National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

NASA Climate Change Research Initiative

Applied Research STEM Curriculum Portfolio

CCRI Unit Plan

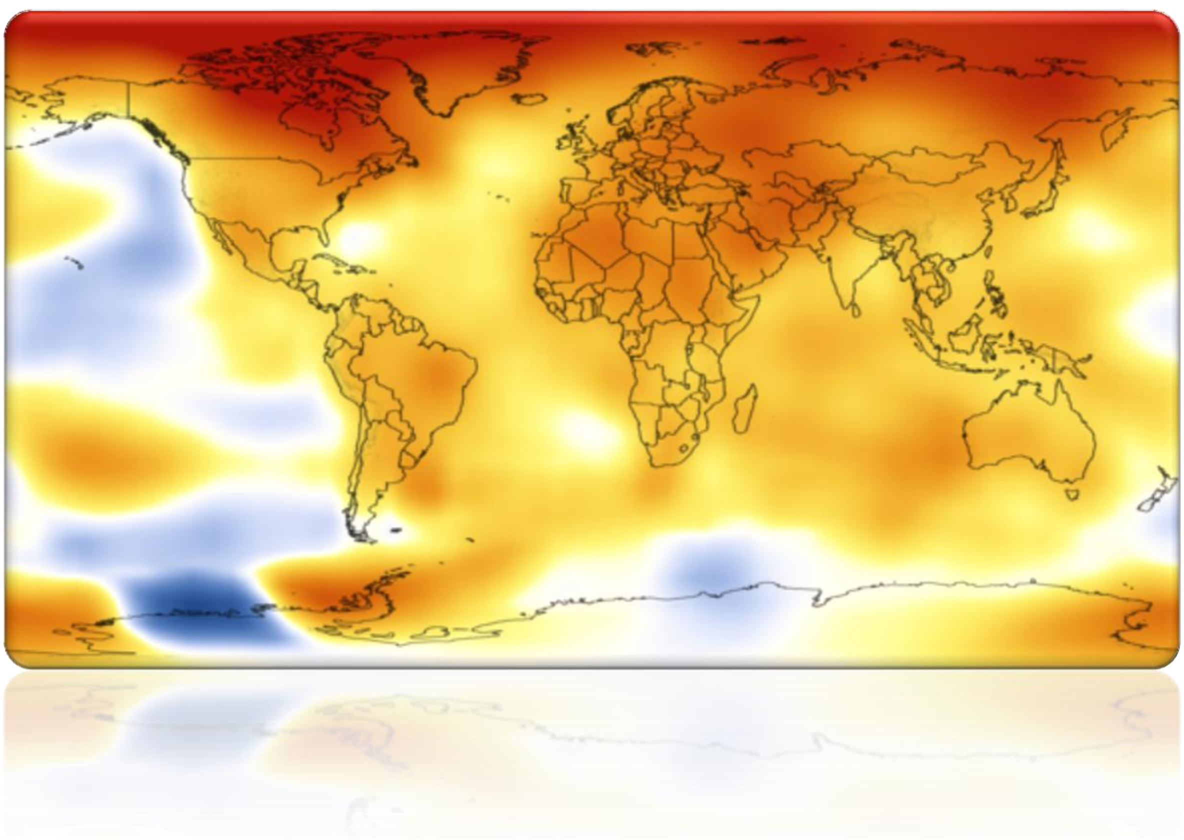
NASA Science Mission Directorate | Earth Sciences Division
NASA Goddard Institute for Space Studies
NASA Goddard Space Flight Center | Office of STEM Engagement

Unit Title: Urban Surface Temperatures and the Urban Heat Island Effects

Overarching Investigative Research Question: How does Urban Heat Island contributes to climate change?

NASA STEM Educator / Associate Researcher: Alejandro Mundo

NASA PI /Mentor: Dr. Christian Braneon



I. Executive Summary

Cities that are growing at a fast pace are notable entities of innovation and city development. As population keeps growing in urban settings, the need to understand urban climates has awakened much interest and discussion among our society. Due to urbanization, land surface temperatures are intensifying with much warmer temperatures than surrounding areas, making cities experience the Urban Heat Island phenomenon.

