ASKEM 18-Month Milestone: Hackathon Scenarios

USE CASE: CLIMATE

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To prepare for the 18-month evaluation scenarios, we have developed a series of hackathon scenarios that are representative of and exercise similar functionality as our target expectations for the evaluation. These questions are meant to help guide and prioritize critical development for success in the evaluation. The goal is to address as much as possible within the Terarium workbench (including the interactive notebook environment). Please be sure to use the logging features of Terarium to ensure that we get accurate timing information.

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Scenario 1: Connecting Climate with Aircraft Performance

Over the years we've seen increases in surface temperatures and atmospheric temperatures, driven by climate change. We are interested in understanding how increasing atmospheric temperature directly affects the domain of aircraft performance via physical laws.

Let's begin by plotting historical and forecasted temperature for select locations - Guam and Little Rock, Arkansas.

1. Search for historical data and climate model output (for future projections) for monthly mean of the daily maximum temperature. For climate model data, search for CMIP5 or CMIP6 outputs.
2. For each of the two locations (Guam, and Little Rock), plot monthly mean of the daily maximum temperature (daily T_{max}) for Jan – Dec for the following:
    - With historical observed data of T_{max}, 1970 – 1999

- Climate model output for T_{max}, 1970—1999 (how well does model output reproduce the observed data?)
- Climate model output for T_{max}, 2020—2049 (future forecast)
- Climate model output for T_{max}, 2040—2069 (future forecast)
- Climate model output for T_{max}, 2060—2099 (future forecast)

3. The US Andersen Air Force Base (https://www.andersen.af.mil/) is located in Guam. For the rest of the questions in this scenario, we are interested in a spatial scale relevant to the size of the base – 50 km. If needed, run downscaling algorithms on the climate data found in Q1, to match this spatial scale.

4. This question asks you to explore how aircraft takeoff distance may be affected by increasing temperatures (as forecasted by climate models). To calculate takeoff distance, you will have to take the temperature data from Q1-3 climate model outputs, and transform it according to Figure 1, and the following equations.

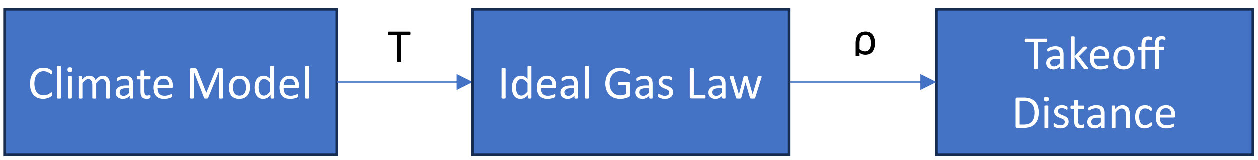

Figure 1. Calculate aircraft takeoff distance, from climate model outputs

Ideal Gas Law

$$PV = nRT \text{ (expressed classically)}$$
$$PM = \rho RT \text{ (expressed with density)}$$

- P: pressure (Pa)
- V: volume (m^3)
- n: number of moles of gas (can be consider "mass")
- R: gas constant
- T: temperature (K)
- M: molar mass (g/moles)
- ρ: density (g/m^3)
- Note: $\rho \propto \frac{1}{T}$ (density is inversely proportional to temperature)

A simplified equation for takeoff distance is given as:

$$D = \frac{T_{to}^2}{2\mu(\frac{W}{S})(\boldsymbol{\rho} V_s^{\,2})}$$

- D: Take off distance (m)
- T_{to}: Take off thrust (N)
- µ: coefficient of friction between tires and runway (0.03 for dry asphalt)
- W: weight of the aircraft (N)

- S: wing reference area (m^2)
- **ρ: air density (kg/m^3)**
    - ***Air density is related to air temperature (i.e. Ideal Gas Law)***
- V_s: stall speed (m/s)

To understand what happens to aircraft performance as the temperature changes, please fill out the following table for the following plane types, carrying two different loads, for the years 2050, 2075, and 2099. Search the literature to find wing reference area, max load, stall speed and take-off thrust. Please show values used.

Table 1. Takeoff distances for aircraft carrying max loads, at Guam

Aircraft	Year	Takeoff distance based on monthly mean of daily T_{max}	Takeoff distance based on monthly mean of daily T_{min}
Boeing 747-8F	2050		
	2075		
	2099		
Lockheed C-130J	2050		
	2075		
	2099		

Table 2. Takeoff distances for aircraft carrying max loads, at Little Rock

Aircraft	Year	Takeoff distance based on monthly mean of daily T_{max}	Takeoff distance based on monthly mean of daily T_{min}
Boeing 747-8F	2050		
	2075		
	2099		
Lockheed C-130J	2050		
	2075		
	2099		

Table 3. Takeoff distances for aircraft carrying 80% of their max loads, at Guam

Aircraft	Year	Takeoff distance based on monthly mean of daily T_{max}	Takeoff distance based on monthly mean of daily T_{min}
Boeing 747-8F	2050		
	2075		
	2099		
Lockheed C-130J	2050		
	2075		
	2099		

Table 4. Takeoff distances for aircraft carrying 80% of their max loads, at Little Rock

Aircraft	**Year**	**Takeoff distance based on monthly mean of daily T_{max}**	**Takeoff distance based on monthly mean of daily T_{min}**
Boeing 747-8F	2050		
	2075		
	2099		
Lockheed C-130J	2050		
	2075		
	2099		

Here is some optional background reading on aircraft takeoff and landing analysis

- https://society-of-flight-test-engineers.github.io/handbook-2013/fixed-wing-performance-standardization.html
- https://eaglepubs.erau.edu/introductiontoaerospaceflightvehicles/chapter/takeoff-landing-performance/
- https://www.t-craft.org/documents/reference/DA_Safety.pdf

