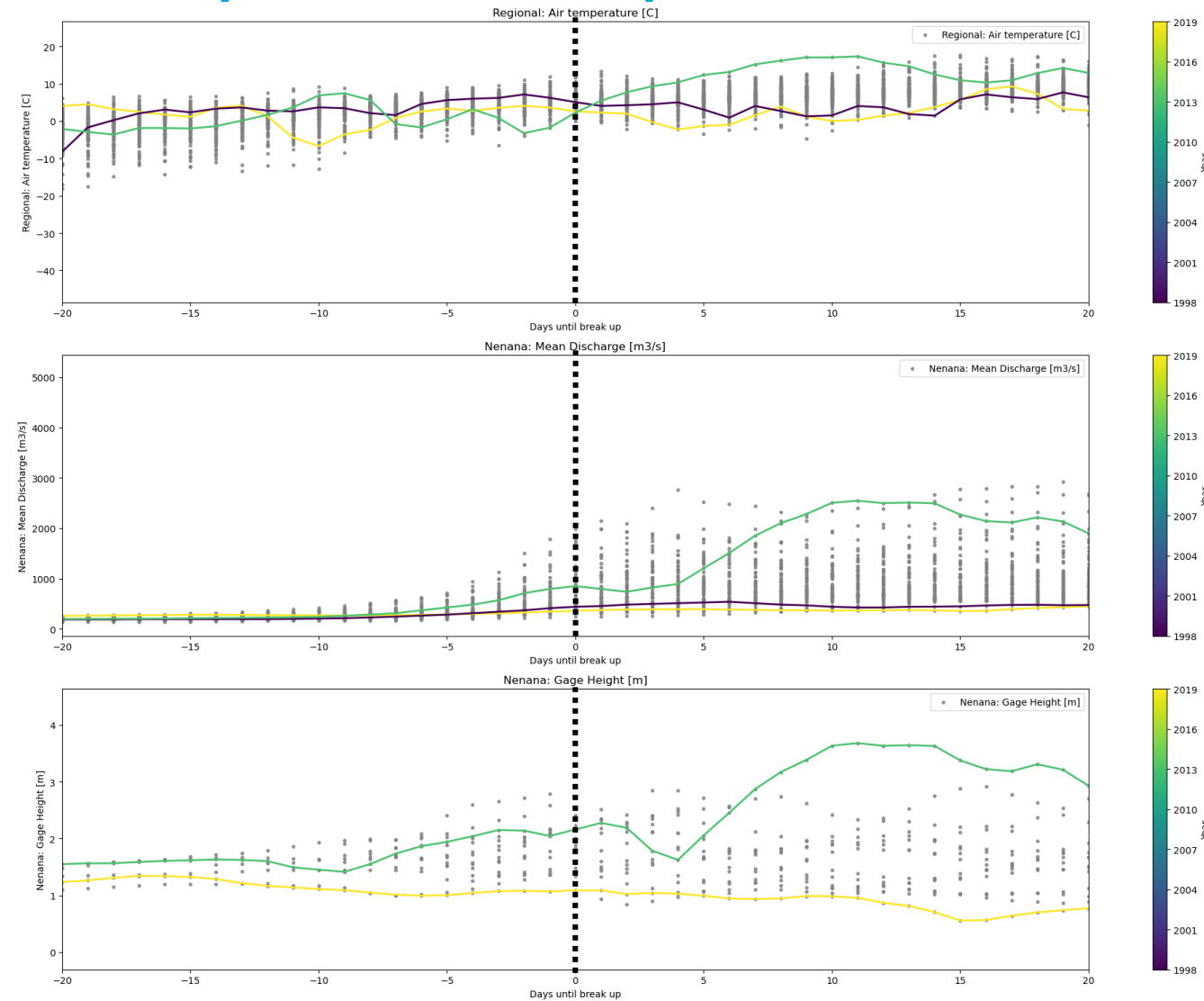
Task 2: Modelling Ice Breakup

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



