ASKEM Final Evaluation (February 2025): Climate Decision-maker Scenario

Impact of Climate on Cloud Formation and Radar Performance

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Scenario Background

Through daily weather patterns, the global climate has operational implications for many DoD-relevant systems, including radar performance. Cloud systems – a seemingly innocuous, but extremely important component of the climate - can impact air defense-related radar systems by degrading detection ability and masking the presence of threats behind them.

With dense clouds, larger water droplets can produce a stronger radar signal reflectivity than thin, wispy clouds, potentially masking targets behind them (illustrated in Figure 1). In most non-precipitating clouds, cloud droplets are typically too small to effectively reflect radar waves but may have a weakening effect on radar signals. When the size of these cloud types is sufficiently large, this attenuation effect absorbs and scatters radar waves, disabling them from reaching targets behind the cloud. For climatology applications, higher frequency radars, e.g., millimeter-wave radars, are better at detecting smaller cloud particles, providing more detailed cloud information.

From the perspective of the radar receiver and the amount of energy, it should be noted that in addition to signal reflectivity (as a loss path) there is also absorption of radar energy by water (as another loss path). There are several loss paths that contribute to a decrease in radar energy at the radar receiver.

In this scenario, imagine that you are a modeler supporting DoD decisionmakers who want to better understand the implications that changes in the global climate may have on the defensive performance of the current radar defense system and for future system acquisitions.

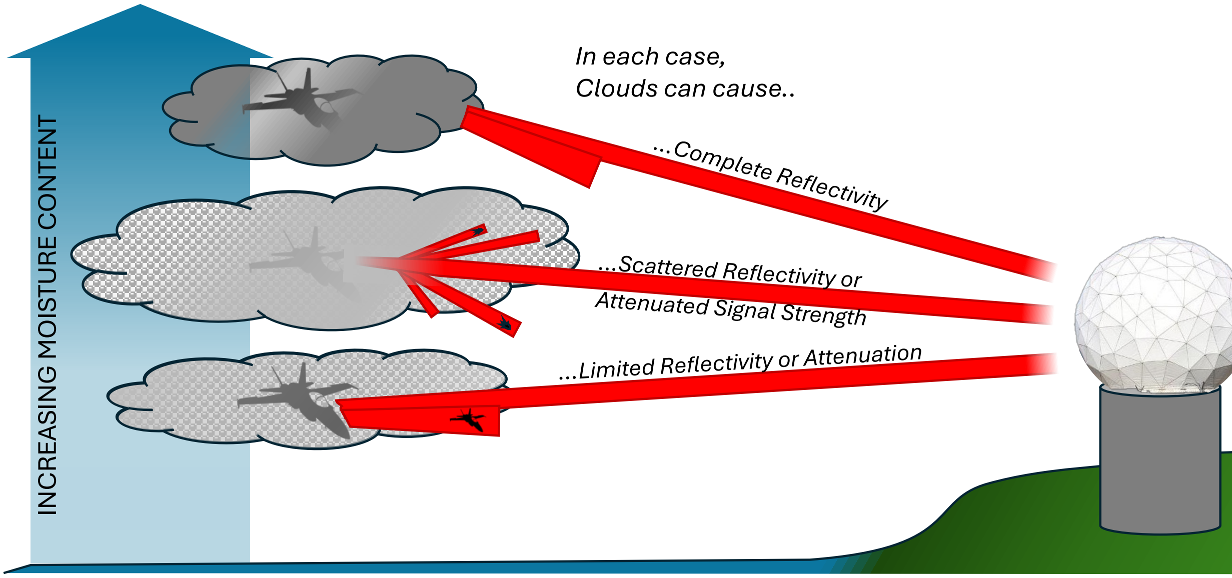

Figure 1.High-Level Illustration of the Problem Context

Decision-Maker Priorities

In this scenario, DoD decision-makers are concerned with the performance of the radar systems that support air defense capabilities. Figure 2 depicts the radar coverage of the North Warning System (NWS).[1] NWS provides early warning capabilities for potential attacks on North America. Additionally, there are other air defense sectors. For example, Western Air Defense Sector (WADS), Pacific Air Defense Sector (PADS), Eastern Air Defense Sector (EADS).

There are three (3) primary regions of concern that this scenario includes: (1) the North American Polar region shared by the United States (Alaska) and Canada centered in Anchorage, AK; (2) the Pacific Northwest centered in the Seattle-Tacoma, WA; and, (3) the Indo-Pacific region centered at Honolulu, HI.