This unit plan called "Urban Surface Temperatures and the Urban Heat Island Effects" has the purpose to educate students how climate is changing in urban settings and produce mitigation solutions for city environmental concerns through the use of groundbreaking technology and authentic science learning experiences.

Students are exposed to real-world scientific experiences like the exploration of climate simulation models, global temperature profiles and climate change evidence analysis during the first lesson. Later, they learn about remote sensing and investigate instruments on climate satellites. Students are exposed to remote sensing imagery analysis and dive into the Urban Heat Island effects on the third lesson. Subsequently, they are immersed into land surface temperature data collection, analysis and review a scientific journal. The unit concludes by having students create a physical model that promotes the concept of the Urban Heat Island and mitigation factors to include human action towards climate in urban settings.

This unit plan has been created for high school students in an Earth Science class or related subject. It has been aligned with science standards from the Next Generation of Science Standards as well as the New York State Earth Science Standards and the Common Core State Standards. Furthermore, this curriculum has been aligned with NASA's mission, vision and STEM resources to enhance scientific understanding of Earth as a system and its response towards natural and human-induced changes in order to improve our ability to predict climate, weather and natural hazards.

By the end of this unit plan comprised of four lessons and a capstone project, students will have a better understanding of the Urban Heat Island phenomenon and its recent and future effects on major cities around the world. In addition, students will have a better understanding of climate and remote sensing as the process to study climate-related issues, such as land surface temperatures.

Keywords:

Climate, Urban Heat Island, land surface temperature, remote sensing, climate change, climate variability, Earth science, greenhouse effects

II. Table of Contents

III. NGSS and Common Core Alignment

Grade Band	11^{th} to 12^{th} grade students
Unit Duration	This unit plan has a duration of approximately 2 weeks, although it can be extended or modified in time based on classroom and students' needs. It includes 4 lessons and one capstone project towards the end.
Sphere	Atmosphere, Hydrosphere, Biosphere, Geosphere, Earth as a system
Phenomena	Land Surface Temperature Earth Materials Urban Heat Island Flow of Energy and Matter
NGSS Disciplinary Core Ideas	ESS2A: Earth Materials and Systems ESS2D: Weather and Climate ESS3D: Global Climate Change ETS1.B: Developing Possible Solutions
NGSS Science and Engineering Practices	Patterns Cause and Effect Analyzing and Interpreting Data Science Addresses Questions About the Natural and Material World
NGSS Crosscutting Concepts	(HSESS3-3) Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible. (HS-ETS1-3) Evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.
Supported NGSS Performance Expectations	**ESS2**: Earth's Systems **ESS3**: Earth and Human Activity
Supported Common Core ELA	**CCSS.ELA-LITERACY.RL.11-12.1** Cite strong and thorough textual evidence to support analysis of what the text says explicitly as well as inferences drawn from the text, including determining where the text leaves matters uncertain. 11-12.RST.7 Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.
Supported Common Core Math	CCSS.MATH.CONTENT.HSN.Q.A.2 Define appropriate quantities for the purpose of descriptive modeling.

IV. CCRI Educator Biography

Inspiring and engaging, Alejandro Mundo positively impacts students, colleagues and the Kingsbridge International High School, a public school in the Bronx, New York. Mundo knows his students can do anything—and he helps them believe it too. Ever since becoming an educator and the head of the science department, he has opened a new world of opportunities in science, technology and engineering for his students, who engage in hands-on learning opportunities in all his classes. In Earth Science, students learn scientific concepts not from lectures, textbooks or memorization but through manipulatives and lab experiences that illustrate the concepts.

Mundo is known for raising minority young scientists and encouraging them to pursue STEM careers. His constant approach on informal learning including science institutions and trips to the American Museum of Natural History, allows his students to investigate science in practical ways. He has taken the lead on students' involvement in community leadership; his focus on schoolwide diversity in science careers led to the creation of his science club, where students not only do science in fun ways inside the classroom, but go out to plant trees, clean parks, attend science community engagement events in order to demonstrate leadership and citizenship responsibility for a better world.