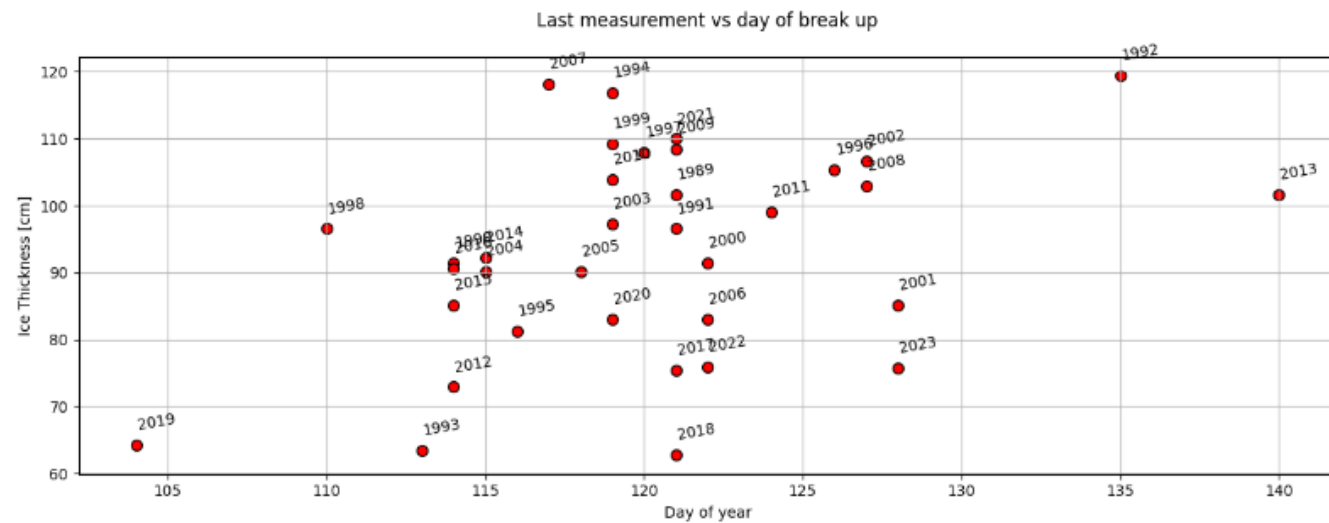
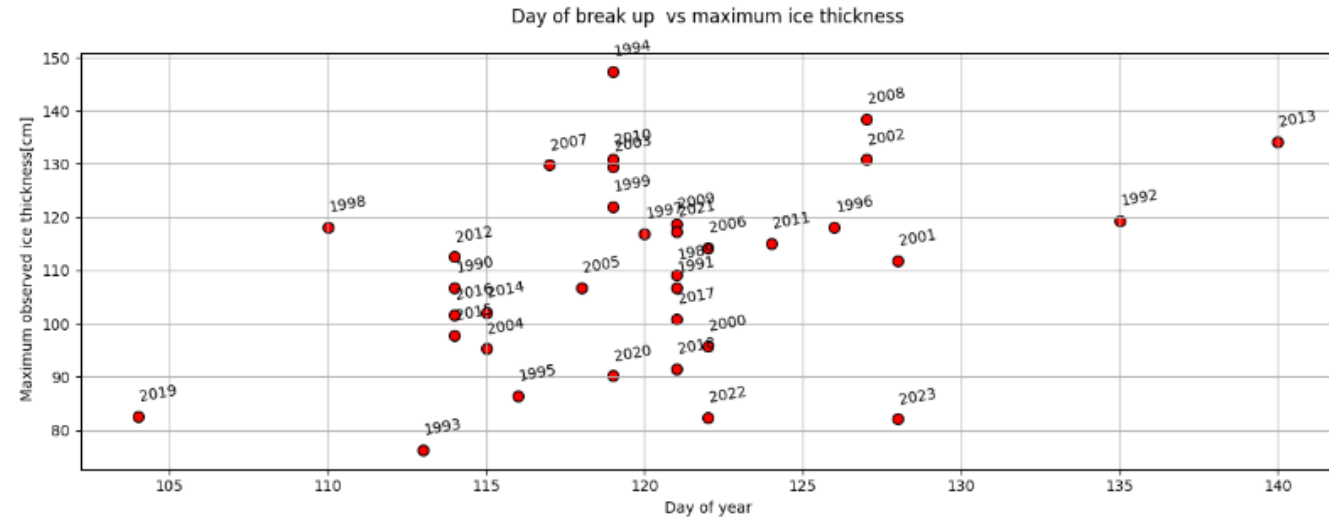
Task 2: Modelling Ice Breakup