[1] More information at: https://en.wikipedia.org/wiki/North_Warning_System

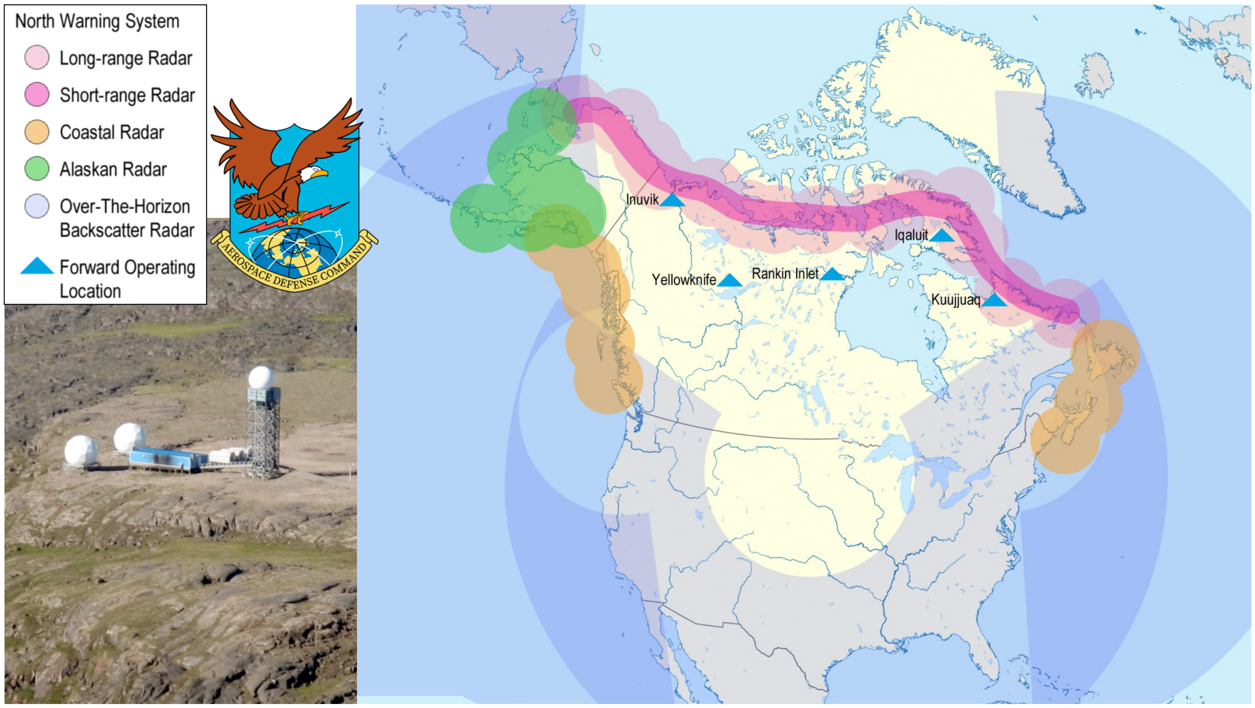

Figure 2. North Warning System - Region 1: Alaska and Northern Canada (highlighted areas)

Region 1: Alaska and Northern Canada
The North Warning System (NWS) is a joint early-warning radar system between the United States and Canada designed for the atmospheric air defense of North America. It provides surveillance of airspace to identify enable response to potential incursions or attacks across the North American polar region (shown in Figure 2).

Region 2: Washington State
From an air defense perspective, Tacoma WA is the command control center for the USAF Western Air Defense Sector (WADS).[2] Shown in Figure 3, the center is located at McChord AFB (part of the Joint Base Lewis-McChord).

[2] More information at: https://en.wikipedia.org/wiki/Western_Air_Defense_Sector

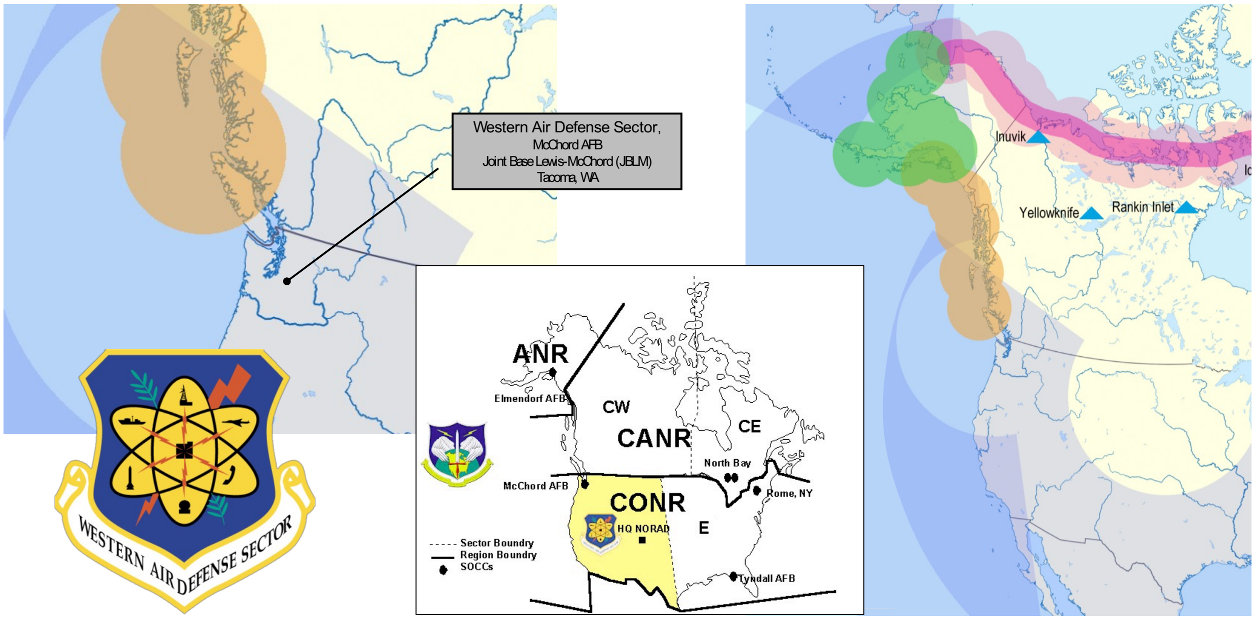

Figure 3. Western Air Defense Sector

Region 3: State of Hawaii

Hawaii is vital to national security as it serves as a central hub. The US Indo-Pacific Command is based in Hawaii, and it serves as a hub where members from all branches of the military forces are located. Its location allows for rapid deployment into the region.