In 2019 he was involved in a National Science Foundation grant that focused on early evolution of animals through the study of the trilobite fossil record in New York where he did paleontology fieldwork and facilitated the integration of these experiences both at the American Museum of Natural History and his students. He has done geologic research in Riverside Park in Manhattan to analyze the pressure-temperature at peak metamorphism and determine the mineralogical composition using the Raman spectroscopy geothermobarometer to study the metamorphism of Manhattan.

His scientific research focuses on environmental sustainability and climate change. He is especially interested in understanding the climate processes that affect urban environments, like the Urban Heat Island Effect, using a remote sensing aspect like Landsat satellite data from past and present distributions of land surface temperatures, calculating normalized difference vegetation indices, as well as making future projections. He is currently working as an associate researcher on the Earth Observation Applications for Resiliency research project at the Climate Change Research Initiative at NASA's Goddard Institute for Space Studies in New York City. His interests include producing mitigation factors in afflicted urban areas due to climate change. He has held multiple STEM engagement events among the community including students, parents, educators and general public in both English and Spanish and has recently been featured as a speaker at the NASA's STEM STARS En Español program.

Mundo arrived to the United States when he was 12 years old; facing the barriers of a new language, customs and culture, he used those obstacles to overcome his fears and achieve the American Dream. He earned a bachelor's degree in geological sciences and a minor in science, technology and society from the California State Polytechnic University, Pomona in 2015, and a master's in teaching earth sciences from the Gilder Graduate School from the American Museum of Natural History in 2017. His professional goal is to build strong relationships with other educators, do meaningful discoveries through scientific research and inspire future generations of minority students to get a STEM career.

Name: Alejandro A. Mundo
School: Kingsbridge International High School **Content:** Earth Science & Astronomy
Contact: mundoalejandro@gmail.com

V. NASA Education Resources Utilized in Unit

1. NASA Science Activation Education Resources Utilized in Unit

This unit plan utilizes the following NASA Education resource:

Mission Earth: Fusing GLOBE with NASA Assets to Build Systemic Innovation in STEM Education

Definition: GLOBE provides students and the public with opportunities to participate in data collection and the scientific process.

Objective: Students will use this education resource to explore the land surface temperatures (LST's) outside of school and compare their results with other young scientists (students) that have compiled their data like them by using NASA's sponsored program GLOBE.

2. Next Gen STEM Resources

This Unit Plan closely aligns and supports the following NASA's Next Gen STEM resources:

Perseverance Rover to Mars *(Lesson 1)*

Description: NASA's Mars Perseverance rover will search for signs of habitable conditions on Mars in the ancient past and for signs of past microbial life itself.

Objective: Students will learn how Perseverance will closely observe Mars' climate and reflect why studying climate and the changing climate is relevant to us.

James Webb Space Telescope *(Lesson 2)*

Description: James Webb Space Telescope will be the largest infrared telescope with a 6.5-meter primary mirror and it will study every phase in the history of our Universe.

Objective: Students will learn about the James Webb Space Telescope instruments and build a satellite and reflect on remote sensing, satellites and their importance in scientific research.

3. Resource Titles, descriptions, web address

Lesson 1: Making Earth Cool Again! What‘s happening to Climate?”

1. “Climate in a Box”
   Link: https://www.youtube.com/watch?v=RNoLTmBKizE
   NASA has begun to facilitate the operation of new desktop sized supercomputers, with the goal of making it substantially easier for more researchers to do meaningful work on vital and essential questions for our world's climate.

2. **“Climate Time Machine”**
   Link: https://climate.nasa.gov/interactives/climate-time-machine/
   Description: This series of visualizations show how some of Earth's key climate indicators are changing over time, specifically the Global Temperature Graph, which displays a color-coded map that shows a progression of changing global surface temperatures since 1884

3. **"Climate Change: How Do We Know?"**

   Link: https://climate.nasa.gov/evidence/
   Description: The Earth's climate has changed throughout history. Just in the last 650,000 years there have been seven cycles of glacial advance and retreat, with the abrupt end of the last ice age about 11,700 years ago marking the beginning of the modern climate era—and of human civilization. The evidence for rapid climate change is compelling and presented here.