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



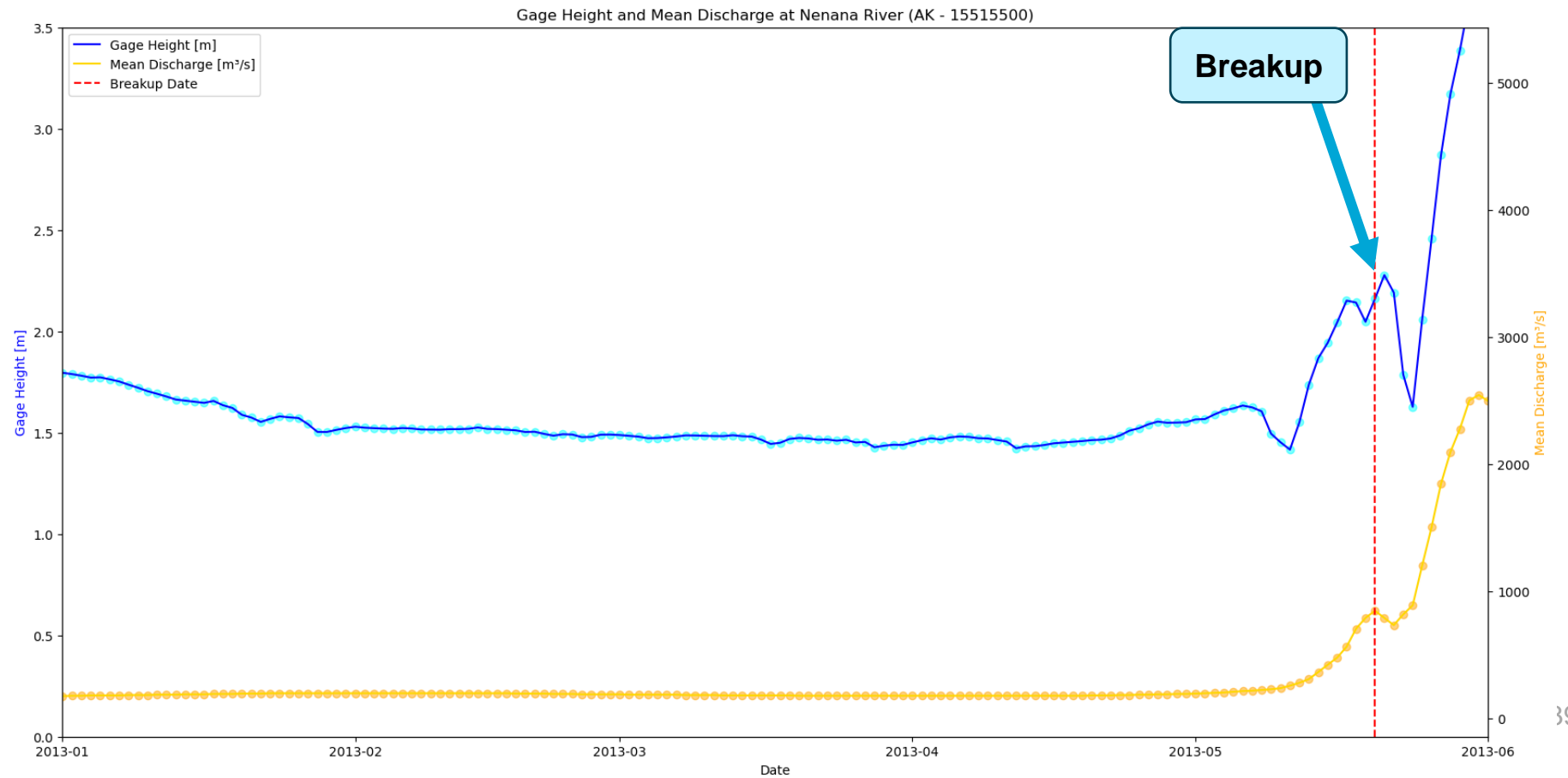
Task 2: Modelling Ice Breakup

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