Scenario 2: Exploring Policies With FUND

1. The Climate Framework for Uncertainty, Negotiation and Distribution (FUND) is an Integrated Assessment Model (IAM). Extract the 50 equations from FUND 3.9. Also extract the tables of parameters from the FUND Table Document. The FUND source code (written in Julia) can be found here.
2. Starting in 1970, calculate the trajectory of M in Equation CO2.1, for a 50-year duration. Sum over any 4 of the 16 regions present in the FUND data.
3. Add a carbon tax of $5/tC (policy #1) and $10/tC (policy #2), and recalculate the trajectory of M. Do this by setting these prices in τ (see Equations CO2.2 and CO2.3, and several other equations). How does implementing these two policies impact M's trajectory, compared to the result of Question 2?
4. Next let's enact a policy that reduces space heating and cooling (Equations E.1 and E.2). Only in these equations, reduce the change in global mean temperature (T_t) to only 1 degree, to indirectly simulate less heating and cooling of indoor temperatures. Recalculate the trajectory of M - how does the result compare with the output from Question 2?
5. Now enact both a carbon tax ($10/tC) and reduction in heating and cooling. What is the combined effect of both policies now?
6. The global mean temperature is defined by Equation C.4. Optimize FUND so that the mean temperature increase does not surpass 3° C over the course of the next 100 years, starting in 2020. Optimize only over the following 5 parameters (and for all other required parameters, find relevant values from the literature). Start with the default values listed for each parameter as written in the documentation.
    a. B_{max} - total stock of potential emissions (Equation DB.1)
    b. α - fraction of emissions E (Equation C.2b with values in text)
    c. ϵ - income elasticity of the share of agriculture in the economy (Equation A.5 with value range in text)
    d. β - income elasticity of wetland value (Equation SLR.11 with value range in text)
    e. η - degree of non-linearity of the response of diarrhea mortality to regional warming (Equation HD.1 with value and error given in text)

Scenario 3: Photosynthesis Model

This scenario asks you to recreate the photosynthesis module (Chapter 8 of the documentation) as it was programmed and defined in CLM/CTSM 4.0 and iteratively update it to match CLM 4.5. It will not be an exact match however, because a few terms require many other parts of CLM to be run, which is out of scope for this scenario. For reference, the photosynthesis module's code can be found here.

1. Extract equations from Chapter 8 of CLM/CTSM 4.0, relating to photosynthesis. There are 28 equations in total to extract.
2. Extract parameters from Tables 8.1, 8.2, and 8.3, in the CLM/CTSM 4.0 documentation. For parameters that can't be found in this chapter or easily incorporated (some of which are defined in other parts of the CLM documentation), find reasonable values from the literature instead.
3. Extract the photosynthesis equations from Chapter 8 of CLM 4.5.
4. Do a model comparison between the extracted models from Q1, and Q3. This requires each model to be grounded, because there are variables representing the same concepts between CLM 4.0 and 4.5, but have different notations.
5. Starting with the CLM 4.0 model extracted in Q1, update the equations to match those in CLM 4.5. In particular, include the following specific changes (equation and table numbering refer to CLM 4.5 documentation):
    - Renaming of the photosynthesis constituent variables
    - Different values of α in Table 8.1
    - Addition of the respiration term in Equation 8.2
    - Change in equation of the PEP carboxylase-limited rate of carboxylation (equation 8.5)
    - Change in the maximum rate of carboxylation (equation 8.4)
    - Inclusion of new PFT root distribution parameters (Table 8.3)
    - Different expression for V_{cmax} (many equations but specifically 8.12)
6. (Challenge) To ensure the updates in Q5 were done correctly, do a model comparison between the Q5 updated model, and the CLM 4.5 photosynthesis model extracted in Q3.
7. (Challenge) Calculate the leaf photosynthesis A, for the updated model in Q5, for 10 plant functional types. Choose 5 plant functional types that have parameters in tables 8.1, 8.2, and 8.3, and find parameters for 5 other plant functional types, from the literature.

Scenario 4: Ice and Ocean Modeling

1. Couple the Halfar dome model previously created using the CISM documentation section 8.1.1, with the Mohamed et al. 2016 exterior calculus solution of incompressible Navier-Stokes as the ocean component. For more information about the Halfar dome, refer to the climate starter kit scenarios, Halfar 1984, and Buehler's notes provided as a file in the starter kit. Place Greenland on a spherical ocean world with no other landmasses. The size of the spherical world should be comparable to the size of the Earth. Let the bottom of the ocean at a constant sea floor depth have impermeable boundary conditions. Let the lateral boundary conditions of the ocean be periodic. Assume this spherical world is non-rotating.
2. Using 1970 data for initial conditions, calibrate the coupled ice-ocean model parameters A , ρ , and n, using ice thickness data for Greenland from the year 1999. You will need to search for Greenland mesh data for 1970. Are the calibrated parameter values reasonable? What are the limitations of this model? How do these results compare to a standalone Halfar model calibration? For all questions, assume you are still in the spherical ocean world.
3. What will Greenland (in the spherical ocean world) look like in 20 and 50 years? Plot Greenland's ice loss over the mesh, as a function of time.
4. (Challenge) Add salinity as a tracer to the coupled model in the manner Oceananigans does, simplifying where possible. Decompose fluid density into three components: the reference density, a background density, and a buoyant tracer - salinity. The buoyant acceleration of the fluid becomes $b = -\frac{g\rho'}{\rho_0}$. Also add the tracer conservation equation $\partial_t c = -\boldsymbol{u} \cdot \nabla c - \boldsymbol{U} \cdot \nabla c - \boldsymbol{u} \cdot \nabla C - \nabla \cdot \boldsymbol{q_c} + F_c$. Map salinity as a function of ocean depth.