ASKEM Final Evaluation (February 2025): Climate Independent Questions (IQ)

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These problems are intended to be more like individual textbook problems. Each Set will have 2-3 questions of varying difficulty/complexity. Most problems are intended to be independent of each other, in order to get timing metrics for different pieces of functionality, with minimal interdependencies.

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Section 1: Technical Area 2 Functionality

Set 1.1: Model Configuration and Execution with Unit Tests

Given a model, configure and execute a unit test to reproduce expected results.

General format of inputs, tasks, and outputs

Inputs	Tasks	Outputs
• Physics model in Decapode (Workbench) or other format (for Baseline) • Geometry (may be described in Euclidean coordinates, or a NetCDF file) • Model configuration for unit test (initial conditions, boundary conditions, parameter values, simulation parameters) • Expected unit test output (could be a plot or characteristics of the output, e.g. variable T peaks at time t and location x)	• Load model • Instantiate model with provided configuration • Run unit test	• Fully configured model in executable state • Unit test results (plots) showing they match expected output

(Q1.1.1) *Set 1.1, Question 1: Simple Physics Model*

Inputs:

- (Workbench) Halfar Decapodes model
- (Baseline) Matlab code of Halfar model (*siaflat.m* and *diffusion.m* for function definitions and *runsia.m* to run the model)
- Geometry: Semicircular ice dome with maximum height and radius of 1 km on a square grid of 2 km x 2 km.
- Unit test model configuration: See default configuration in the “Halfar Description” document under the “Halfar Notes” folder in the supplementary materials. Run the simulation for 10,000 years.
- Unit test expected output: Ice height should flatten out and decrease in height over time

Tasks:

- Load the Halfar model. For the baseline modelers, Matlab code has been provided in the supplementary materials. For the workbench modelers, locate the Halfar Decapodes model. More info on the Decapodes model can be found here. For all teams, background materials on the Halfar model can be found in the supplementary materials.
- Execute a unit test with the default parameters indicated in the inputs, for the geometry described.
- Plot the difference in ice structure from the initial condition, at 10 years, 100 years, and 10,000 years into the simulation.

Outputs:

- Fully configured and executable model
- Unit test results: Plots of ice structure

(Q1.1.2) *Set 1.1, Question 2: Medium-Complexity Physics Model*

Inputs:

- (Workbench) Incompressible Navier-Stokes Decapodes model
- (Baseline) Oceananigans Julia package (which contains the incompressible Navier-Stokes model)
- Geometry: see details in tasks below
- Unit test model configuration: See details in tasks below
- Unit test expected output: see Figure 1 below

Tasks:

- Load the Navier-Stokes model. For the baseline modelers, install and use the Oceananigans package (do not count the installation time in your timing for this question). For workbench modelers, locate the incompressible Navier-Stokes Decapodes model. More information on the Decapodes can be found here. Repeat a similar unit test to the one described in the Oceananigans documentation here, but use the following configuration:
    - 128x128 rectangular grid with extent of 2π x 2π
    - Neumann boundary condition (0 flux) for all edges
    - Random initial velocities with 0 mean velocity
    - Scalar diffusivity $\nu = 1e - 4 \left[\frac{unit\ of\ length^2}{unit\ of\ time}\right]$
    - Simulate for 100 timepoints
- Plot vorticity and speed over time (i.e. create an animation).

Outputs:

- Fully configured and executable model
- Unit test results: Plots of vorticity and speed. They should look similar to those in Figure 1.

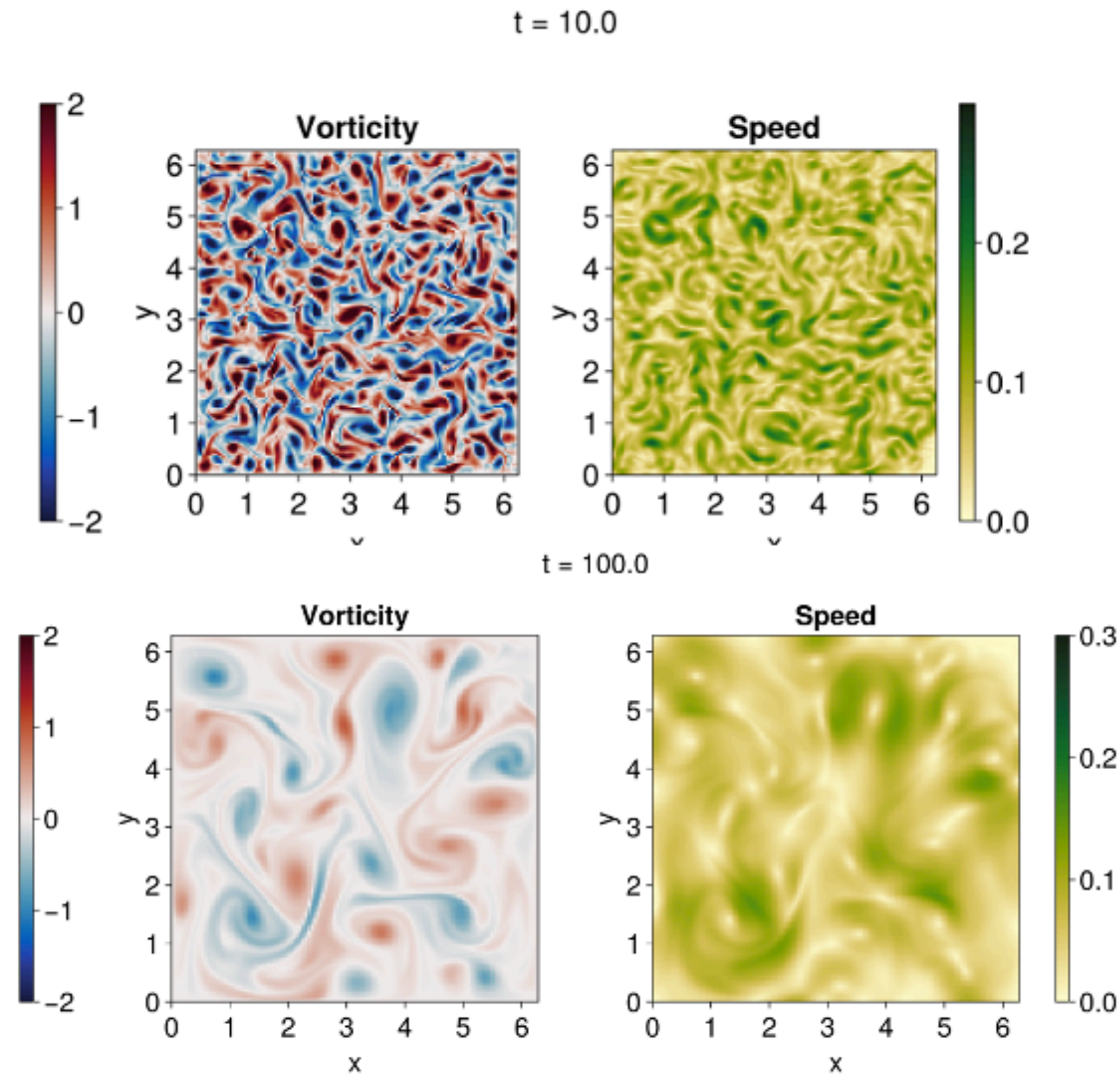

Figure 1. Expected unit test output for Q1.1.2

(Q1.1.3) *Set 1.1, Question 3: High-Complexity Physics Model*

Inputs:

- (Workbench) 3D Incompressible Navier-Stokes Decapodes model
- (Baseline) 3D Laminar Flow model in COMSOL (begin with Model Wizard and select 3D Laminar Flow template)
- Geometry: see details in task description
- Model Configuration: See details in task description

Tasks:

- Load the model. Create geometry and run a unit test with the following configuration:
    - 3D pipe with 25 mm diameter, 300 mm length

- Material in the pipe is water
- Inlet is one side of pipe with a velocity of 0.001 m/s and outlet is on the other side of the pipe
- Boundary condition on the walls is slip
- Temperature of the water is 300 K
- Solve for the steady state solution

Outputs:

- Fully configured and executable model
- Plot of water velocity in the pipe

Set 1.1 Summary Table

Question	Inputs (Baseline)	Inputs (Workbench)	Task	Output
Q1.1.1	2D Halfar Matlab	2D Halfar Decapodes model	Run the unit test for the shape of the ice dome in *X* years	• Fully configured model • Plots of difference in ice structure
Q1.1.2	2D NS Oceananigans model	2D NS Decapodes model	Configure model and run the unit test for vorticity and speed	• Fully configured model • Plots of vorticity and speed over time
Q1.1.3	3D model of Laminar Flow	3D Decapode of Laminar Flow	Set up pipe geometry, configure model, and run unit test	• Fully configured model • Plot of water velocity

Set 1.2: Model Editing

Given a model, perform a variety of modifications.

