TOPIC
Climate Models, Evaluation of models, Mathematical Connections and Reasoning, and Problem Solving

KEY QUESTION
How do you evaluate and rank each climate model and develop a method for making an overall ranking of the models through analyzing the simulation results from each model and an observed record?

LEARNING GOALS
Students will:
• Use numeric and visual data to create a reasonable measurement scheme
• Consider how to use and exclude data
• Create a new procedure for quantifying qualitative information
• Make decisions about whether or not a solution meets the needs of a client
• Communicate the solution clearly to the client

GUIDING DOCUMENTS
This activity has the potential to address many mathematics and science standards. Please see pages 5-7 for a complete list of mathematics and science standards.

RECOMMENDED SUPPLIES FOR ALL MODEL-ELICITING ACTIVITIES
It is recommended to have all of these supplies in a central location in the room. It is recommended to let the students know that they are available, but not to encourage them to use anything in particular.

• Overhead transparencies and transparency markers/pens, whiteboards and markers, or other presentation tools such as a document camera.
• Calculators
• Rulers, scissors, tape
• Markers, colored pencils, pencils
• Construction paper, graph paper, lined paper
• Paper towels or tissues (for cleaning transparencies)
• Manila folders or paper clips for collecting the students’ work
• Optional: Computers with programs such as Microsoft Word and Excel

WHAT ARE MODEL-ELICITING ACTIVITIES (MEAs)?
Model-Eliciting Activities are problem activities explicitly designed to help students develop conceptual foundations for deeper and higher order ideas in mathematics, science, engineering, and other disciplines. Each task asks students to mathematically interpret a complex real-world situation and requires the formation of a mathematical description, procedure, or method for the purpose of making a decision for a realistic client. Because teams of students are producing a description, procedure, or method (instead of a one-word or one-number answer), students’ solutions to the task reveal explicitly how they are thinking about the given situation.

THE CLIMATE MODEL MEA CONSISTS OF FOUR COMPONENTS:
1) Newspaper article: Students individually read the newspaper article to become familiar with the context of the problem. This handout is on page 8-9.
2) Readiness questions: Students individually answer these reading comprehension questions about the newspaper article to become even more familiar with the context and beginning thinking about the problem. This handout is on page 10. (Optional)
3) Problem statement: In teams of three or four, students work on the problem statement
for 45 – 90 minutes. This time range depends on the amount of self-reflection and revision you want the students to do. It can be shorter if you are looking for students’ first thoughts, and can be longer if you expect a polished solution and well-written letter. The handouts are on pages 11-16. Each team needs the handouts on pages 11-16.

4) Process of sharing solutions: Each team writes their solution in a letter or memo to the client. Then, each team presents their solution to the class. Whole class discussion is intermingled with these presentations to discuss the different solutions, the mathematics involved, and the effectiveness of the different solutions in meeting the needs of the client. In totality, each MEA takes approximately 2-3 class periods to implement, but can be shortened by having students do the individual work during out-of-class time. The Presentation Form can be useful and is explained on page 4 and found on page 18.

RECOMMENDED PROGRESSION OF THE CLIMATE MODEL MEA

While other implementation options are possible for MEAs, it is recommended that the MEA be implemented in a cooperative learning format. Numerous research studies have proven cooperative learning to be effective at improving student achievement, understanding, and problem solving skills. In this method students will complete work individually (Newspaper article and readiness questions; as well as initial thoughts on the problem statement) and then work together as a group. This is important because brainstorming works best when students have individual time to think before working as a group. Students can be graded on both their individual and group contributions. Social skills’ discussion at the beginning of the MEA and reflection questions at the end of the MEA are also essential aspects of cooperative learning.

Social Skills (3 -5 minutes)
Students must be taught how to communicate and work well in groups. Several social skills that are essential to group work are decision-making, asking questions, and communicating and listening. The teacher can show part of a YouTube video and discuss aspects of these skills before beginning the MEA.
(http://www.youtube.com/user/flowmathematics)

Newspaper Article and Readiness Questions:
The purpose of the newspaper article and the readiness questions is to introduce the students to the context of the problem.

(10 minutes): Give the article and the questions to the students the day before for homework. Then, in the next class, discuss as a class the answers to the readiness questions before beginning to discuss the problem statement.