Part 1: Setup with Multiphysics Modeling

For Part 1 of this scenario, you will find relevant climate data and implement various physics models that are being used as approximations of cloud formation in the atmospheric. Parts 2 and 3 will build upon this work.

Parts 1-2 support <u>Decision-maker Confidence Metric 1</u>, "Confidence in having/developing an appropriate model (or set of models) and associated parameter space to sufficiently explore the scenario/problem." The scenario involves updating or modifying the model, and decisionmakers will evaluate whether this was done in a sensible way and whether final model can support all the questions asked in the scenario.

1) (TA4 Data Search) Find temperature and humidity data as a function of location, year (historical or future), and altitude (see specifications in Table 1). For each location, try to find data for a 100km x 100km region in the x-y plane, at the given altitude; in this coordinate system, altitude increases in the z direction. For future timeframes, you may choose the climate scenario pathway(s) being modeled.

   While you can use any data source, we recommend starting with the Earth System Grid Federation (ESGF) platform. ESGF contains historical data collections, historical model simulation data, and future prediction model data. Please cite all data sources you use.

Table 1. Locations, years, and altitude, for the climate data to collect in Q1.

Location	Year	Altitude	Variables
Anchorage, Alaska	Historical and current data: 1970, 2025	Mean sea level (MSL)	Seasonal temperature
			Seasonal relative humidity
		750 m	Seasonal temperature
			Seasonal relative humidity
		1500m	Seasonal temperature
			Seasonal relative humidity
		3050 m	Seasonal temperature
			Seasonal relative humidity
		6100 m	Seasonal temperature
			Seasonal relative humidity
	Future data: 2050 and 2075 (if it exists)	Mean sea level (MSL)	Seasonal temperature
			Seasonal relative humidity
		750 m	Seasonal temperature
			Seasonal relative humidity

		1500m	Seasonal temperature
			Seasonal relative humidity
		3050 m	Seasonal temperature
			Seasonal relative humidity
		6100 m	Seasonal temperature
			Seasonal relative humidity
Seattle/Tacoma, Washington	Historical and current data: 1970, 2025	Mean sea level (MSL)	Seasonal temperature
			Seasonal relative humidity
		750 m	Seasonal temperature
			Seasonal relative humidity
		1500m	Seasonal temperature
			Seasonal relative humidity
		3050 m	Seasonal temperature
			Seasonal relative humidity
		6100 m	Seasonal temperature
			Seasonal relative humidity
	Future data: 2050 and 2075 (if it exists)	Mean sea level (MSL)	Seasonal temperature
			Seasonal relative humidity
		750 m	Seasonal temperature
			Seasonal relative humidity
		1500m	Seasonal temperature
			Seasonal relative humidity
		3050 m	Seasonal temperature
			Seasonal relative humidity
		6100 m	Seasonal temperature
			Seasonal relative humidity
Honolulu, Hawaii	Historical and current data: 1970, 2025	Mean sea level (MSL)	Seasonal temperature
			Seasonal relative humidity
		750 m	Seasonal temperature

			Seasonal relative humidity
		1500m	Seasonal temperature
			Seasonal relative humidity
		3050 m	Seasonal temperature
			Seasonal relative humidity
		6100 m	Seasonal temperature
			Seasonal relative humidity
	Future data: 2050 and 2075 (if it exists)	Mean sea level (MSL)	Seasonal temperature
			Seasonal relative humidity
		750 m	Seasonal temperature
			Seasonal relative humidity
		1500m	Seasonal temperature
			Seasonal relative humidity
		3050 m	Seasonal temperature
			Seasonal relative humidity
		6100 m	Seasonal temperature
			Seasonal relative humidity

2) (TA4 Data Transformation and Visualization) For each of the datasets you've found, how does temperature and the amount of moisture vary over the 100km x 100km extent, and as a function of location, altitude, and time? Use figures and plots to help communicate your answer.

3) (TA2 Model Configuration and Unit Tests) **Setting up the Cahn-Hilliard Model**: The Cahn Hilliard model is a partial differential equation that describes spinodal decomposition, by which two components of a binary fluid spontaneously separate into two phases without nucleation. We will be using this model as a simplified estimation of cloud formation. In reality, cloud microphysics is a complex subfield of climate science and the process of cloud formation does in fact involve nucleation, but for the purposes of making this a tractable scenario to be exercised at a time-bound event, we will use the Cahn-Hilliard equation, which is as follows[3]: $\frac{\partial c}{\partial t} = D\nabla^2(c^3 - c - \gamma\nabla^2 c)$, where:
    - D is a diffusion coefficient with units of $\frac{m^2}{s}$

[3] https://en.wikipedia.org/wiki/Cahn%E2%80%93Hilliard_equation

- γ is the mobility (units $\frac{m^3 s}{kg}$), and is defined as $\gamma = \chi\varepsilon^2$ where χ is the mobility tuning parameter (units $\frac{ms}{kg}$)
- ε (units m) is the length of the transition regions between the domains, also referred to as the 'capillary' width or interface thickness parameter
- $\mu = c^3 - c - \gamma\nabla^2 c$ is the chemical potential
- c is a dimensionless phase field variable that can take on values between +1 and -1. As this system evolves over time, the binary fluid will evolve to show separation of two phases, with fluid 1 represented by $c = -1$ values, and fluid 2 represented by $c = +1$ values. When interpreted as a dimensionless phase field variable, you can calculate volume fraction of fluid 1 as $V_{f1} = \frac{1-c}{2}$ and volume fraction of fluid 2 as $V_{f2} = \frac{1+c}{2}$. Note that sometimes c itself is interpreted as concentration.
- Note that there are alternate formulations of this equation, but you can generally map equivalency between the different versions in terms of the parameters.