General format of inputs, tasks, and outputs

Inputs	Tasks	Outputs
• Physics model in Decapode or other format (for Baseline) • Geometry (may be described in Euclidean coordinates, or a NetCDF file) • Instructions on what model edits need to be made (provided as a new equation or terms with new parameter values)	• Load model • Configure and run 'before modification' simulation • Make models edits of varying complexity according to instructions	• Modified model in executable state • Plots comparing 'before modification' and 'post modification'

• Model configuration for 'pre modification' simulation (initial conditions, boundary conditions, parameter values, simulation parameters) • Model configuration for 'post modification' simulation (initial conditions, boundary conditions, parameter values, simulation parameters)	• Configure and run 'post modification' simulation	simulation results • Commentary on whether modified model results make physical sense

(Q1.2.1) *Set 1.2, Question 1: Simple Model Edits - Melting*

Inputs:

- (Baseline) Matlab file for Halfar model (*siaflat.m* and diffusion.m for function definitions and *runsia.m* to run the model)
- (Workbench) Halfar Decapodes model
- Geometry: Semicircular ice dome, see configurations for details
- Pre Modification Configuration:
  - ($R_0, H_0, T_0,$ sim_length) = (60000 m, 2000 m, 300 K, [10 years, 100 years, 10000 years]). Use default values for all other parameters, as found in the "Halfar Description" document
- Post Modification Configuration:
  - ($R_0, H_0, T_0, A_{default},$ sim_length) = (60000 m, 2000 m, 300 K, 1E-16 Pa^{-3}/s, [10 years, 100 years, 10000 years]). Use default values for all other parameters, as found in the "Halfar Description" document
- Expected outputs: Ice height should flatten out and decrease over time more quickly with the melting term

Tasks:

- Load the Halfar model. Background on the Halfar model can be found in in the supplementary materials.
- Before Modifications: simulate the model for 10 years, 100 years, and 10,000 years, and plot ice height and extent over time
- Edits:
  - We want to add a melting term to the Halfar model. Currently, the model conserves ice mass so only diffusion occurs. Change the constant parameter A to a function of temperature: $A(T) = \frac{T}{273\ K} * A_{default}$, where $A_{default}$ =1E-16 [Pa^{-3}/s]
  - As a simple approximation of melting (i.e. making ice not a conserved quantity), add a mask to the output for the locations places where the ice height is below 0.5 m (H<0.5 m), essentially treating those areas as if the ice melted and disappeared.
- Post Modifications: Simulate your modified model with the following configuration: initial radius of 60,000 m, initial height of 2000 m, and initial temperature of 300 K. Use default values for all other parameters, as found in the "Halfar Description" document. Run the simulation for 10 years, 100 years, and 10,000 years.

Outputs:

- Modified model
- Plots comparing simulation outputs with and without melting term
- Commentary on whether edited model results make physical sense

(Q1.2.2) *Set 1.2, Question 2: Medium Complexity Model Edits - Salinity*

Inputs:

- (Baseline) Matlab files for Halfar model (*siaflat.m* and *diffusion.m* for function definitions and *runsia.m* to run the model), *with edits from previous question Q1.2.1*
- (Workbench) Halfar Decapodes model *with edits from previous question Q1.2.1*
- Pre Modification Configuration:
  - ($R_0, H_0, T_0, A_{default}$, sim_length) = (60000 m, 2000 m, 300 K, 1E-16 Pa^{-3}/s, [10 years, 100 years, 10000 years]). Use default values for all other parameters, as found in the "Halfar Description" document
- Post Modification Configuration:
  - ($R_0, H_0, T_0, A_{default}, k, m$, sim_length) = (60000 m, 2000 m, 300 K, 1E-16 Pa^{-3}/s, 1.86 °C/m, 0.5 mol/kg, [10 years, 100 years, 10000 years]). Use default values for all other parameters, as found in found in the "Halfar Description" document
- Expected outputs: Rate of ice height flattening and decrease is slower than the prev. question (Q1.2.1), but faster than the baseline version with no melting.

Tasks:

- Before Modifications: simulate input model (which should include melting) for 10 years, 100 years, and 10,000 years, and plot ice height and extent over time
- Edits:
  - In addition to the melting term from the previous question, we want to add a salinity component. Salty ice has a lower melting point than pure ice. To represent salinity, add an additional factor ΔT to the A function as follows:
  $$\Delta T = k \cdot m$$
  $$A(T) = \frac{T}{(273\,K - \Delta T)} * A_{default}$$
  Where k is the freezing point depression constant (1.86°C/m for water) and m is the molality of the solution (0.5 mol/kg)
- Post Modifications: Simulate your modified model and plot the difference in ice structure from both the baseline version for the model (no melting term), and the version from Q1.2.1 with the melting term but no salinity. Plot the difference at 10 years, 100 years, and 10,000 years.

Outputs:

- Modified model
- Plots comparing output with and without melting and salinity terms
- Commentary on whether model results make physical sense

(Q1.2.3) *Set 1.2, Question 3: Complex Model Modifications - Seasonality*

Inputs:

- (Baseline) Matlab files for Halfar model (*siaflat.m* and *diffusion.m* for function definitions and *runsia.m* to run the model), *with edits from previous question Q1.2.2*
- (Workbench) Halfar Decapodes model *with edits from previous question Q1.2.2*
- Pre Modification Configuration: use the 'Post Modification' configuration from the previous question Q1.2.1
- Post Modification Configuration:
  - ($R_0, H_0, T_0, A_{default}, k, m$, T_0 , T_{osc}, sim_length) = (60000 m, 2000 m, 300 K, 1E-16 Pa^{-3}/s, 1.86 °C/m, 0.5 mol/kg, 0° C, 50° C, [10 years, 100 years, 10000 years]). Use default values for all other parameters, as found in the "Halfar Description" document.
- Expected outputs: The rate of ice height flattening and decrease will no longer be constant but seasonal over each year. However, ice height will always be decreasing and never increase due to there being no mechanism for ice deposition in the Halfar model.

Tasks:

- Before Modifications: simulate input model (which should include melting and salinity) for 10 years, 100 years, and 10,000 years, and plot ice height and extent over time
- Edits:
  - We want to add a seasonality component. Add a seasonal insolation cycle to temperature such that $T(t) = T_0 + T_{osc} \cdot \sin\left(\frac{2\pi}{year} \cdot t\right)$ where T_{osc} is the amount of temperature oscillation over a year. Set this to 50° C. T_0 should be set to 0° C. Add $T(t)$ as a scale factor to the function A such that $A(T) = \frac{T(t)}{(273\,K - \Delta T)} * A_{default}$ and $\Delta T = k \cdot m$.
- Post Modifications: Simulate your modified model and plot the difference in ice structure from the input model (which has melting and salinity but no seasonality), at 10 years, 100 years, and 10,000 years.

Outputs:

- Modified model
- Plots comparing output with and without seasonality
- Commentary on whether model results make physical sense

Set 1.2 Summary Table

Question	Inputs (Baseline)	Inputs (Workbench)	Task	Output
Q1.2.1	2D Halfar Matlab model	2D Halfar Decapodes model	• Add melting term • Simulate edited model and plot differences with and without melting term at 10 years, 100 years, and 10,000 years	• 2D Halfar model with melting • Difference plots
Q1.2.2	2D Halfar Matlab model with melting term	2D Halfar Decapodes model with melting term	• Add salinity term • Simulate edited model and plot differences with and without salinity term at 10 years, 100 years, and 10,000 years	• 2D Halfar model with melting and salinity • Difference plots
Q1.2.3	2D Halfar Matlab model with melting and salinity	2D Halfar Decapodes model with melting and salinity	• Add seasonality term • Simulate edited model and plot differences with and without seasonality term at 10 years, 100 years, and 10,000 years	• 2D Halfar model with melting, salinity, and seasonality • Difference plots

Set 1.3 Multiphysics Model Composition

Couple two more component models representing different physical processes.

General format of inputs, tasks, and outputs

Inputs	Tasks	Outputs
• List of 2 or more component physics models • Instructions on how to do model coupling (e.g. which variables in component models are meant to interact, boundary conditions for individual model couplings, etc.) • Model configuration for coupled model simulation (geometry, initial conditions, boundary conditions, parameter values, simulation parameters)	• Load component models • Do model coupling according to instructions • Instantiate and run coupled model simulation with given model configuration	• Fully composed model in executable state • Coupled model simulation outputs (plots) • Commentary on whether coupled model results make physical sense

(Q1.3.1) *Set 1.3, Question 1: Simple Complexity Model Composition*

<u>*Inputs*</u>:

- Models to couple: (Navier Stokes with Laminar Flow conditions, Heat Transfer)
- Coupled Model Configuration:
  - Geometry: **2D** pipe with 25 mm diameter, 300 mm length
  - Material: The fluid is water at a temperature of 300 K
  - Boundary Conditions: **Use a no slip boundary condition** on the walls and use one end of the pipe as the inlet and one as the outlet. The water inflow velocity is 0.05 m/s. The heat flux from the top wall of the rectangular pipe is 1000 W/m^2.

<u>*Tasks:*</u>

- Load up the models and apply each to the described geometry. Laminar flow and heat transfer both apply to the water. Fluid density ρ in the Navier Stokes laminar flow model, should depend on temperature T from the heat transfer model.
- Configure coupled model as described in input, and simulate to find steady state solution. Plot velocity and surface temperature of the fluid, at steady state.

<u>*Outputs*</u>:

- Fully composed model in executable state
- Fluid velocity and surface temperature plots
- Commentary on whether model results make physical sense

(Q1.3.2) *Set 1.3, Question 2: Medium Complexity Model Composition*

<u>*Inputs*</u>:

- Models to couple: (Navier Stokes with Laminar Flow conditions, Heat Transfer)
- Coupled Model Configuration:
  - Geometry: **3D** pipe with 25 mm diameter, 300 mm length
  - Material: The fluid is water at a temperature of 300 K
  - Boundary Conditions: **Use a no slip boundary condition** on the walls and use one end of the pipe as the inlet and one as the outlet. The water inflow velocity is 0.05 m/s. The heat flux at the top wall of the rectangular pipe is 1000 W/m^2. This size of this section will depend on how you set up your geometry and mesh, but this should be the top surface of the pipe if it lays horizontally.

<u>*Tasks:*</u>

- Load up the models and apply each to the described geometry. Laminar flow and heat transfer both apply to the water. Fluid density ρ in the Navier Stokes laminar flow model, should depend on temperature T from the heat transfer model.
- Configure coupled model as described in input, and simulate to find steady state solution. Plot velocity and surface temperature of the fluid, at steady state.