Problem Statement:
You may want to read the problem statement to the students and then identify as a class: a) the client that the students are working for and b) the product that the students are being asked to produce. Once you have addressed the points above, allow the students to work on the problem statement. Let the students know that they will be sharing their solution to the rest of the class. Tell students you that you will randomly pick a group member to present for each group. Tell the students that they need to make sure that everyone understands their group’s solution so they need to be sure to work together well. The group member who will present can be picked by assigning each group member a number.

Working on the Problem Statement (35-50 minutes): Place the students in teams of three or four. Students should begin to work by sharing their initial ideas for solving the problem. If you already use teams in your classroom, it is best if you continue with these same teams since results for MEAs are better when the students have already developed a
working relationship with their team members. If you do not use teams in your classroom and classroom management is an issue, the teacher may form the teams. If classroom management is not an issue, the students may form their own teams. You may want to have the students choose a name for their team to promote unity.

**Teachers’ role:** As they work, your role should be one of a facilitator and observer. Avoid questions or comments that steer the students toward a particular solution. Try to answer their questions with questions so that the student teams figure out their own issues. Also during this time, try to get a sense of how the students are solving the problem so that you can ask them questions about their solutions during their presentations.

**Presentations of Solutions** (15-30 minutes): The teams present their solutions to the class. There are several options of how you do this. Doing this electronically or assigning students to give feedback as out-of-class work can lessen the time spent on presentations. If you choose to do this in class, which offers the chance for the richest discussions, the following are recommendations for implementation. Each presentation typically takes 3 – 5 minutes. You may want to limit the number of presentations to five or six or limit the number of presentations to the number of original (or significantly different) solutions to the MEA.

Before beginning the presentations, encourage the other students to not only listen to the other teams’ presentations but also to a) **try to understand the other teams’ solutions** and b) **consider how well these other solutions meet the needs of the client.** You may want to offer points to students that ask ‘good’ questions of the other teams, or you may want students to complete a reflection page (explanation – page 4, form – page 20) in which they explain how they would revise their solution after hearing about the other solutions. As students offer their presentations and ask questions, whole class discussions should be intermixed with the presentations in order to address conflicts or differences in solutions. When the presentations are over, collect the student teams’ memos/letters, presentation overheads, and any other work you would like to look over or assess.

**ASSESSMENT OF STUDENTS’ WORK**
You can decide if you wish to evaluate the students’ work. If you decide to do so, you may find the following Assessment Guide Rubric helpful:

Performance Level Effectiveness: Does the solution meet the client’s needs?

**Requires redirection:** The product is on the wrong track. Working longer or harder with this approach will not work. The students may need additional feedback from the teacher.

**Requires major extensions or refinements:** The product is a good start toward meeting the client’s needs, but a lot more work is needed to respond to all of the issues.

**Requires editing and revisions:** The product is on a good track to be used. It still needs modifications, additions or refinements.

**Useful for this specific data given, but not shareable and reusable OR Almost shareable and reusable but requires minor revisions:** No changes will be needed to meet the immediate needs of the client for this set of data, but not generalized OR Small changes needed to meet the generalized needs of the client.

**Share-able or re-usable:** The tool not only works for the immediate solution, but it would be easy for others to modify and use in similar situations. OR The solution goes above and beyond meeting the immediate needs of the client.
IMPLEMENTING AN MEA WITH STUDENTS FOR THE FIRST TIME

You may want to let students know the following about MEAs:

• MEAs are longer problems; there are no immediate answers. Instead, students should expect to work on the problem and gradually revise their solution over a period of 45 minutes to an hour.

• MEAs often have more than one solution or one way of thinking about the problem.

• Let the students know ahead of time that they will be presenting their solutions to the class. Tell them to prepare for a 3-5 minute presentation, and that they may use overhead transparencies or other visuals during their presentation.

• Let the students know that you won’t be answering questions such as “Is this the right way to do it?” or “Are we done yet?” You can tell them that you will answer clarification questions, but that you will not guide them through the MEA.

• Remind students to make sure that they have returned to the problem statement to verify that they have fully answered the question.

• If students struggle with writing the letter, encourage them to read the letter out loud to each other. This usually helps them identify omissions and errors.

OBSERVING STUDENTS AS THEY WORK ON THE CLIMATE MODEL MEA

You may find the Observation Form (page 19) useful for making notes about one or more of your teams of students as they work on the MEA. We have found that the form could be filled out “real-time” as you observe the students working or sometime shortly after you observe the students. The form can be used to record observations about what concepts the students are using, how they are interacting as a team, how they are organizing the data, what tools they use, what revisions to their solutions they may make, and any other miscellaneous comments.