Before we couple this model with other physics, first ensure that you can execute this model by itself, and run the following unit test:

- Geometry: 10m x 10m 2D square in the x-y plane. Later we will update the geometry to be a more realistic size.
- Boundary conditions: use closed wall boundary conditions where a fluid-fluid interface can move along the wall, and the angle between each fluid and the wall is $\pi/2$ rad
- Let ε=0.1 m, χ =1 $\frac{ms}{kg}$ and $\gamma = 0.01 \frac{m^3 s}{kg}$
- D = 1.07 $\frac{m^2}{s}$
- Let the initial values of c across the domain be random values that are drawn from a uniform distribution ranging from (-0.1,0.1) with a mean of 0
- Simulation length = 20 seconds, and dt = 0.5 seconds
- Plot the V_{f1}, the volume fraction of fluid 1. Your result should look similar to the following plots in Figure 4.

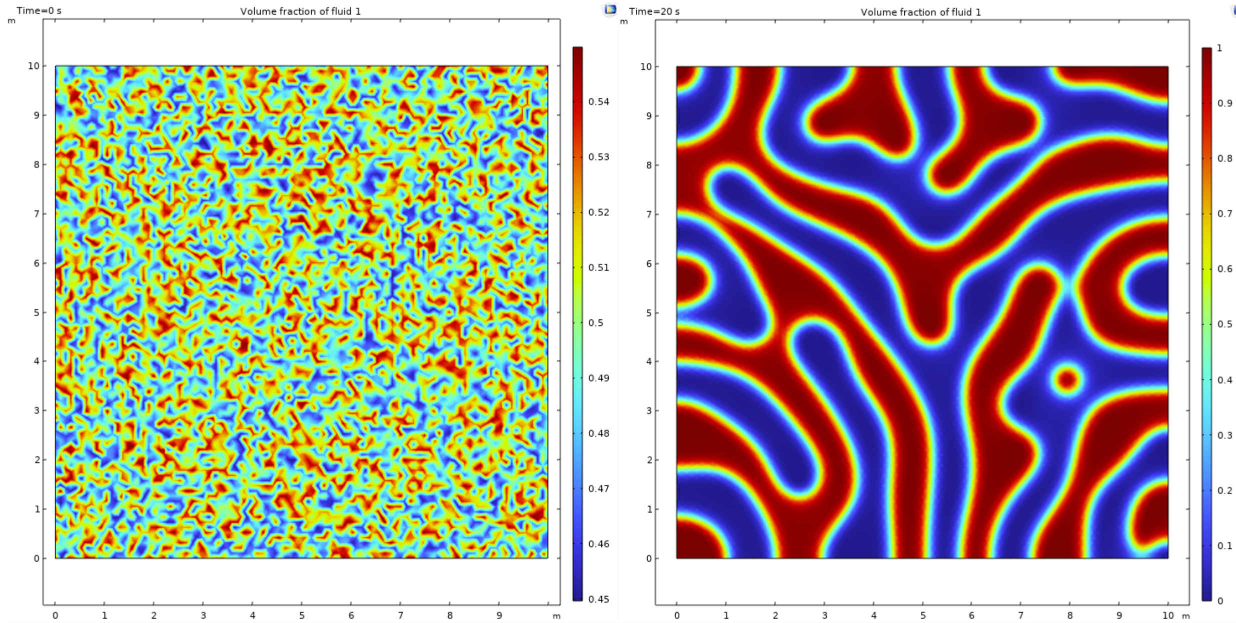

Figure 4. Expected unit test output, Q3. ***Left****: Volume fraction for fluid 1, t = 0 seconds.* ***Right****: Volume fraction for fluid 1 at t=20 seconds.*

4) (TA2 Model Configuration and Unit Test) **Setting up the Navier Stokes Model**, **Laminar Flow**: For this question we make an (unrealistic) assumption that laminar flow is the dominant type of fluid dynamics in clouds. In a later problem, you will be asked to update this assumption to account for turbulent flow.

   Before we couple this model with other physics, first ensure that you can execute this model by itself, and run the following unit test:
   - Assume incompressible flow
   - Geometry: 10m x 10m 2D square
   - Material: Water
   - Inlet boundary condition on the left edge, with velocity field
     $$\vec{\boldsymbol{v}}(x, y) = 2\frac{m}{s}\vec{\boldsymbol{\imath}} + \frac{m}{s}\vec{\boldsymbol{\jmath}}$$
   - Open boundary condition on the right edge, with normal stress = 0 $\frac{N}{m^2}$
   - All other boundaries are no slip wall conditions
   - Let the initial velocity field across the domain be $\overrightarrow{\boldsymbol{v_0}}(x, y) = 2\frac{m}{s}\vec{\boldsymbol{\imath}} + \frac{m}{s}\vec{\boldsymbol{\jmath}}$
   - Simulation length = 1 second, and dt = 0.01 seconds
   - Plot the velocity magnitude and velocity field. Your result should look similar to the plots in Figure 5.