<u>*Outputs*</u>:

- Fully composed model in executable state
- Fluid velocity and surface temperature plots
- Commentary on whether model results make physical sense

(Q1.3.3) *Set 1.3, Question 3: Challenging Model Composition*

<u>*Inputs*</u>:

- Models to couple: (Laminar Flow, Heat Transfer)
- Coupled Model Configuration: Model Laminar Flow through a pipe of 25 mm diameter, 300 mm length **in 3D**. The fluid is water at a temperature of 300 K. **Use the slip boundary condition** on the walls and use one end of the pipe as the inlet and one as the outlet. The heat flux from the top wall of the rectangular pipe is 1000 W/m^2. The inflow velocity is 0.05 m/s.

<u>*Tasks:*</u>

- Load up the models and apply each to the described geometry. Laminar flow and heat transfer both apply to the water. Fluid density ρ in the Navier Stokes laminar flow model, should depend on temperature T from the heat transfer model.
- Configure coupled model as described in input, and simulate to find steady state solution. Plot velocity and surface temperature of the fluid, at steady state.

<u>*Outputs*</u>:

- Fully composed model in executable state
- Fluid velocity and surface temperature plots
- Commentary on whether model results make physical sense

Set 1.3 Summary Table

Question	Inputs (Baseline)	Inputs (Workbench)	Task	Output
Q1.3.1	Laminar Flow in COMSOL (2D), Heat Transfer in COMSOL (2D)	Navier Stokes with Laminar Flow conditions Decapodes model (2D), Heat Transfer Decapodes model (2D)	• Load up and couple these two models together. • Temperature T from the heat transfer model should affect fluid density ρ in the Navier Stokes laminar flow model. • Use a 2D pipe and no slip boundary conditions.	• Fully composed model • Fluid velocity and surface temperature plots • Commentary on sensibility of results
Q1.3.2	Laminar Flow in COMSOL (3D), Heat Transfer in COMSOL (3D)	Navier Stokes with Laminar Flow conditions Decapodes model (3D), Heat Transfer Decapodes model (3D)	• Load up and couple these two models together. • Temperature T from the heat transfer model should affect fluid density ρ in the Navier	

			Stokes laminar flow model. • Use a 3D rectangular pipe and no slip boundary conditions.	
Q1.3.3	Laminar Flow in COMSOL (3D), Heat Transfer in COMSOL (3D)	Laminar Flow/Navier Stokes Decapode (3D), Heat Transfer Decapode	Couple these two models together using T from the heat transfer model to affect ρ in the NS Laminar Flow model. Use slip on the boundaries.	

Section 2: Technical Area 3 Functionality

Set 2.1: Forecasting or Forward Simulation (Physics Models)

Create forecasts/simulations with physics models.

General format of inputs, tasks, and outputs

Inputs	Tasks	Outputs
• Physics model • Model configuration for forecast/simulation (geometry, initial conditions, boundary conditions, parameter values, simulation parameters)	• Load model • Instantiate model with provided configuration • Perform forecast/simulation	• Simulation output plots

(Q2.1.1) *Set 2.1, Question 1: Simple Forecasting Task*

Inputs:

- (Workbench) Halfar Decapodes model
- (Baseline) Matlab code of Halfar model (*siaflat.m* and *diffusion.m* for function definitions and *roughice.m* to run the model with arbitrary ice topography)
- Model configuration:
    - Geometry: Assume an ice dome with radius equal to its initial height, and it sits on a flat surface of infinite size. Use initial dome radius of 2,500 m on a gridded mesh size of 10,000 m x 10,000 m.
    - Forecast what the ice dome will look like in 50 years in the future.
    - For parameter values, use the default values indicated in the "Halfar Description" document in the supplementary materials

Tasks:

- Forecast according to the provided configuration and plot the evolution of the ice dome.

Outputs:

- Forecast plot

(Q2.1.2) *Set 2.1, Question 2: Medium-Complexity Forecasting Task*

Inputs:

- (Workbench) Halfar Decapodes model
- (Baseline) Matlab code of Halfar model (*siaflat.m* and *diffusion.m* for function definitions and *roughice.m* to run the model with arbitrary ice topography)
- Model configuration:
    - Geometry: Apply the Halfar to the Grigoriev ice cap (data), and use the data to set initial conditions for radius and ice thickness.

- Set the ice cap on a sphere with a radius of 50 km; the sphere is empty except for the ice cap. The sphere is not big enough to make the approximation that the ice cap is on a flat surface.
- Forecast what the ice dome will look like in 50 years in the future.
- For parameter values, use the default values indicated in the "Halfar Description" document in the supplementary materials.

Tasks:

- Forecast what the Grigoriev Ice cap (data) will look like in 50 years. Plot the evolution of the ice cap. This dome is on a sphere with a radius of 50 km, that is empty save for the ice cap. The sphere is not big enough to make the approximation that the ice cap is on a flat surface.

Outputs:

- Plot of Grigoriev ice cap forecast

(Q2.1.3) *Set 2.1, Question 3: Challenging Forecasting Task*

Inputs:

- (Workbench) Halfar Decapodes model
- (Baseline) Matlab code of Halfar model (*siaflat.m* and *diffusion.m* for function definitions and *roughice.m* to run the model with arbitrary ice topography)
- Model configuration:
    - Geometry: Grigoriev ice cap (data), which is on a cube with side length of 5km, and empty except for the ice cap. Place the Grigoriev ice cap in the center of one of the cube faces.
    - Forecast what the ice dome will look like in 50 years in the future.
    - For parameter values, use the default values indicated in the "Halfar Description" document in the supplementary materials

Tasks:

- Forecast what the Grigoriev ice cap (data) will look like in 50 years. Plot the evolution of the ice cap.

Outputs:

- Plot of Grigoriev ice cap forecast

Set 2.1 Summary Table

Question	Inputs (Baseline)	Inputs (Workbench)	Task	Output
Q2.1.1	Halfar Matlab code and provided input configuration	Halfar Decapodes model, provided input configuration	Forecast the evolution of the ice dome on a rectangular grid, 50 years in the future	Plot of the forecast
Q2.1.2	Halfar Matlab code, provided input	Halfar Decapodes model, provided input	Forecast the evolution of the Grigoriev ice cap on	Plot of the forecast

	configuration, Grigoriev ice Cap data	configuration, Grigoriev ice Cap data	a sphere, 50 years in the future	
Q2.1.3	Halfar Matlab code, provided input configuration, Grigoriev ice Cap data	Halfar Decapodes model, provided input configuration, Grigoriev ice Cap data	Forecast the evolution of the Grigoriev ice cap on a cube, 50 years in the future	Plot of the forecast

Set 2.2: Sensitivity Analysis

Determine how one or more parameters influence one or more variables in a model.

General format of inputs, tasks, and outputs

Inputs	Tasks	Outputs
• Physics model fully configured with initial conditions, boundary conditions, parameter values, simulation parameters • List of parameters of interest in sensitivity analysis, with valid ranges or probability distributions	• Load model • Perform sensitivity analysis - determine how one or more parameters influence one or more output variables	• Plots of sensitivity results with units for each parameter and variable, with some indication of how a change in model parameter value(s), results in an amount of change in output variable(s) • (If relevant) List of model parameters that have greatest impact on output variable(s), in order of impact

(Q2.2.1) *Set 2.2, Question 1: Simple Sensitivity Analysis*

Inputs:

- (Workbench) Halfar Decapodes model
- (Baseline) Matlab code of Halfar model (*siaflat.m* and *diffusion.m* for function definitions and *runsia.m* to run the model)
- Parameter of interest: *A*

Tasks:

- Determine the sensitivity of the model to parameter *A*. Keep all other parameter values at their defaults provided in the "Halfar Description" document in the supplementary materials.
- Plot sensitivity results with units for each parameter and variable, with some indication of how a change in parameter *A* values, results in an amount of change in ice thickness

Outputs:

- Sensitivity analysis results

(Q2.2.2) *Set 2.2, Question 2: Medium Complexity Sensitivity Analysis*

Inputs:

- (Workbench) Halfar Decapodes model
- (Baseline) Matlab code of Halfar model (*siaflat.m* and *diffusion.m* for function definitions and *runsia.m* to run the model)
- Parameters of interest: A and n

Tasks:

- Determine the sensitivity of the model to parameters A and n. Keep all other parameter values at their defaults provided in the "Halfar Description" document in the supplementary materials.
- Plot sensitivity results with units for each parameter and variable, with some indication of how a change in parameter A and n values, results in an amount of change in ice thickness

Outputs:

- Sensitivity analysis results

(Q2.2.3) *Set 2.2, Question 3: Challenging Sensitivity Analysis*

Inputs:

- (Workbench) Halfar Decapodes model
- (Baseline) Matlab code of Halfar model (*siaflat.m* and *diffusion.m* for function definitions and *runsia.m* to run the model)
- Parameters of interest: A, r, and n

Tasks:

- Determine the sensitivity of the model to parameters A, r, and n using a Bayesian analysis where you analyze how the choice of priors (defaults in the table below) affect the final parameter posterior distributions. Keep all other parameter values at their defaults provided in the "Halfar Description" document in the supplementary materials.
- Plot sensitivity results with units for each parameter and variable, with some indication of how a change in parameter A, r, and n, results in an amount of change in model output
- For reference material on Bayesian sensitivity analysis, see the supplementary materials folder.

Outputs:

- Sensitivity analysis results

Table 1. Parameter prior distributions, for Q2.2.3

Parameter	Distribution Type	Distribution Parameters
A	Gaussian	$\mu = 1 x 10^{-16}, \sigma = 2.5x 10^{-17}$ [Pa^{-3}/s]
r	Gaussian	$\mu = 910, \sigma = 10$ [kg/m^3]
n	Uniform	Range: 2.75-3.25 [unitless]

Set 2.2 Summary Table

Question	Inputs (Baseline)	Inputs (Workbench)	Task	Output
Q2.2.1	Halfar Matlab code, parameters of interest	Halfar Decapodes model, parameters of interest	Determine the sensitivity of simulation outputs with respect to 1 parameter.	Sensitivity results plot with units
Q2.2.2	Halfar Matlab code, parameters of interest	Halfar Decapodes model, parameters of interest	Determine the sensitivity of simulation outputs with respect to 2 parameters.	Sensitivity results plot with units
Q2.2.3	Halfar Matlab code, priors for parameters of interest	Halfar Decapodes model, priors for parameters of interest	Determine the sensitivity of simulation outputs with respect to 3 parameters with a Bayesian analysis.	Sensitivity results plot with units

Set 2.3: Calibration w/ Data

Calibrate one or more parameters for a provided model based on data.