PRESENTATION FORM (Optional)

As the teams of students present their solutions to the class, you may find it helpful to have each student complete the presentation form on page 20. This form asks students to evaluate and provide feedback about the solutions of at least two teams. It also asks students to consider how they would revise their own solution to the Climate Model MEA after hearing of the other teams’ solutions.

STUDENT REFLECTION FORM

You may find the Student Reflection Form (page 21) useful for concluding the MEA with the students. The form is a debriefing tool, and it asks students to consider the concepts that they used in solving the MEA and to consider how they would revise their previous solution after hearing of all the different solutions presented by the various teams. Students typically fill out this form after the team presentations.

STANDARDS ADDRESSED

NCTM Mathematics Standards

Numbers and Operations:

• Work flexibly with fractions, decimals, and percents to solve problems

• Understand and use ratios and proportions to represent quantitative relationships

• Understand the meaning and effects of arithmetic operations with fractions, decimals, and integers

• Develop and analyze algorithms for computing with fractions, decimals, and integers and develop fluency in their use

• Judge the reasonableness of numerical computations and their results

Algebra
• Represent, analyze, and generalize a variety of patterns with tables, graphs, words, and, when possible, symbolic rules
• Relate and compare different forms of representation for a relationship
• Model and solve contextualized problems using various representations, such as graphs, tables, and equations
• Use symbolic algebra to represent and explain mathematical relationships
• Identify essential quantitative relationships in a situation and determine the class or classes of functions that might model the relationships
• Draw reasonable conclusions about a situation being modeled

Geometry
• Use Cartesian coordinates and other coordinate systems, such as navigational, polar, or spherical systems, to analyze geometric situations
• Use geometric ideas to solve problems in, and gain insights into, other disciplines and other areas of interest such as art and architecture
• Use geometric models to represent and explain numerical and algebraic relationship
• Recognize and apply geometric ideas and relationships in areas outside the mathematics classroom, such as art, science, and everyday life.

Measurement
• Solve simple problems involving rates and derived measurements for such attributes as velocity and density
• Understand relationships among units and convert from one unit to another within the same system
• Use common benchmarks to select appropriate methods for estimating measurements
• Analyze precision, accuracy, and approximate error in measurement situations

Data Analysis and Probability
• Find, use, and interpret measures of center and spread, including mean and interquartile range
• Discuss and understand the correspondence between data sets and their graphical representations, especially histograms, stem-and-leaf plots, box plots, and scatter plots
• Select, create, and use appropriate graphical representations of data, including histograms, box plots, and scatter plots

Problem Solving
• Build new mathematical knowledge through problem solving

ABILITIES OF TECHNOLOGICAL DESIGN
• Solve problems that arise in mathematics and in other contexts
• Apply and adapt a variety of appropriate strategies to solve problems
• Monitor and reflect on the process of mathematical problem solving

Reasoning and Proof
• Develop and evaluate mathematical arguments and proofs
• Make and investigate mathematical arguments and proofs

Communication
• Organize and consolidate their mathematical thinking through communication
• Communicate their mathematical thinking coherently and clearly to peers, teachers, and others
• Analyze and evaluate the mathematical thinking and strategies of others
• Use the language of mathematics to express mathematical ideas precisely

Connections
• Recognize and use connections among mathematical ideas
• Understand how mathematical ideas interconnect and build on one another to produce a coherent whole
• Recognize and apply mathematics in contexts outside of mathematics

Representation
• Create and use representations to organize, record, and communicate mathematical ideas
• Select, apply, and translate among mathematical representations to solve problems
• Use representations to model and interpret physical, social, and mathematical phenomena

NRC SCIENCE STANDARDS

Inquiry
• Use appropriate tools and techniques to gather, analyze and interpret data
• Develop descriptions, explanations, predictions, and models using evidence
• Think critically and logically to make the relationships between evidence and explanations
• Recognize and analyze alternative explanations and predictions
• Communicate scientific procedures and explanations
• Use mathematics in all aspects of scientific inquiry

• Identify appropriate problems for technological design.
• Design a solution or product.
• Evaluate completed technological designs or products.
• Communicate the process of technological design.