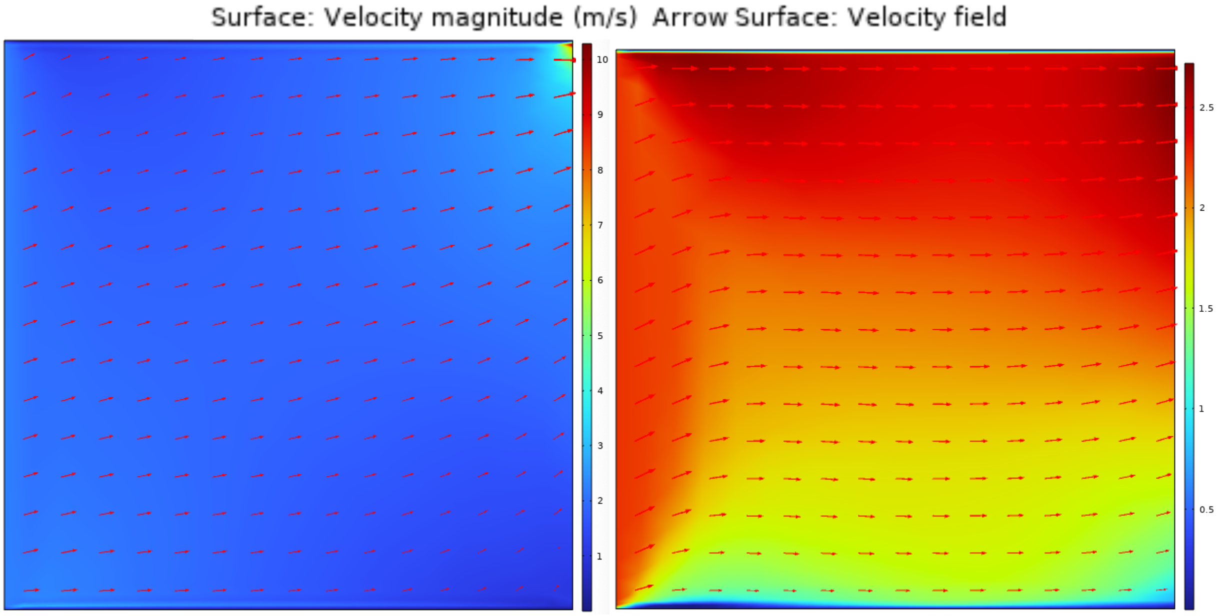

*Figure 5. Expected unit test output, Q4. **Left**: Velocity field and magnitude, t = 0 seconds. **Right**: Velocity field and magnitude, t = 1 second*

5) (TA2 Model Coupling and Unit Test) **Two-Phase Flow with Cahn-Hilliard and Laminar Flow Models**: To demonstrate that you can do multiphysics simulations, now couple the Q3 and Q4 Cahn-Hilliard and Laminar Flow models, and run some test simulations. Do your results make physical sense?

Part 2: Updating Model to Add Realism

In Part 2, you will continue to build up and update your model(s) from Part 1, increasing realism so that they can be better leveraged to support decision-maker priorities in Part 3.

Parts 1-2 support Decision-maker Confidence Metric 1, “Confidence in having/developing an appropriate model (or set of models) and associated parameter space to sufficiently explore the scenario/problem.” The part involves updating or modifying physics models, and decisionmakers will assess whether this was done in a sensible way and whether final model can support all the questions asked in the scenario.

6) (TA2 Model Configuration) **Update Parameters and Model Components**: To add realism to your coupled model, now update the geometry and parameters:
    - The 2D z-slices of the atmosphere we want to simulate in this scenario at a given altitude z, are boxes of size 100 km x 100 km (which match the data you found in Q1). Image that these boxes are sections of the atmosphere, surrounded by other sections of the atmosphere (i.e., you are focusing on one cell in a large, ‘infinite’ system system). Update your geometry in the coupled model in Q5 to be of the appropriate size, and scale up your parameters accordingly.
    - Given the context of cloud microphysics, choose realistic physical parameter values. You may draw from any reasonable source, including peer-reviewed academic literature, and cite your sources. For parameters which don’t have much reference data to draw on, make reasonable assumptions and document your choices.
    - Consider adding a wind velocity field to your simulation, which could be constant or spatiotemporally varying.
    - Consider exploring various types of boundary conditions to increase realism (e.g. inlet, outlet, open boundary conditions, periodic boundary conditions, etc.)

    Simulate your updated model and comment on the outputs – do they seem physically realistic (given the constraints of the simple model you are working with)?

7) (TA2 Model Configuration and Unit Test) **Setting up Navier Stokes Model, Turbulent Flow**: In Part 1, you executed the Navier Stokes model under laminar flow conditions, which is generally much easier to simulate than turbulent conditions. However, in reality, turbulent flow is the dominant behavior in the atmosphere. In this question, demonstrate that you can correctly execute the Navier Stokes model under turbulent flow conditions, and simulate the following unit test:
    - Geometry: 1m x 1m 2D square with a hole in the center, with radius = 0.1m (see Figure 6)
    - Material: Water
    - Inlet boundary condition on the left edge, with velocity field
      $$\vec{\boldsymbol{v}}(x,y) = 2\frac{m}{s}\vec{\boldsymbol{\imath}} + \frac{m}{s}\vec{\boldsymbol{\jmath}}$$
    - Open boundary condition on the right edge, with normal stress = 0 $\frac{N}{m^2}$
    - All other boundaries are walls with slip boundary conditions