General format of inputs, tasks, and outputs

Inputs	Tasks	Outputs
• Physics model • Dataset and indication of which features to use for calibration, with at least two time points • Model configuration, including initial conditions, boundary conditions, simulation parameters, and all model parameter values other than those to be calibrated. Known parameters that won't be calibrated, may still have a range of values. • List of parameters to calibrate, possibly with prior distributions	• Load model and data • Perform calibration	• For each calibrated parameter, provide mean parameter value(s) pre- and post-calibration, prior and posterior distributions, and variance pre- and post-calibration • Some measure of goodness-of-fit for the calibrated parameters, such as mean absolute error (MAE) between projected value for one or more state variables, and observational data from calibration dataset

(Q2.3.1) *Set 2.3, Question 1: Simple Calibration*

Inputs:

- (Workbench) Halfar Decapodes model (2D)
- (Baseline) Matlab code of Halfar model (*siaflat.m* and *diffusion.m* for function definitions and *runsia.m* to run the model)
- Dataset for calibration: ice dome data in 'halfar_level1.csv', at t = 100 years
- Model configuration: Use default values as provided in the "Halfar Description" document in the supplementary materials. This configuration includes the initial guesses for the parameters to be calibrated. Initial radius and central thickness of the ice dome at t = 0 are $R_0 = 60e3\ m, H_0 = 2000\ m$
- Parameters to calibrate: *A*

Tasks:

- Load model and data
- Apply the input model configuration
- Calibrate the parameter *A* in the model with the calibration dataset
- Calculate a measure of goodness-of-fit for *A* (e.g. mean absolute error (MAE) between model output and data from calibration dataset)

Outputs:

- What is the calibrated value for *A*? Provide mean parameter value pre- and post-calibration, prior and posterior distributions, and variance pre- and post-calibration
- Provide measures of goodness-of-fit for the calibrated value of *A*

(Q2.3.2) *Set 2.3, Question 2: Medium Complexity Calibration*

Inputs:

- (Workbench) Halfar Decapodes model (2D)
- (Baseline) Matlab code of Halfar model (*siaflat.m* and *diffusion.m* for function definitions and *runsia.m* to run the model)
- Dataset for calibration: ice dome data in 'halfar_level2.csv', at t = 100 years
- Model configuration: Use default values as provided in the "Halfar Description" document in the supplementary materials. This configuration includes the initial guesses for the parameters to be calibrated. Initial radius and central thickness of the ice dome at t = 0 are $R_0 = 60e3\ m, H_0 = 2000\ m$
- Parameters to calibrate: *A* and *n*

Tasks:

- Load model and data
- Apply the input model configuration
- Calibrate the parameters *A* and *n* with the calibration dataset
- Calculate some measure of goodness-of-fit for *A* and *n* (e.g. mean absolute error (MAE) between model output and data from calibration dataset)

Outputs:

- What are the calibrated values for parameters *A* and *n*? Provide mean parameter value pre- and post-calibration, prior and posterior distributions, and variance pre- and post-calibration
- Provide measures of goodness-of-fit for the calibrated values of *A* and *n*

(Q2.3.3) *Set 2.3, Question 3: Challenging Calibration*

Inputs:

- (Workbench) Halfar Decapodes model (2D)
- (Baseline) Matlab code of Halfar model (*siaflat.m* and *diffusion.m* for function definitions and *runsia.m* to run the model)
- Dataset for calibration: ice dome data in 'halfar_level3.csv', at t = 100 years
- Model configuration: Use default values as provided in the "Halfar Description" document in the supplementary materials. Initial radius and central thickness of the ice dome at t = 0 are $R_0 = 60e3\ m, H_0 = 2000\ m$
- Parameters to calibrate: *A,* r*,* and *n*. Prior distributions for these parameters are provided in Table 2.

Table 2. Prior distributions for parameters to be calibrated, Q2.3.3

Parameter	**Distribution Type**	**Distribution Parameters**
A	Gaussian	$\mu = 1\ x\ 10^{-16}$, $\sigma = 2.5x\ 10^{-17}$
r	Gaussian	$\mu = 910$, $\sigma = 10$
n	Uniform	Range: 2.75-3.25

Tasks:

- Load model and data
- Apply the input model configuration
- Calibrate the parameters *A,* r*,* and *n* with the calibration dataset, using a Bayesian approach.
- Calculate some measure of goodness-of-fit for *A,* r*,* and *n* (e.g. mean absolute error (MAE) between model output and data from calibration dataset)

Outputs:

- What are the calibrated values for parameters *A,* r*,* and *n*? Provide mean parameter value pre- and post-calibration, plot prior and posterior distributions, and provide variance pre- and post-calibration.
- Provide measures of goodness-of-fit for the calibrated values of *A,* r*,* and *n*

Set 2.3 Summary Table

Question	Inputs (Baseline)	Inputs (Workbench)	Task	Output
Q2.3.1	• Halfar Matlab code • 'halfar_level1.csv' • Default configuration • Parameters to be calibrated - *A*	• Halfar Decapodes model • 'halfar_level1.csv' • Default configuration • Parameters to be calibrated - *A*	Calibration for 1 parameter, for 2D version of model	• Calibrated value for parameter *A* • Mean parameter value pre- and post-calibration, • Prior and posterior distributions • Variance pre- and post-calibration • Goodness of fit measure
Q2	• Halfar Matlab code • 'halfar_level2.csv' • Default configuration • Parameters to be calibrated – *A* and *n*	• Halfar Decapodes model • 'halfar_level2.csv' • Default configuration • Parameters to be calibrated – *A* and *n*	Calibration for 2 parameters, for 2D version of model	• Calibrated values for parameters *A* and *n* • Mean parameter value pre- and post-calibration • Prior and posterior distributions • Variance pre- and post-calibration • Goodness of fit measure
Q3	• Halfar Matlab code • 'halfar_level3.csv' • Default configuration • Parameters to be calibrated - *A, r,* and *n*	• Halfar Decapodes model • 'halfar_level3.csv' • Default configuration • Parameters to be calibrated - *A, r,* and *n*	Bayesian calibration for 3 parameters, for 2D version of model	• Calibrated values for parameters *A, r,* and *n* • Mean parameter value pre- and post-calibration, • Prior and posterior distributions • Variance pre- and post-calibration • Goodness of fit measure

Section 3: Technical Area 4 Functionality

For Sets 3.1-3.4, you will be working with the following models in the Mimi framework. Get access to these models either by installing them in a local environment (Baseline) or getting access to them in Beaker (Workbench). Do not count installation time as part of the time spent on questions.

- MimiFUND
- MimiFAIRv2

Set 3.1 Integrated Assessment Model (IAM) Understanding

Leverage documentation, code, model descriptions, and any other tools to improve IAM model understanding and answer specific questions.

General format of inputs, tasks, and outputs

Inputs	**Tasks**	**Outputs**
• IAM model in the Mimi framework • Code repository • Model documentation • Question(s) about the IAM model. E.g. What are x/y/z variable and parameter definitions? How are a/b/c components of the model interdependent? Where do policy interventions fit into the model?	• Load model • Leveraging documentation, code repositories, model description, and any other tools, develop answer to input questions.	Answers to questions (which could include enhanced/annotated model description with equations and variable and parameter definitions with units, model flow diagrams, other explanations about the model and discussion, etc.)

(Q3.1.1) *Set 3.1, Question 1: Simple Comprehension Question*

Understanding for 1 IAM, ask about explaining model flow for one or more components that are clearly explained in documentation

Inputs:

- MimiFUND (https://github.com/fund-model/MimiFUND.jl)
- Documentation, papers, code repositories, and other resources associated with the FUND Model, at https://www.fund-model.org/

Tasks:

- Inspect the *socioeconomic* module and list out the set of equations
- Define each variable and parameter, including units

Outputs

- List of equations for each variable
- Definitions for all variables and parameters, including units

(Q3.1.2) *Set 3.1, Question 2: Medium Complexity Comprehension*

Inputs:

- MimiFUND (https://github.com/fund-model/MimiFUND.jl)
- Documentation, papers, code repositories, and other resources associated with the FUND Model, at https://www.fund-model.org/

Tasks:

- List all the variables in the FUND model that are disaggregated to the regional level, and group them under the modules they fall under
- For each variable, provide a description and units

Outputs:

- List of variables with regional resolution, grouped by module, with description and units

(Q3.1.3) *Set 3.1, Question 3: Challenging Comprehension Question*

Inputs:

- Model A: *FUND Model*. Access to MimiFUND, and documentation, papers, code repositories, and any other resources associated with the FUND Model, https://www.fund-model.org/; https://github.com/fund-model/MimiFUND.jl
- Model A: *FAIR 2.0 Model*. Access to MimiFAIRv2 and documentation, papers, code repositories, and any other resources associated with the FAIR 2.0 Model, https://github.com/anthofflab/MimiFAIRv2.jl; https://gmd.copernicus.org/articles/14/3007/2021/gmd-14-3007-2021.html

Tasks:

For each of the two models, do the following:

- Generate a high level model flow diagram to explain how the modules are interdependent.
- Run the model with default parameter values and initial conditions, until the year 2100.
- Now based on your model flow diagram, list modules and variables that are similar in topic between the two models. For each variable in the list, how do the results from your simulation runs compare between Model A and Model B? Do trends over time generally agree, or differ? If they differ, can you explain why?