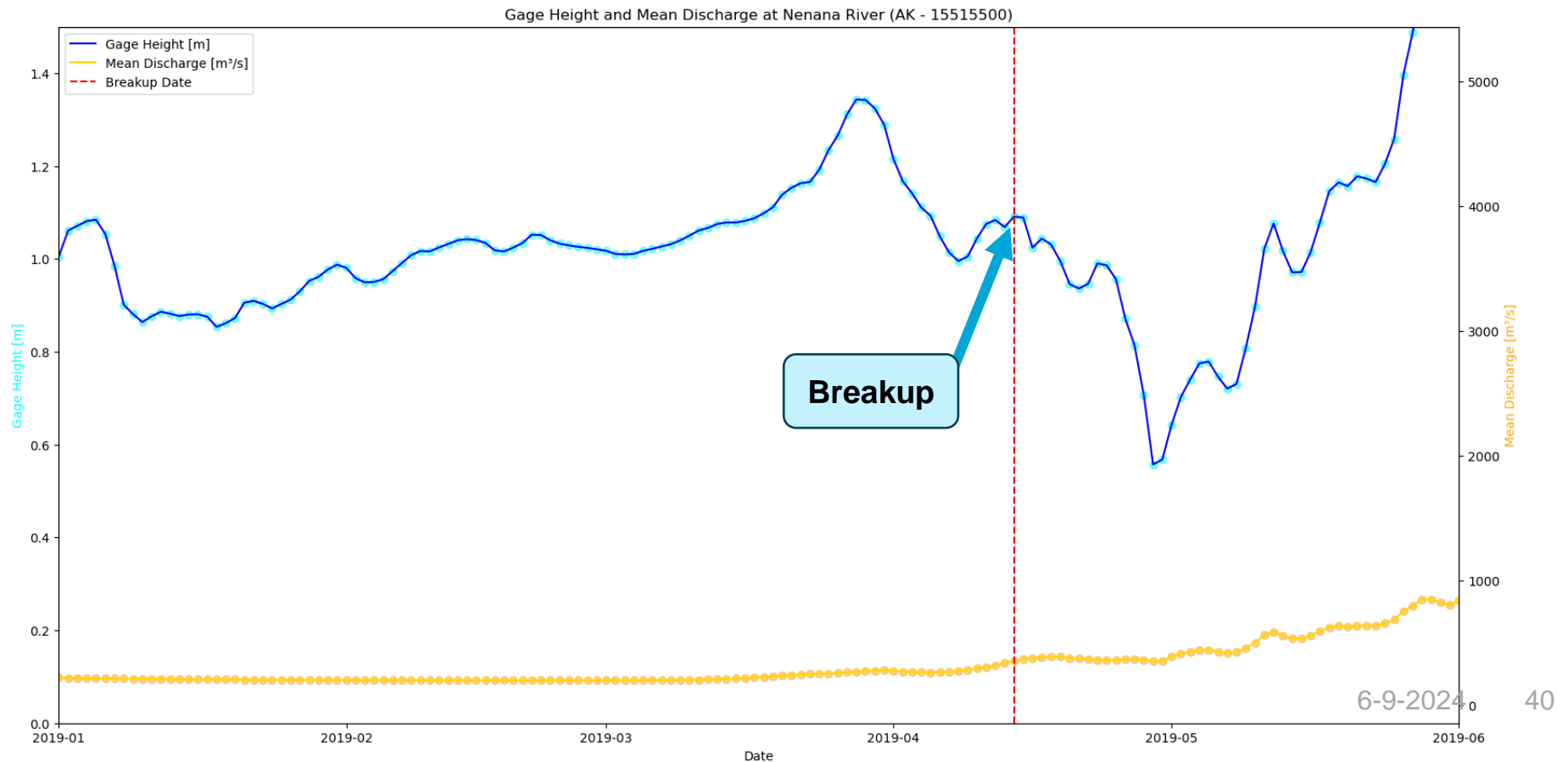
Task 2: Modelling Ice Breakup

- 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



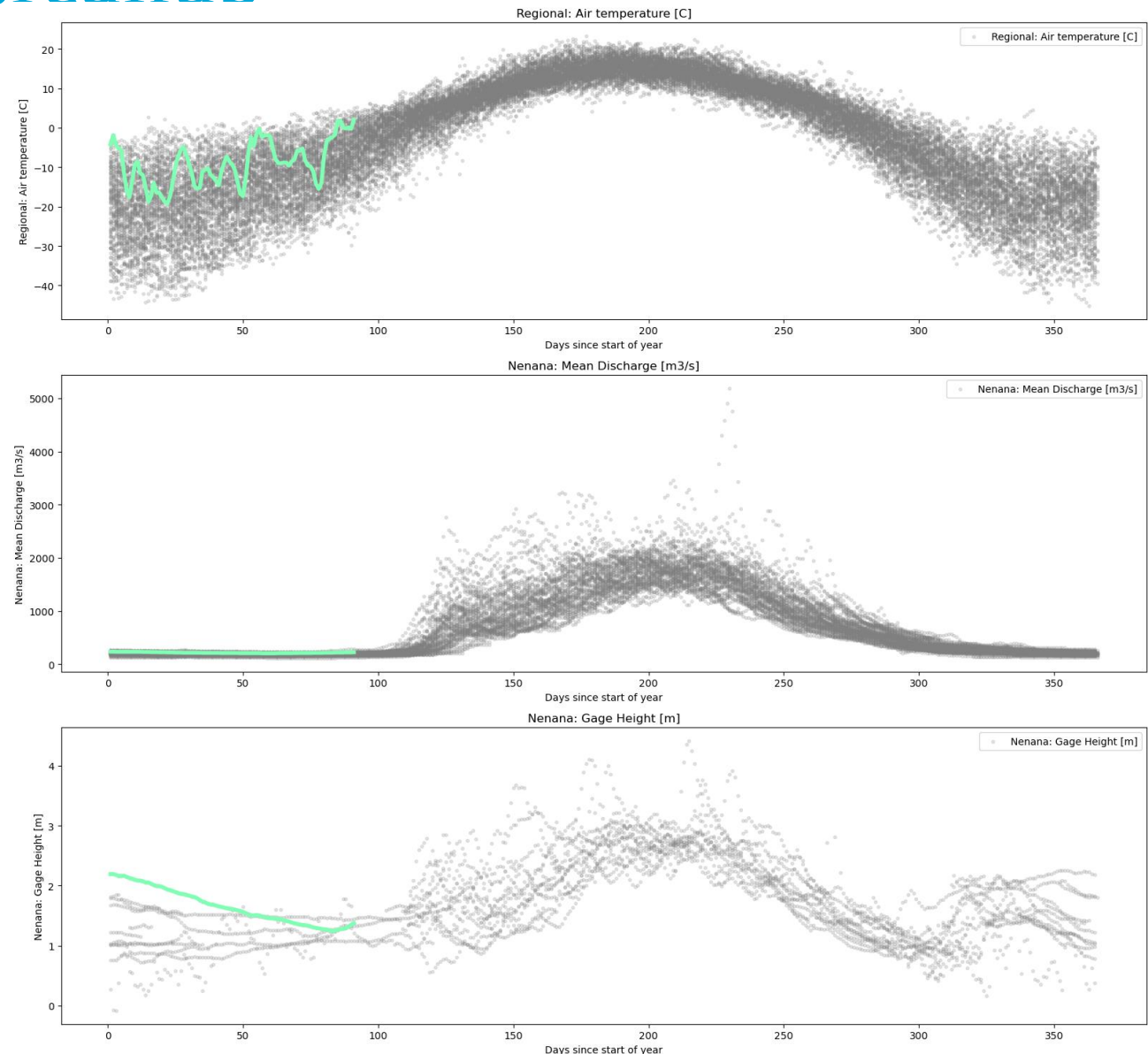