- Let the initial velocity field across the domain be $\overrightarrow{\boldsymbol{v_0}}(x, y) = 2\frac{m}{s}\vec{\boldsymbol{\imath}} + \frac{m}{s}\vec{\boldsymbol{\jmath}}$
- Simulation length = 1 second, and dt = 0.01 seconds
- Plot the velocity magnitude and velocity field. Your result should look similar to the plots in Figure 7.
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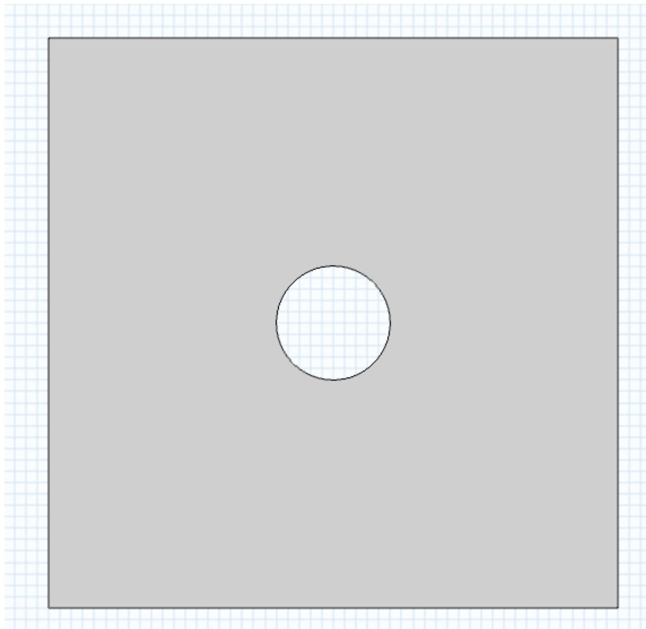

Figure 6. Geometry for Q7.

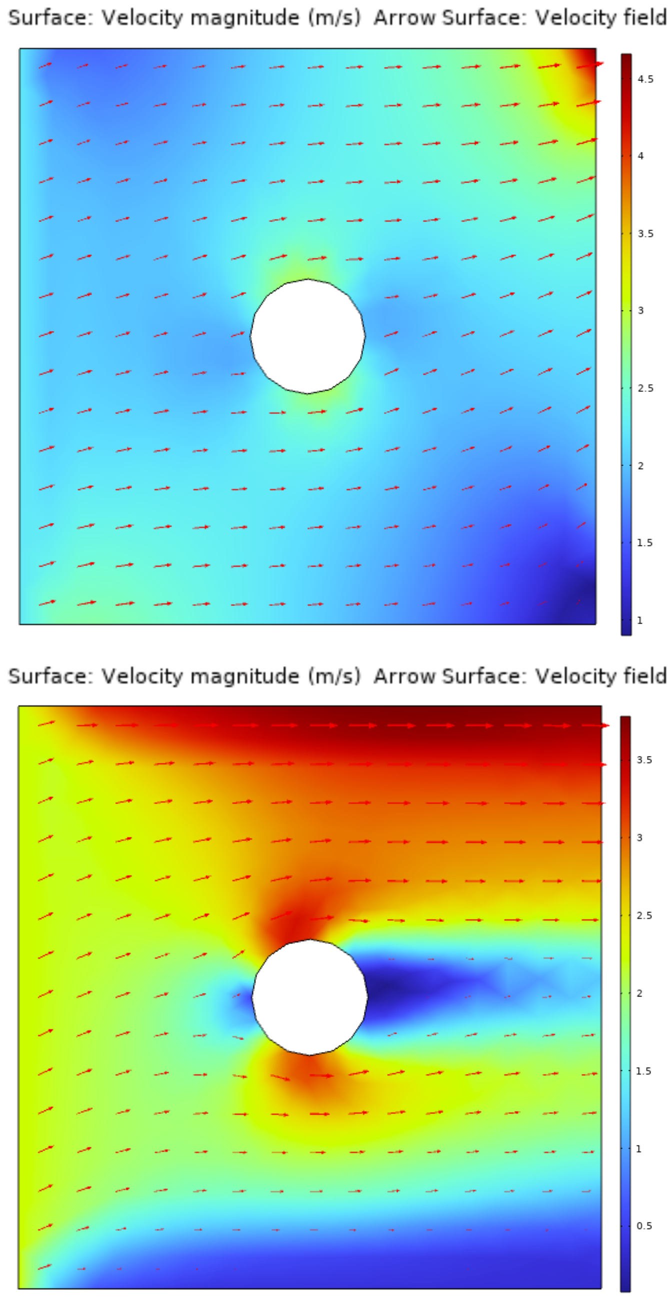

*Figure 7. Expected unit test output, Q7. **Top**: Velocity field and magnitude, t = 0 seconds. **Bottom**: Velocity field and magnitude, t = 1 second*

8) (TA2 Model Coupling) **Coupled Cahn-Hilliard and Turbulent Flow Model**: Create a coupled Cahn-Hilliard and Turbulent Flow model. You may do this either by 1) updating your coupled model from Q6 by replacing the Laminar Flow component with the Turbulent Flow model, or 2) coupling the Cahn-Hilliard and Turbulent Flow models from scratch and then updating the geometry and parameters. Ensure you can run some test simulations with the coupled system and that the results make physical sense. If needed, update your parameters and initial and boundary conditions to increase realism.