Outputs:

- Two model flow diagrams
- List of modules and variables similar between the two models
- Description (through plots and a few sentences) of how simulation results for common variables are similar or different between the two models.
- If there are differences, provide a possible explanation for why.

Set 3.1 Summary Table

Question	Inputs (Both)	Task	Output
Q3.1.1	MimiFUND and all supporting documentation and resources	• Inspect the *socioeconomic* module and list out equations • Define variables and parameters, including units	• List of equations for each variable in the *socioeconomic* module • Definitions for all variables and parameters, including units
Q3.1.2	MimiFUND and all supporting documentation and resources	• List all variables that are disaggregated to the regional level, and group by module • For each variable, provide description and units	List of variables with regional resolution, grouped by module, with description and units
Q3.1.3	MimiFUND, MimiFAIRv2, and all supporting documentation and resources	• Generate model flow diagram for each model • Simulate models with default configuration, until 2100 • List modules and variables similar in topic between two models, and compare/contrast their outputs in the simulation runs	• Two model flow diagrams • List of modules and variables similar between the two models • For common variables, brief description of similarities and differences in their simulation outputs. Provide explanations when there are differences.

Set 3.2: Forecasting or Forward Simulation (IAMs)

Create forecasts/simulation with Integrated Assessment Models (IAMs).

General format of inputs, tasks, and outputs

Inputs	Tasks	Outputs
• IAM model in the Mimi framework or in another programming language • Model configuration for forecast/simulation (initial conditions, parameter values, simulation parameters)	• Load model • Instantiate model with provided configuration • Perform forecast/simulation	• Forecast plots

(Q3.2.1) *Set 3.2, Question 1: Simple Forecast*

Inputs:

- MimiFAIRv2 model and documentation, papers, code repositories, and any other resources associated with the FAIR 2.0 Model
- Model configuration for forecast:
    - (start year, end year) = (1750, 2100)
    - Set all other parameters to default values
    - Iterate over all possible options for *'emissions_forcing_scenario'*

Tasks:

- Recreate the figure shown in this model's README: https://github.com/anthofflab/MimiFAIRv2.jl (also recreated in Figure 2).
- Let the starting year for the forecast be the default year 1750. Set the end year to 2100.
- Keep other parameters at their default values, except for the *'emissions_forcing_scenario'*, which you should iterate values over all the possible options.

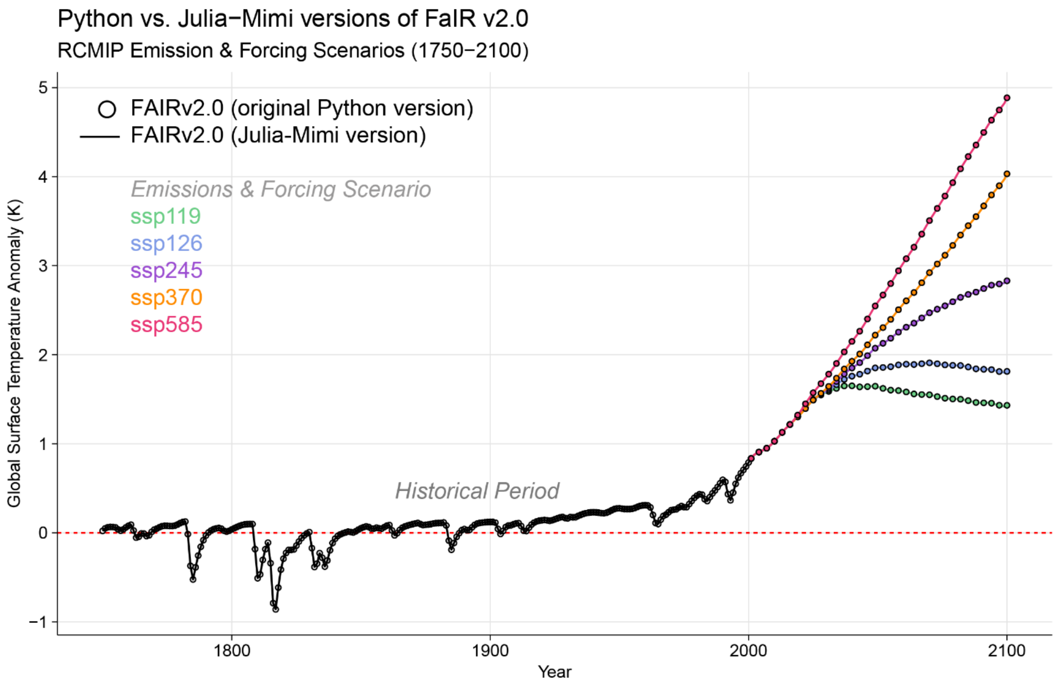

Figure 2. Unit test for Q3.2.1

Outputs: Forecast plot

(Q3.2.2) *Set 3.2, Question 2: Challenging Forecast*

Inputs:

- MimiFAIRv2 model and documentation, papers, code repositories, and any other resources associated with the FAIR 2.0 Model
- Model configuration for forecast:
    - (start year, end year) = (1750, 2300)
    - Set all other parameters to default values
    - Iterate over all possible options for emissions scenario

Tasks:

- For each emissions scenario, run a Monte Carlo simulation from 1750-2300, with 10,000 samples. Visualize the results and spread across the sample runs.

Outputs:

- Results from each Monte Carlo simulation, for all state variables

Set 3.2 Summary Table

Question	Inputs (Both)	Task	Output
Q3.2.1	MimiFAIR model and resources Forecast configuration	Configure model and simulate forecast	Forecast plots

Q3.2.2	MimiFAIR model and resources Forecast configuration	Configure model and perform Monte Carlo simulations for each emission scenario	Monte Carlo simulation results

Set 3.3: Interventions (IAMs)

Implement interventions in a provided model, simulate, and assess impact.

General format of inputs, tasks, and outputs

Inputs	Tasks	Outputs
• IAM in Mimi framework or in another programming language, with pre-intervention configuration identified (including initial conditions, parameter values, and simulation parameters) • One or more interventions to implement, specified as changing the value of one or more parameters or adding components to the model structure, and creating and applying a new model configuration. • Specific outputs of interest we want to measure the impact of the intervention against (e.g. global temperature).	• Load model • Simulate IAM model with pre-intervention configuration to get baseline results with respect to the indicated outputs of interest • Create new model configuration (intervention configuration) with the specified interventions • Simulate IAM model with intervention configuration • Calculate impact of intervention with respect to the outputs of interest	• Plots for relevant impacted state variables, each in a separate plot

(Q3.3.1) *Set 3.3, Question 1: Simple Intervention*

Inputs:

- MimiFUND model and documentation, papers, code repositories, and any other resources associated with the FUND model
- Preintervention configuration: default configuration with simulation end year = 2100
- Intervention configuration: set the intervention parameter $\tau_{t,r}$ to be a carbon tax of $10/tC (tC = ton of carbon), and apply to all regions from the current. Year, until 2100
- Out of interest to measure impact: global temperature

Tasks:

- Simulate the FUND model with pre-intervention default results for global temperature rise
- Apply carbon tax intervention and simulate model
- Simulate IAM model with intervention configuration
- Calculate impact of tax intervention with respect to global increase in temperature, compared to the baseline

Outputs:

- Plots for global increase in temperature, pre- and post- intervention
- quantitative impact of intervention on global increase in temperature

(Q3.3.2) *Set 3.3, Question 2: Challenging Intervention*

Inputs:

- MimiFUND model and documentation, papers, code repositories, and any other resources associated with the FUND model
- Preintervention configuration: default configuration with simulation end year = 2100
- Intervention configuration: set the intervention parameter $\tau_{t,r}$ to be a carbon tax of $10/tC (tC = ton of carbon), each year applying it to the top CO2 emitting region from the year before. Begin from the current year and continue simulation until 2100.
- Out of interest to measure impact: global temperature

Tasks:

- Simulate the FUND model with pre-intervention default results for global temperature rise
- Apply carbon tax intervention as specified and simulate model
- Simulate IAM model with intervention configuration
- Calculate impact of tax intervention with respect to global increase in temperature, compared to the baseline

Outputs:

- Plots for global increase in temperature, pre- and post- intervention
- Quantitative impact of intervention on global increase in temperature

Set 3.3 Summary Table

Question	Inputs (Both)	Task	Output
Q3.3.1	MimiFUND Carbon tax applies to all regions from this year until 2100	Implement intervention calculate impact with respect to global temperature increase	• Plots for global increase in temperature, pre- and post- intervention

Q3.3.2	MimiFUND Carbon tax applies to top CO2-emitting region each year	Implement intervention calculate impact with respect to global temperature increase	• Quantitative impact of intervention on global increase in temperature

Set 3.4: Optimizing Interventions (IAMs)

Find optimal interventions based on provided goals.

Given a configured model and a goal, optimize interventions and then create requested plots to prove that the optimized intervention satisfies the goal. Optimization can be value-based (optimize intervention parameter values), or time-based (find the earliest or latest time for an intervention, or minimize the total amount of time an intervention is in effect).

General format of inputs, tasks, and outputs

Inputs	**Tasks**	**Outputs**
• IAM in Mimi framework or in another programming language, with initial unoptimized configuration applied (initial conditions, parameter values, and simulation parameters) • Objective function with single objective. E.g. minimal carbon tax required to achieve outcome W (defined as one or more constraints); minimize the period of time carbon tax needs to be implemented to achieve outcome X; given a flow rate, find min/max channel size to maintain certain flow characteristics Y; in power generation and carbon emission, determine max load on generation while maintaining constraint Z. • Constraints on the optimization problem, in terms of parameters, state variables, or observable functions. Constraints can apply for the entire simulation, or just for certain time periods. E.g. $p_1 >= 2 * p_2$, $\Delta T < 3$ °C for all t; maintain certain fluid flow characteristics in a channel or geometry; keep pollutant levels below threshold P.	• Load model • Simulate model with unoptimized configuration to get baseline results with respect to the objective • Perform value- or time-based optimization (or some combination of the two) • Simulate model with optimal intervention	• A solution to the objective function (e.g., to achieve W, the minimum required carbon tax is c) • A verification that the provided solution solves the optimization question (e.g. plot showing results with respective to objective and constraints, pre- and post-optimization, etc.)