Task 2: Modelling Ice Breakup

- 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



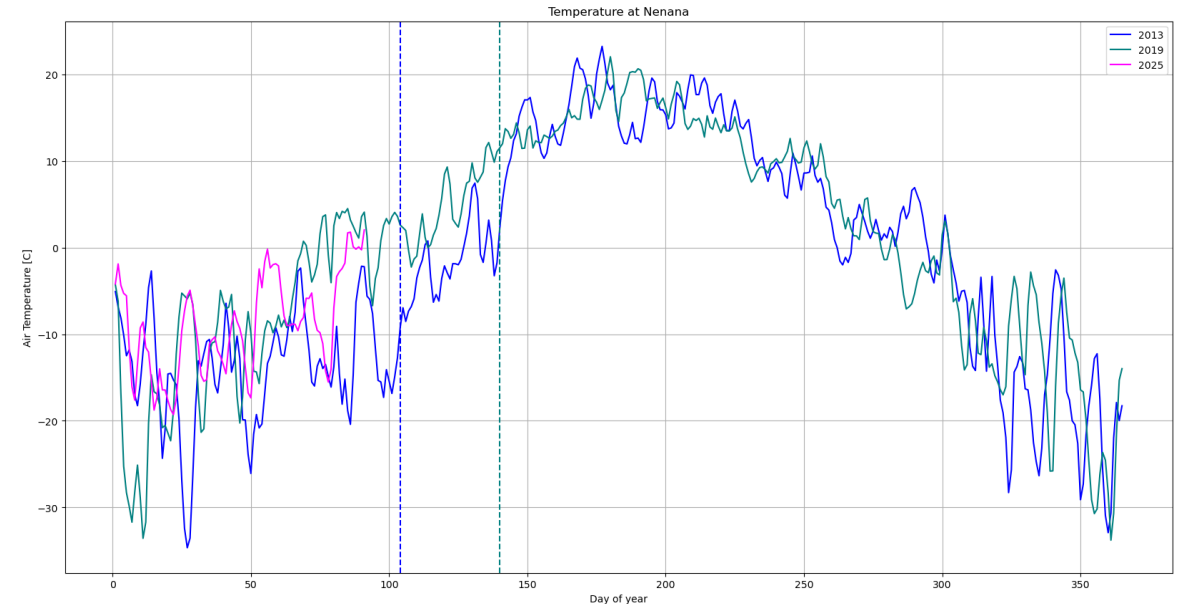