SCIENCE AND TECHNOLOGY IN LOCAL, NATIONAL, AND GLOBAL CHALLENGES

• Understanding basic concepts and principles of science and technology should precede active debate about the economics, policies, politics, and ethics of various science- and technology-related challenges. However, understanding science alone will not resolve local, national, or global challenges.

Common Core Math Standards

4.G. 3 Recognize a line of symmetry for a two-dimensional figure as a line across the figure such that the figure can be folded along the line into matching parts. Identify line-symmetric figures and draw lines of symmetry.

6.NS.5 Understand that positive and negative numbers are used together to describe quantities having opposite directions or values (e.g., temperature above/below zero, elevation above/below sea level, credits/debits, positive/negative electric charge); use positive and negative numbers to represent quantities in real-world contexts, explaining the meaning of 0 in each situation.

6.NS.6 Understand a rational number as a point on the number line. Extend number line diagrams and coordinate axes familiar from previous grades to represent points on the line and in the plane with negative number coordinates.

a) Recognize opposite signs of numbers as indicating locations on opposite sides of 0 on the number line; recognize that the opposite of the opposite of a number is the number itself, e.g., –(–3) = 3, and that 0 is its own opposite.

6.SP.2 Understand that a set of data collected to answer a statistical question has a distribution which can be described by its center, spread, and overall shape.

6.SP.5 Summarize numerical data sets in relation to their context, such as by:

a. Reporting the number of observations.

b. Describing the nature of the attribute under investigation, including how it was measured and its units of measurement.

c. Giving quantitative measures of center (median and/or mean) and variability (interquartile range and/or mean absolute deviation), as well as describing any overall pattern and any striking deviations from the overall pattern with reference to the context in which the data were gathered.

d. Relating the choice of measures of center and variability to the shape of the data distribution and the context in which the data were gathered.

7.NS.1 Apply and extend previous understandings of addition and subtraction to add and subtract rational numbers; represent addition and subtraction on a horizontal or vertical number line diagram.

a. Describe situations in which opposite quantities combine to make 0. For example, a hydrogen atom has 0 charge because its two constituents are oppositely charged.

b. Understand \( p + q \) as the number located a distance \(|q|\) from \( p \), in the positive or negative direction depending on whether \( q \) is positive or negative. Show that a number and its opposite have a sum of 0 (are additive inverses). Interpret sums of rational numbers by describing real-world contexts.

HS. S.IC. 6 Evaluate reports based on data
<table>
<thead>
<tr>
<th>Mathematical Practice</th>
<th>How it occurs in MEAs</th>
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<tbody>
<tr>
<td>1. Make sense of problems and persevere in solving them.</td>
<td>As participants work through iterations of their models they continue to gain new insights into ways to use mathematics to develop their models. The structure of MEAs allows for participants to stay engaged and to have sustained problem solving experiences.</td>
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<td>2. Reason abstractly and quantitatively</td>
<td>MEAs allow participants to both contextualize, by focusing on the real world context of the situation, and decontextualize by representing a situation symbolically.</td>
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<td>3. Construct viable arguments and critique the reasoning of others.</td>
<td>Throughout MEAs while groups are working and presenting their models.</td>
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<tr>
<td>4. Model with mathematics.</td>
<td>This is the essential focus of MEAs; for participants to apply the mathematics that they know to solve problems in everyday life, society, or the workplace. This is done through iterative cycles of model construction, evaluation, and revision.</td>
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<tr>
<td>5. Use appropriate tools strategically.</td>
<td>Materials are made available for groups as they work on MEAs including graph paper, graphing calculators, computers, applets, dynamic software, spreadsheets, and measuring devices.</td>
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<tr>
<td>6. Attend to precision.</td>
<td>Precise communication is essential in MEAs and participants develop the ability to communicate their mathematical understanding through different representations including written, verbal, symbolic, graphical, pictorial, concrete, and realistic.</td>
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<tr>
<td>7. Look for and make use of structure.</td>
<td>Participants in MEAs can use their knowledge of mathematical properties and algebraic expressions to develop their solutions.</td>
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<td>8. Look for and express regularity in repeated reasoning.</td>
<td>As participants develop their models the patterns they notice can assist in their model development.</td>
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Evaluating Climate Models
Background Reading

Twin Cities, Minnesota – Researchers from around the world are interested in studying Earth’s climate. Some scientists are interested in the current climate and weather conditions. They make observations using real-time information from weather stations, weather balloons, and satellites. Others study what the climate was like hundreds, thousands, and millions of years ago (called paleoclimate) by looking at ice cores, sediments from the bottom of the ocean, tree rings, and fossils. While it is valuable to know about Earth’s climate in the past and present, people are most interested in predicting what the climate will be like in the future.