(Q3.4.1) *Set 3.4, Question 1: Simple IAM Optimization – Optimize Tax Amount*

Inputs:

- MimiFUND model
- Unoptimized configuration: default parameter values, and set $\tau_{t,r}$ = \$10/tC for the top 10 emitters of CO_2 in the past year, from this year until 2100
- Objective: find minimum carbon tax intervention parameter $\tau_{t,r}$ in units [\$/tC](tC = ton of carbon)
- Constraint: Keep global temperature increase below 3°C over the course of the 21st century (2000-2100)

Tasks:

- Implement the unoptimized intervention configuration and simulate
- You want to implement a carbon tax policy to the top 10 emitters of CO_2 in the past year, but have not set an amount. The tax will continue from the current year through 2100. With the goal of ensuring global temperature increase does not surpass 3°C over the course of the 21st century (2000-2100), what is the minimum carbon tax that should be implemented?
- Simulate the model with the optimal carbon tax amount

Outcome:

- Minimum carbon tax
- Plots demonstrating that answer solves optimization problem and meets constraints, etc.

(Q3.4.3) *Set 3.4, Question 3: Challenging IAM Optimization – Optimize Tax Time*

Inputs:

- MimiFUND model
- Unoptimized configuration: default parameter values, and set $\tau_{t,r}$ = \$20/tC for the 10 regions who are projected to have the fastest grown in CO_2
- Objective: find latest tax implementation time
- Constraint: Keep global temperature increase below 3°C over the course of the 21st century (2000-2100)

Tasks:

- Implement the unoptimized intervention configuration and simulate
- You want to implement a carbon tax policy to the 10 regions who are projected to have the fastest grown in CO_2 over the 21st century (2000-2100). You have decided that the tax should be \$20/tC, but are not sure when it should be implemented. The tax will continue from the current year through 2100. With the goal of ensuring global temperature increase does not surpass 3°C over the course of the 21st century (2000-2100), when is the ***latest*** that this tax can be implemented?
- Simulate the model with the optimal start time for this tax

Outcome:

- Latest carbon tax starting year
- Plots demonstrating that answer solves optimization problem and meets constraints, etc.

Set 3.4 Summary Table

Question	Inputs (Both)	Task	Output
Q3.4.1	• MimiFUND model • Unoptimized configuration • Objective and constraints for optimization	• Implement unoptimized configuration and simulate • Find minimum carbon tax • Implement optimized configuration and simulate	• Minimum carbon tax • Plots demonstrating that your solution solves the optimization problem and meets constraints
Q3.4.3		• Implement unoptimized configuration and simulate • Find latest time for carbon tax • Implement optimized configuration and simulate	• Latest tax time • Plots demonstrating that your solution solves the optimization problem and meets constraints

Set 3.5: Data Search

Search for climate data through Earth System Grid Federation (ESGF) platform.

General format of inputs, tasks, and outputs

Inputs	Tasks	Outputs
• Spatial and temporal resolution • Spatial and temporal extent (geographic area and time range) • Specific climate/meteorological variables of interest (e.g. temperature, precipitation)	• Search for datasets that meet input criteria, and select the best one (based on user judgement) from search results • Find specific information from the relevant datasets	• Answers to specific questions in the tasks • Description of selected dataset, and indication of the search criteria it meets: o Title o Type of data o Data node and institution o Spatiotemporal resolution o Spatiotemporal extent (e.g. time period and geographic areas covered by data)

Guam Island (part of the Northern Mariana Islands), and Weno Island (part of the Federated States of Micronesia), are two islands in the Pacific Ocean near Asia and Oceania. This set of questions will use these two islands and ask you to find data sets or data outputs that fit the required criteria. The input will be a given data criteria and a given date or range of dates. The expected output is a data point, data points, or count of data points that answer the question asked.

For baseline modelers, please use the following websites for the three questions in Set 3.5:

- ESGF Website: https://aims2.llnl.gov/search
- ESGF API: https://esgf.github.io/esg-search/ESGF_Search_RESTful_API.html#

Supporting documentation: Both teams may use this documentation to examine variables present in ESGF data. Both teams may also use this documentation for a python library that can be used to work with netCDF data: https://github.com/Unidata/netcdf4-python/blob/master/examples/reading_netCDF.ipynb.

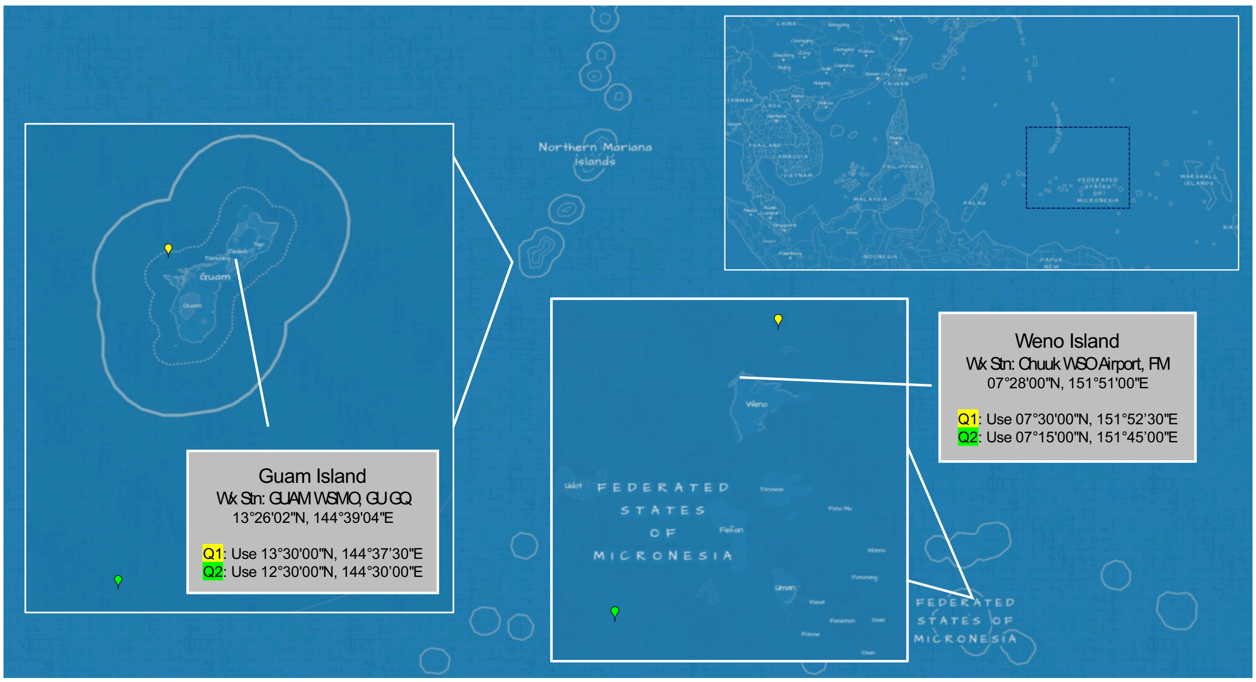

Figure 3. Locations for Set 3.5 Questions 1 – 3, Set 3.6 Question 1

(Q3.5.1) *Set 3.5, Question 1: Simple Data Search*

Inputs:

- (Baseline) ESGF website or ESGF API
- (Workbench) ESGF API through Beaker Climate context
- Geographic area: Weno Island and Guam Island (location coordinates in Figure 3)
- Time range: see details in tasks
- Spatiotemporal resolution: see details in tasks
- Variables of interest: see details in tasks
- Do not use historical data that doesn't include human input (e.g. don't use historical-natural-only)
- Use data from the CMIP6 project
- Use data from NOAA through LLNL data nodes
- If you find multiple relevant datasets, select the one with the spatial resolution matching gr1 if possible

Tasks:

- Use the following approximate coordinate locations: use 7° 30'00" N, 151° 52' 30" E for Weno Island and use 13° 30'00" N, 144° 37' 30" E for Guam Island. For these locations, find:
    a. the near-surface air temperature on 25 October 2004 (data set should have resolution of one value per day) at the coordinate location you used
    b. average near-surface air temperature in the month of November 2004 (data set should have resolution of one value per month) and the coordinate location you used

Outputs:

- Numerical values for each location, for each part (a) and (b), with appropriate units.
- Description of selected datasets and which criteria it meets:
    - Title
    - Type of data (e.g., CMIP6 model data or observational)?
    - What is the data node and institution?
    - Spatiotemporal resolution and does it meet the criteria?
    - Spatiotemporal extent (time period and geographic area) and does it meet the criteria?
    - Other model type information (if applicable)?
    - Does dataset contain correct variables of interest?

(Q3.5.2) Set 3.5, Question 2: Medium Complexity Data Search

Inputs:

- (Baseline) ESGF website or ESGF API
- (Workbench) ESGF API through Beaker Climate context
- Geographic area: Near Weno Island and Guam Island (location coordinates in Figure 3). Use approximate coordinate locations given in question.
- Time range: see details in tasks
- Spatiotemporal resolution: see details in tasks
- Variables of interest: see details in task
- Use data from the obs4MIP project (observational data)

Tasks:

Use a data resolution of one value per month for part a) and b). Note any data sets you find that, upon examination, do not work and why they do not work. Be sure to identify the correct units for your answers. Identify:

a. The number of months of available observational data on precipitation flux, and the precipitation at coordinate location 7° 15' 0" N, 151° 45' 0" E (approximate location for Weno Island) on May 5, 2005
b. The number of months with observed wind speed, and the observed wind speed for the coordinate location 12° 30' 0" N, 144° 30' 0" E (an approximate location for Guam Island) in the month of February 1990

Outputs:

- Numerical values (for each location) for each part (a) and (b), with appropriate units.