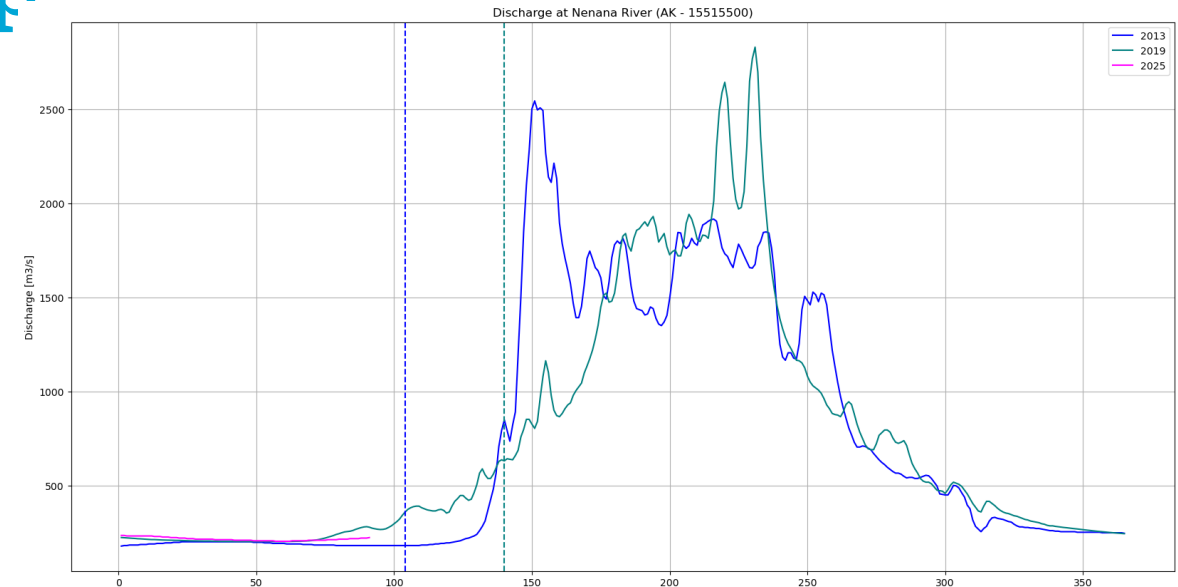
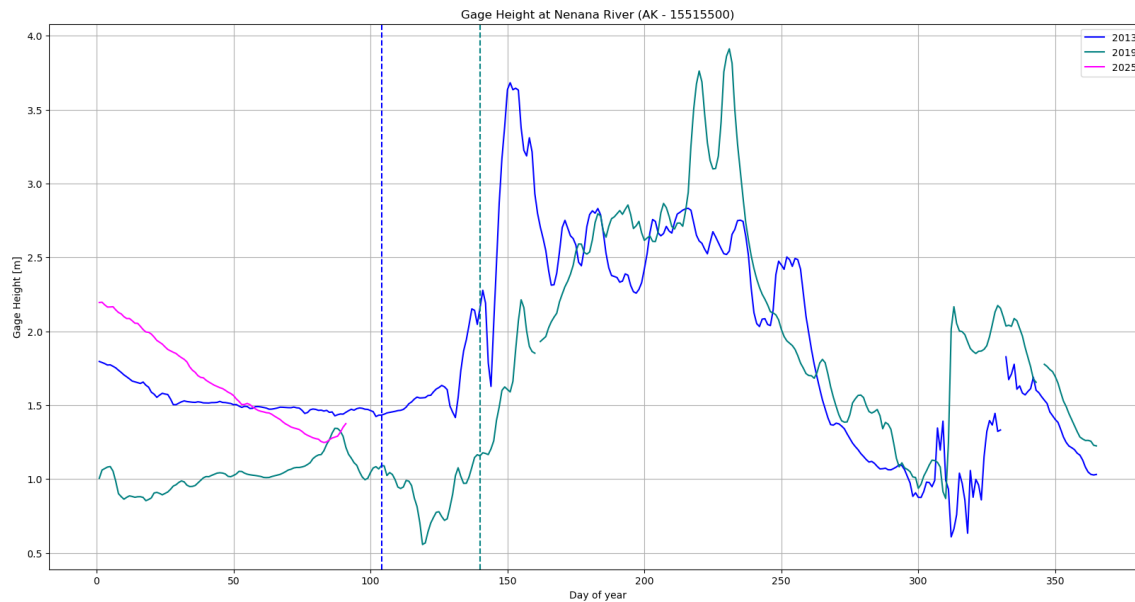
Task 2: Modelling Ice Breakup

- Hypothetical situation, April 1st 2025,



Task 2: Modelling Ice Breakup

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



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

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.