Parts 1-2: Decision-maker Panel Questions

How confident are you that the modeling team appropriately modified and developed a model or set of models, to sufficiently explore the scenario/problem? Select confidence level on a 7-point scale.

1	2	3	4	5	6	7
Very Low	Low	Somewhat Low	Neutral	Somewhat High	High	Very High

Metric Explanation: This part involves updating or modifying physics models. Decision makers will assess whether this was approached in sensible way and whether the final model(s) is likely to support decision-maker priorities for this scenario.

The decision-maker confidence score should be supported by the answers to the following questions:

- Did modelers clearly explain the changes being made and key differences between the original and updated models? Did the modifications/extensions the modelers made make sense and were they reasonable to you?
- Are you confident that the starting model was updated in ways that make sense? Is the final model structurally sound?
- As the model was updated, was the parameter space being explored reasonable and broad enough/complete enough to support the questions required by the scenario?

Part 3: Addressing Decision-Maker Priorities

In Part 3, you will leverage the data and physics models you found and developed in Parts 1 and 2, to address various DoD decisionmaker questions aligned with the priorities described in the scenario background.

Due to the limitations of a time-bound evaluation, there will be a number of simplifications in this analysis and the focus of this scenario will be on the way temperature and relative humidity (or water vapor in the atmosphere) impact radar performance, but please note that in reality there are a number of other relevant environmental factors are relevant.

Part 3 supports <u>Decision-maker Confidence Metric 3</u>: "Confidence in understanding model results." Decision makers will be asked about their confidence in understanding model output, and confidence in interpreting uncertainty and the conclusions that can be made.

To determine radar characteristics, you will be using the **Radar Equation in Receiver Output SNR (Signal to Noise Ratio) Form:**

$$SNR = \frac{P_r}{N} = \frac{P_t \tau G_t G_r \lambda^2 \sigma}{(4\pi)^3 k T_s R_t^2 R_r^2 L_{atm}}$$

- R_t = transmitter range to target (m). For monostatic radar, the transmit and receive range are identical; therefore $R_t = R_r$
- R_r = receiver range to target (m). For monostatic radar, the transmit and receive range are identical; therefore $R_t = R_r$
- P_t = power transmitted by radar (watts)
- k = Boltzmann constant (J/K)
- T_s = ambient temperature of radar location(K)
- τ = pulse duration (μs)
- G = antenna gain (dB), which is a measure of how focused the radar beam is. For monostatic radar, the transmit and receive antenna gains are identical, thus $G_t = G_r$
- λ = wavelength of radar pulse (m)
- L_{atm} = atmospheric loss factor (dB)
- σ = radar cross section (m^2)

Consider a radar system with the following technical specifications. Assume this system is the same system being used at all of the locations under consideration in this scenario.

- Monostatic radar
  - Antenna gain for both transmit and receive are the same
  - Range for both transmit and receive are the same
- For the following questions, you will consider the following signal-to-noise ratio (SNR) values: [10dB, 20dB, 30dB, 40dB]. Higher SNR means better detection capabilities of the radar system.
- Gain G = 10 dB
- Wavelength λ = 0.03 m (corresponding to 10GHz; X-Band range)

- Pulse duration τ = 10 μs
- For target radar cross-section (RCS) σ, you will consider several targets as described in Q10
- Transmitted peak power P_t = 1e6 W

If you need to review background material on this topic, there are a number of very good references online and Matlab has a Radar Toolbox and excellent tutorial material on the topic (The reference section below provides additional online information from MathWork®).

9) (TA2/3 Model Simulation) **Simulate Clouds and Determine Moisture Content**: Use the climate data that you found in Q1 to initialize and simulate your coupled Cahn-Hilliard and Turbulent Flow model from Q8, for the following locations, years, and altitudes:

    - **Locations**: Anchorage, Alaska; Seattle/Tacoma, Washington; Honolulu, Hawaii
    - **Time periods**: 1970, 2025, 2050 and 2075
    - **Altitudes**: MSL, 750 m, 1500 m, 3050 m, 6100 m
    - For each simulation, you can use the temperature data to set pressure for each altitude according to the ideal gas law (see References for relevant equations).
    - For each simulation, you can use humidity data to initialize the phase field variable for the Cahn-Hilliard portion of your model.

    Simulate your model under these conditions and determine how cloud formation patterns, size, and moisture content (based on volume fraction of fluid) vary by location, year, and altitude.

10) (TA4 Data Transformation) **Impact of Cloud Patterns on Radar Performance**: Based on your simulations from Q9, now determine the impact of cloud formation on *max range for detection* (R_t) of the specified radar system, according to the radar equation described above. Determine impact on R_t for the following locations, years, and altitudes:

    - **Locations**: Anchorage, Alaska; Seattle/Tacoma, Washington; Honolulu, Hawaii
    - **Time periods**: 1970, 2025, 2050 and 2075
    - **Altitudes**: MSL, 750 m, 1500 m, 3050 m, 6100 m

    For each of your simulations from Q9, are there points in time where one or more of the following targets could be 'hidden' or where their detection signature could be largely degraded, based on the size of the cloud formations? If so, use your simulation outputs at those points in time to answer this question.