One approach scientists have developed to predict future climate is computer modeling of the global environment. A climate model is a tool that researchers use to understand the workings of the intricate systems that make up the earth’s climate. Climate researchers can’t conduct experiments in the real world to check their ideas. But computer simulations—which use equations to represent the physical processes of the climate—allow researchers to experiment with a virtual world.

Climate models are complex—like climate itself. Because there are still wide gaps in our understanding of the complexity of Earth’s climate, different models incorporating different data and assumptions produce varying projections of the planet’s future climate. To test a climate model, scientists compare the model’s predictions to observations made in the real world. This process, known as validation, allows researchers to see where a model’s predictions match reality—and where the model goes astray. They can then be used to predict future changes by adjusting the computer code numbers to account for higher levels of atmospheric greenhouse gases.

Currently, scientists are working to understand a number of important factors that contribute to climate change—including how the climate varies naturally, how it reacts to emissions of greenhouse gases and aerosols, and how various feedback mechanisms contribute to climate change.

For example, one feedback mechanism that could amplify the effect of global warming relates to the melting of snow and ice. Earth’s temperature depends, in part, on how much sunlight the planet absorbs, and how much it reflects back into space. Snow and ice reflect more sunlight than bare ground or water. As the earth’s temperature increases, its snow and ice cover...
decreases, and more bare ground and open water are revealed. As a result, the earth might absorb more sunlight, which could result in further warming.

But because there is still a lot that researchers don’t understand about these processes, the climate models that combine them to project the future don’t always agree. As George Mason University physicist James Trefil points out: “Computer models of climate are the most complicated, ingenious computer systems I’ve ever seen. I mean, they really are good. But in the end, you have to just face the fact that they are not going to be able to give you precise, certain answers. They’re going to give you, ‘We think this is what’s going to happen, and here’s the limits of error.’ And that’s the uncertainty, and you have to choose.”
Readiness Questions

Answer the following questions once you have completed the background reading

1. Why are climate models helpful to researchers?

2. How are climate models tested?

3. Why do different climate models produce different results?

4. What further questions do you have about climate models?
Evaluating Climate Models

INTERNAL MEMORANDUM

TO: Climate Model Evaluation Team
FROM: Profs. Thomas Stocker & Qin Dahe
       Co-Chairs, Working Group I, United Nations Intergovernmental Panel on Climate Change (IPCC)
RE: "Assessment Report: Climate Model Evaluation"

Research teams from the United States, Japan, United Kingdom, China, and Germany (among other countries) have developed global climate models for the upcoming IPCC Assessment Report. This report will be used to assess scientific, technical, and socio-economic information concerning climate change, its potential effects, and options for adaptation and mitigation. Climate models are an important research tool for understanding Earth’s climate and predicting how our climate might change in response to possible future conditions.

As part of this report, we must evaluate the five research teams’ models by determining how well each simulates present climate. If a model poorly simulates the present climate this could indicate that certain physical or dynamical processes have been misrepresented in the model. The better a model simulates the complex spatial patterns, and seasonal and daily cycles of present climate, the more confidence we can have that all the important processes have been taken into account. In turn we can have more confidence that a model can provide accurate predictions of future climate conditions.

We have asked each research team to run their computer models to simulate the climate over the past 30 years and provide maps of the following: average yearly temperature, average seasonal temperature range, average daily temperature range, and average annual precipitation. We have also provided the observed data over this time period with a map of the difference between the observed and the modeled data. (To avoid bias into your rankings, we have labeled the data ‘Model 1’, ‘Model 2’, etc.)

Based on this information, your job is to develop a reliable procedure for evaluating and ranking each model. Then, using your procedure, provide an overall ranking of the models, as well as rankings for each of the four categories.

In your final memo, please include the following:

1. A detailed procedure for evaluating and ranking each model
2. Overall rankings for the five models
3. Rankings for each of the four categories (average yearly temp, average seasonal temperature range, average daily temperature range, and average yearly precipitation)

Thank you in advance for your hard work on this important project.