- Description of selected datasets and which criteria they meet:
    - Title
    - Type of data (e.g., CMIP6 model data or observational)?
    - What is the data node and institution?
    - Spatiotemporal resolution and does it meet the criteria?
    - Spatiotemporal extent (time period and geographic area) and does it meet the criteria?
    - Other model type information (if applicable)?
    - Does dataset contain correct variables of interest?

(Q3.5.3) *Set 3.5, Question 3: Challenge Data Search*

Figure 4. Airport Locations for Question 3 in both Set 3.5 and Set 3.6

Inputs:

- (Baseline) ESGF website or ESGF API
- (Workbench) ESGF API through Beaker Climate context
- Geographic area: Locations at Air Force Bases (Figure 4)
- Time range: see details in tasks
- Spatiotemporal resolution: see details in tasks
- Variables of interest: see details in task
- Use historical data from the CMIP6 project

Tasks:

- Search for two (2) datasets, one with northward near-surface winds, and the other with eastward near-surface winds. Use a time resolution of 3-hr and the finest spatial grid resolution possible.
- Determine the northward and eastward winds for the month of January 1950 using the closest grid point in each data set to the Airport Reference Points (ARPs) shown in Figure 4.

Outputs:

- Northward and eastward winds for the requested time and location
- A list of data sets you found that would answer this question. For each relevant dataset, provide a description and which criteria it meets:
    - Title
    - Type of data (e.g., CMIP6 model data or observational)?
    - What is the data node and institution?
    - Spatiotemporal resolution and does it meet the criteria?
    - Spatiotemporal extent (time period and geographic area) and does it meet the criteria?
    - Other model type information (if applicable)?
    - Does dataset contain correct variables of interest?

Set 3.5 Summary Table

Question	Inputs (Baseline)	Inputs (Workbench)	Task	Output
Q3.5.1	ESGF website or ESGF API	ESGF through Beaker Climate context	Identify a. The average surface temperature on 25 Oct 2004 b. Average surface temperature in November 2004	• Numerical values (for each location) for each part (a)-(b), with appropriate units. • Data checklist and information
Q3.5.2	ESGF website or ESGF API	ESGF through Beaker Climate context	Identify: a. The number of months of available observational data on precipitation flux, and the precipitation at approximate location for Weno Island on 5/5/05. b. The number of months with observed wind speed, and the observed wind speed at approximate location for Guam Island in February 1990.	• Numerical values (for each location) for each part (a)-(b), with appropriate units. • Data checklist and information
Q3.5.3	ESGF website or ESGF API	ESGF through Beaker Climate context	• Identify the two (2) datasets with northward near-surface winds, and with eastward near-surface winds using a time	• Numerical values for the northward and eastward winds

			resolution of 3-hr and the finest spatial grid resolution possible. • Determine the northward and eastward winds for the month of January 1950 using the closest grid point in each data set to the Airport Reference Points (ARPs)	• Data checklist and information

Set 3.6: Data Transformation

Perform structured data wrangling and processing, derivation of new variables, and calculation of descriptive statistics, to help connect raw data and model output, to a specific application (e.g. understanding climate impacts at a societal level, supporting DoD decisionmakers, etc.)

General format of inputs, tasks, and outputs

Inputs	Tasks	Outputs

• Structured data (including model output or observational data)
• Instructions on how data should be transformed, which could include:
  • Creating a derived quantity (e.g. go from daily temperature data to number of extreme heat days per month given some temperature threshold)
  • Calculating basic statistics (e.g. go from daily temperature data to mean temperature for each month; go from hourly temperature data to daily maximum temperature; calculate average temperature over a geographic area)
	Calculate the desired derived quantity or descriptive statistics for the data, and plot results, performing data wrangling and processing as needed.	• Plots of descriptive statistics or derived quantities

The three questions in this set involve wrangling data, plotting data, and processing basic statistics. This set of questions will ask you to do basic data processing tasks to answer questions about the climate at various locations.

The first question involves the set of coordinate locations provided in Figure 3 for Guam Island and Weno Island (which were the same locations used in Set 3.5 questions).

The second and third question involves three US Air Force Base (AFB) locations: MacDill AFB FL, Ellsworth AFB, and Luke AFB - see Figure. The third question will involve a coordinate transformation to determine headwinds and crosswinds for the three Air Force Bases.

The input for each question will be a data set and a date or range of dates. Data are located in the supplementary materials folder. The expected output could be a plot of the data, a plot plus a relationship between two data observations, or a data transformation and basic summary statistics about the transformed data. The baseline team may use whatever non-ASKEM data analysis and processing tools they would like. The workbench team should use Beaker. The supplementary materials also contains a Python file titled "set_3_6_template.py", which can be utilized for some of these questions. This file outlines how bilinear interpolation can be used to get the value of a specific coordinate location, given a grid of data points with corners that may not directly intersect with the coordinate locations we are interested in.

(Q3.6.1) *Set 3.6, Question 1: Simple Data Transformation*

Inputs:

- (Both teams) Observed precipitation flux netCDF dataset: "set_3_6_1_pr_day_GFDL-CM4_historical_r1i1p1f1_gr1_19900101-20091231.nc"
- (Both teams) Maximum Temperatures netCDF dataset: "set_3_6_1_ tasmax_day_GFDL-CM4_historical_r1i1p1f1_gr1_19900101-20091231.*nc"*
- (Both teams) Minimum Temperatures netCDF dataset: "set_3_6_1_ tasmin_day_GFDL-CM4_historical_r1i1p1f1_gr1_19900101-20091231.*nc"*

Tasks:

For the coordinate locations of Weno Island and Guam Island shown in Figure 2, identify the total number of days in 2003 where:

a. observed precipitation data exists (i.e., number of data points available, or size of data set).
b. the maximum temperature was greater than 80°F.
c. the minimum temperature was greater than 80°F.

Outputs: Numerical values (for each location) for each part (a) and (b), with appropriate units.

(Q3.6.2) *Set 3.6, Question 2: Medium Complexity Data Transformation*

Inputs:

- (Both teams) Temperature netCDF dataset: set_3_6_2_*ts_Amon_CNRM-CM6-1_historical_r3i1p1f2_gr_185001-201412.nc*
- (Both teams) Precipitation netCDF dataset: set_3_6_2_*pr_Amon_CNRM-CM6-1_historical_r3i1p1f2_gr_185001-201412.nc*

Tasks:

For the decades 1970-1979, 1980-1989, 1990-1999, and 2000-2009, and for each of the three given locations in Figure 3 (MacDill AFB, Luke AFB, and Ellsworth AFB), plot the relationship between average daily surface temperature for each month, and average precipitation for each month. As an example, one plot should consist of data for one location, with a point plotted for each month in each year in the decade.

Outputs: One plot for each location per decade (12 plots total). Each plot should have correct units, axis labels, and a title describing the data and decade the plot is representing

(Q3.6.3) *Set 3.6, Question 3: Challenging Data Transformation*

In this question you will be plotting histograms of 3-hour headwinds and crosswinds in knots from 1 Jul 2019 to 30 Dec 2019 inclusive, for each airport with respect to the listed runways in Figure 4. Note that the runway headings listed in Figure 4 and Figure 5 are shown adjusted for magnetic variation and that times may remain in Zulu time. Figure 6 and Figure 7 illustrate the effect of magnetic variation on heading transformation. For the purposes of this exercise, assume that the magnetic variation for 2025 and 2019 are equivalent.

The following table should be referenced for the appropriate grid-point for the Northward and Eastward Near-Surface Wind data.

Table 3. Location data for Q3.6.3

Site	Northward (V-direction)	Eastward (U-direction)
Luke AFB (Glendale, AZ)	33.516625N, 112.3242W	33.6328125N, 112.5W
Ellsworth AFB (Rapid City, SD)	44.0625N, 103.1836W	44.1796875N, 103.0078W
MacDill AFB (Tampa, FL)	27.890625N, 082.4414W	27.7734375N, 082.6172W