    Targets to consider:

    - F-18, which has RCS of 1 m^2
    - A Tomahawk missile, which has an RCS of 0.5 m^2
    - A commercial airline, which has an RCS on the order of 10 m^2

    To determine R_t you will first need to determine atmospheric loss (L_{atm}), which can be calculated with Matlab's built-in function from their Radar Toolbox called **fogpl** (*R, freq,* *T, den*). Additional information on the Radar Toolbox is provided in reference section below. There are also exemplar python libraries noted in the reference section. The inputs to the **fogpl** function are as follows:

- *R* is the signal path length and not the range to the target. Set *R* to be the length scale of the clouds that are causing the loss factor for the radar system. You can use the length of the biggest cross section area of cloud from each of your simulations. Units are meters.
- *freq* (units Hz) = c/λ; c is the speed of light; λ is the wavelength of light.
- *T* = temperature at a particular altitude, in ºC. Set this according to the data you found in Q1.
- *den* = cloud liquid water density (g/m^3). To calculate this, use the volume fraction of fluids from your simulations in Q10, and the density of water.

The output of **fogpl**(*R, freq, T, den*) is atmospheric loss (L_{atm}), in units dB.

Using L_{atm} and the Radar Equation, calculate and plot *max range for detection* (R_t) as a function of location, year, and altitude.

11) **Conclusions and Recommendations for Decisionmakers**: Please summarize your findings for DoD decisionmakers and if appropriate, recommend courses of action. You may want to consider the following:
    - Are there instances (locations, altitudes) where radar detection range improves or is degraded over time and due to changing climate conditions, and by how much?
    - Which of the three locations under consideration in this scenario are most impacted by future climate conditions in 2050 and 2075, compared to the current year?

    Based on your findings and conclusions in this scenario, recommend courses of action for DoD decisionmakers, for each location discussed in the scenario.

    This question is intentionally open-ended, to allow you to have flexibility in the types of recommendations you think are appropriate, and that can be evidence-based and backed up by all of the work you have developed in this scenario.

References

MathWorks® MATLAB® Radar Toolbox

- https://www.mathworks.com/help/radar/index.html
- https://www.mathworks.com/help/radar/ug/modeling-the-propagation-of-rf-signals.html

Python Libraries for Radar

- Py-ART (https://arm-doe.github.io/pyart/)
- Wradlib (https://wradlib.org/)

Books

- Harrison, A., "Introduction to Radar using Python and MATLAB®", 2020, ARTECH HOUSE, 685 Canton Street, Norwood, MA 02062. ISBN 13: 978-1-63081-597-4. (PDF and source code online).

Table 2. Forms of the Ideal Gas Law

$PV = nRT\ (expressed\ classically)$ $PM = \rho RT\ (expressed\ with\ density)$	▪ P = pressure [Pa] ▪ V = volume [m^3] ▪ n = number of moles of gas (can be consider "mass") ▪ R = universal gas constant = 8.31432 [N*m/mol*K] ▪ T = temperature [K] ▪ M = molar mass [kg/moles]. Earth's air = 0.0289 [kg/mol] ▪ ρ = gas density [kg/m^3] ▪ Note: $\rho \propto \frac{1}{T}$ (density is inversely proportional to temperature)
$\frac{\rho_1}{\rho_2} = \frac{T_2}{T_1}$	▪ Use a modified form of the Ideal Gas Law to calculate the air density at each temperature
STP: Standard Temperature and Pressure	▪ T = 273.15K (0^{o}C, 32^{o}F) ▪ P = absolute pressure of exactly 1 bar (100 kPa, 10^5 Pa) ▪ Sea Level

Table 3. Barometric Law, Explicit Form

Sea Level to Troposphere. Calculate air pressure at a given altitude (pressure and temperature at sea level must be known): $P = P_b\left[1 - \frac{L_b}{T_b}(H - H_b)\right]^{\frac{g_0 M}{R L_b}}$ Calculate altitude at a given air pressure (pressure and temperature at sea level must be known): $H = H_b - \frac{T_b}{L_b}\left[\left(\frac{P}{P_b}\right)^{\frac{R L_b}{g_0 M}} - 1\right]$	• P_b [Pa]= reference pressure (pressure at sea level) • T_b [K] = reference temperature at reference level *b*. For *b* = 0, this is temperature at sea level • $L_{,b}$ [K/m] = temperature lapse rate for reference level *b*. For *b* = 0, this is 0.0065 [K/m] • *H* [m]= height at which pressure is calculated • H_b [m]= height at the bottom of the reference level b. For *b* = 0, this is sea level, 0 m • *R* = universal gas constant = 8.31432 [N*m/mol*K] • g_0 = gravitational acceleration = 9.80665 [m/sec^2] • *M* = molar mass Earth's air = 0.0289 [kg/mol]

Part 3: Decision-maker Panel Questions

With what degree of confidence do you feel that you understand the modelers' results? Select confidence level on a 7-point scale.

1	2	3	4	5	6	7
Very Low	Low	Somewhat Low	Neutral	Somewhat High	High	Very High

Explanation: Based on the information presented to you by the modelers, determine your confidence in model results, and (if relevant) how uncertainty factors in.

The decision-maker confidence score should be supported by the answers to the following questions:

- Did simulation results make sense? If results did not match your intuition or expectations, did modelers explain the reason(s)? Did their explanations make sense? (Please focus on general trends rather than exact numbers).
- Is it clear how to interpret any uncertainty in the results? Do you understand the key drivers of uncertainty in the results?
- Are you confident in making decisions as indicated in the scenario, based on model results and recommendations from the modelers?