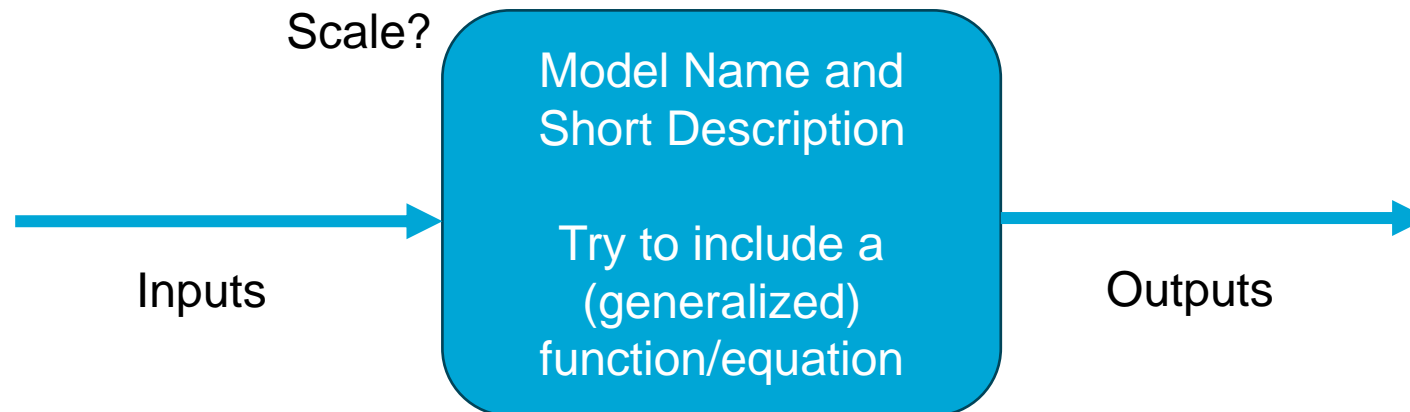
The answer? Recognizing that the hypothetical conditions described for 2025 are similar to 2013 and choosing a day similar to that would be sufficient. Also good to note that 2013 is extremely late in May, so maybe on the earlier side is better – how about.....May 12!?

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?

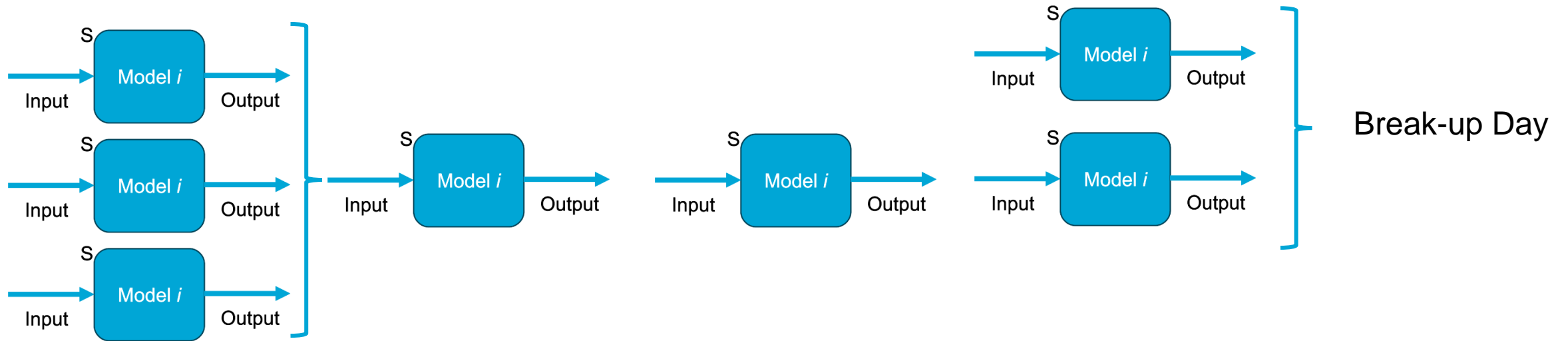
Task 3: Improving the Model

- 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



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.