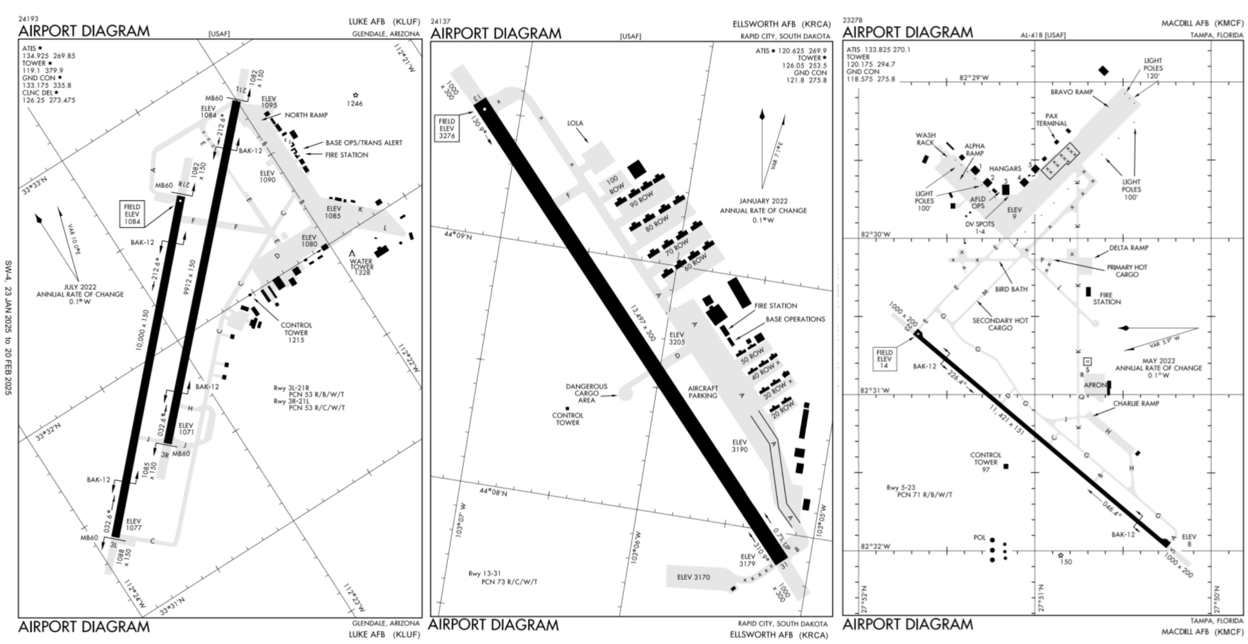

Figure 5. Airport Diagrams for Set 3.6 Question 3

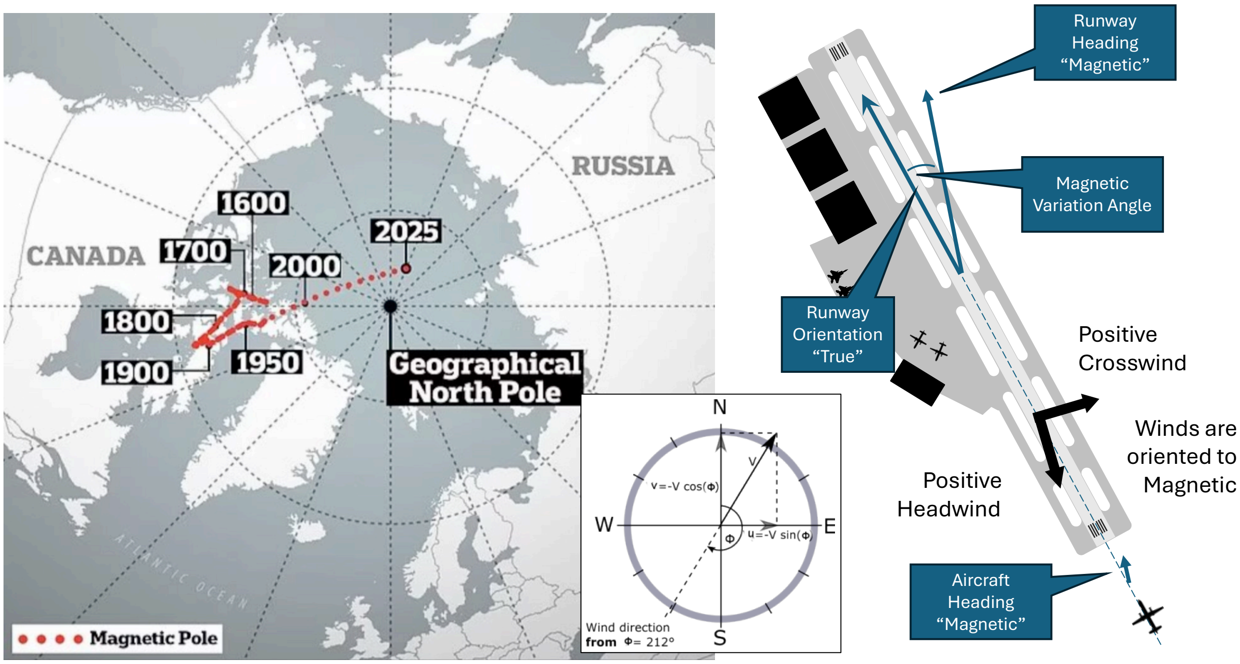

Figure 6. Magnetic North vs. True North Orientation.

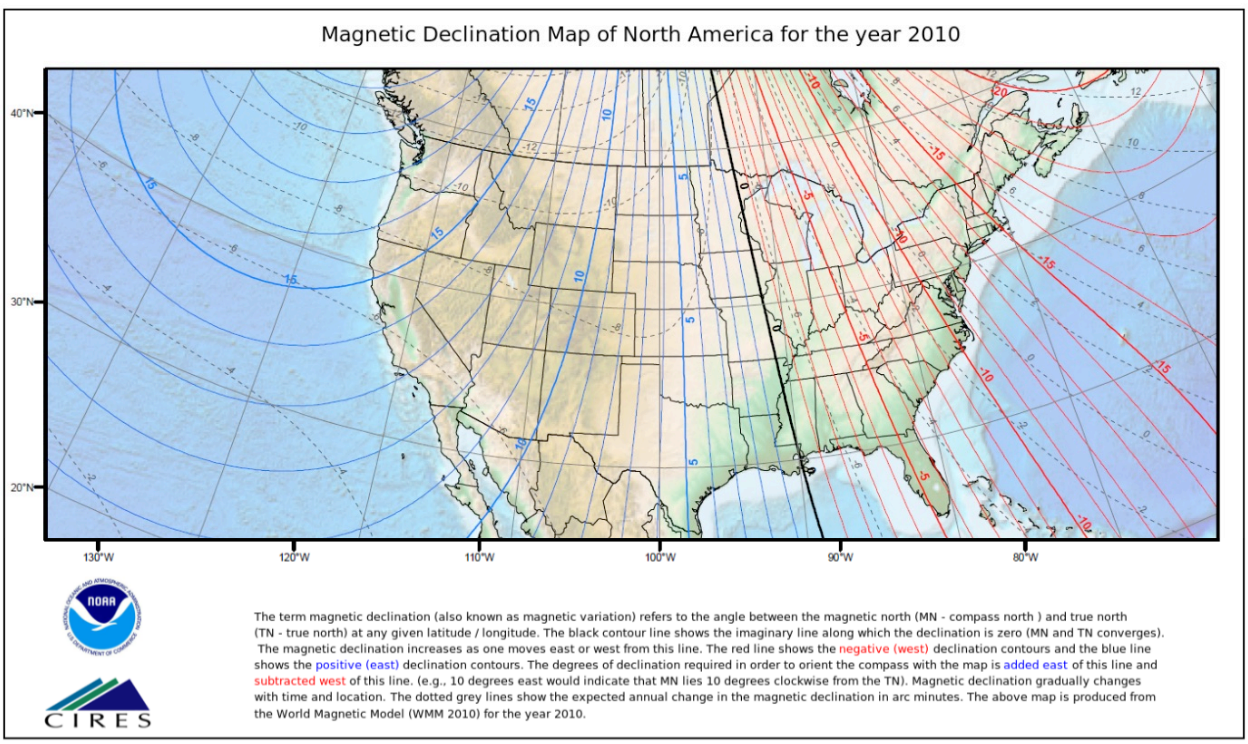

Figure 7. US Map of Magnetic Declination in 2010.

Inputs:

- (Both teams) NetCDF datasets for Northward and Eastward Near-Surface Winds:
    - "vas_3hr_HadGEM3-GC31-HM_highres-future_r1i3p1f1_gn_201907010000-201912302100.nc"
    - "uas_3hr_HadGEM3-GC31-HM_highres-future_r1i3p1f1_gn_201907010000-201912302100.nc"

Tasks:

- Use the provided data sets. Filter between the dates 1 Jul 2019 - 30 Dec 2019.
- Obtain the two wind magnitudes for each 3-hour increment for each airport location and convert into headwind and crosswind (in knots) for the identified runway heading.
- Plot histograms for each of the three Air Force Bases for headwinds and crosswinds over the 6-month date range for a reasonable increment. The plots should be on separate graphs and should have descriptive titles and legends. There will be 6 plots total.

Outputs:

- Three (3) plot pairs (one (1) headwind, one (1) crosswind – shown in knots) for each AFB runway heading of the 6-month span.

Set 3.6 Summary Table

Question	Inputs (Both)	Task	Output
Q3.6.1	NetCDF datasets titled: • 'set_3_6_1_ pr_mon_GPCP-Daily-3-2_RSS_gn_200301-200312.*nc*' • 'set_3_6_1_ tasmax_day_GFDL-CM4_historical_r1i1p1f1_gr1_19900101-20091231.*nc*' • 'set_3_6_1_ tasmin_day_GFDL-CM4_historical_r1i1p1f1_gr1_19900101-20091231.*nc*'	Identify the <u>total number of days per year</u> in 2003 where: a. observed precipitation data exists (i.e., number of data points available, or size of data set) b. the maximum temperature was greater than 80°F c. the minimum temperature was greater than 80°F	Numerical values (for each location) for each part (a)-(c), with appropriate units.
Q3.6.2	NetCDF datasets titled: • 'set_3_6_2_*ts_Amon _CESM2_amip-*	Plot the relationship between average daily surface temperature and average daily	One plot for each location per decade (12 plots total), where each plot has correct units, axis labels, title.

	hist_r2i1p1f1_gn_197001-201412.nc' • 'set_3_6_2*_pr_Amon_CESM2_amip-hist_r2i1p1f1_gn_197001-201412.nc'*	precipitation. Make one plot per decade.	
Q3.6.3	NetCDF datasets titled: • "vas_3hr_HadGEM3-GC31-HM_highres-future_r1i3p1f1_gn_201907010000-201912302100.nc" • "uas_3hr_HadGEM3-GC31-HM_highres-future_r1i3p1f1_gn_201907010000-201912302100.nc"	a. Use the provided data sets. Filter between the dates 1 Jul 2019 - 30 Dec 2019. b. Transform the location 2 wind vectors data into headwind and crosswind for each airport. c. Plot histograms for each of the three Air Force Bases for headwinds and crosswinds over the 6-month date range for a reasonable increment. The six (6) separate graphs should have descriptive titles and legends.	Three (3) plot pairs (one (1) headwind, one (1) crosswind – shown in knots) for each AFB runway heading of the 6-month time span.