4. **"Images of Change"**

   Link: https://climate.nasa.gov/images-of-change
   Description: The images of Change gallery features images of different locations on planet Earth, showing change over time periods ranging from centuries to days. Some of these effects are related to climate change, some are not. Some document the effects of urbanization, or the ravage of natural hazards such as fires and floods.

Lesson 2: Seeing From Another View Through Satellites

1. **"Twenty Years of Terra in Our Lives"**

   Link: https://terra.nasa.gov/news/twenty-years-of-terra-in-our-lives
   Description: Is the flagship of NASA's Earth Observing System. The satellite's five instruments concurrently observe Earth atmosphere, ocean, land, snow and ice providing insights into Earth systems such as the water, carbon and energy cycles. Terra's instruments are: ASTER, MOPITT, MISR, CERES and MODIS.

2. **"ASTER"**

   Link: https://terra.nasa.gov/about/terra-instruments/aster
   Description: Advanced Spaceborne Thermal Emission and Reflection Radiometer. ASTER is a TERRA's instrument was used to create detailed maps of Earth's temperature, emissivity, reflectance, and elevation.

3. **"CERES"**

   Link: https://terra.nasa.gov/about/terra-instruments/ceres
   Description: The Clouds and the Earth's Radiant Energy System. CERES is a TERRA's instrument that gets information about the Earth's radiation balance.

4. **"MISR"**

   Link: https://terra.nasa.gov/about/terra-instruments/misr
   Description: The Multi-angle Imaging SpectroRadiometer-R. MISR is a new type of instrument of TERRA designed to see Earth with cameras pointed at nine different angles and it can distinguish different types of clouds, aerosol particles, and surfaces.

5. **"MODIS"**

   Link: https://terra.nasa.gov/about/terra-instruments/modis
   Description: Moderate Resolution Imaging Spectroradiometer. TERRA's instrument has a sensor that observes where and when disasters strike—such as volcanic eruptions, floods, severe storms, droughts, and wildfires.

6. **"MOPITT"**

   Link: https://terra.nasa.gov/about/terra-instruments/mopitt

Description: Measurements of Pollution In The Troposphere. It is an instrument of TERRA designed to enhance our knowledge of the lower atmosphere and to observe how it interacts with the land and ocean biosphere.

7. **"Landsat"**

   Link: https://landsat.gsfc.nasa.gov/about/
   Description: A series of satellites equipped with sensors that observe and capture information using images of the Earth's surface and coastal regions.

8. **"Earth Now"**

   Link: https://climate.nasa.gov/earth-now/
   Description: Explores a real-time data visualization of NASA's Earth-orbiting satellites and the data they collect about climate change.

Lesson 3: When Heat Is Trapped and Urban Heat Island Takes Over

1. **"NASA Urban Heat Islands"**

   Link: https://www.youtube.com/watch?v=lnBO4vX82Fs
   Description: The data collected and shown on this video spans from 1995 to 2005 and provides an idea of why cities are warmer than their surrounding areas, as well as what effect this will have on the planet.

2. **"Urban Heat Islands"**

   Link: https://mynasadata.larc.nasa.gov/basic-page/urban-heat-islands
   Description: Urban Heat Island is a phenomenon that is best described when a city experiences much warmer temperatures than in nearby rural areas

3. **"Earth Explorer"**

   Link: https://earthexplorer.usgs.gov/
   Description: The USGS EarthExplorer (EE) tool provides users the ability to query, search, and order satellite images, aerial photographs, and cartographic products from several sources.

4. **"Google Earth Engine App"**

   Link: https://yceo.users.earthengine.app/view/uhimap

   Description: Service that runs in the Google Cloud and combines a multi-petabyte catalog of satellite imagery and geospatial datasets with planetary-scale analysis capabilities and makes it available for scientists, researchers, and developers to detect changes, map trends, and quantify differences on the Earth's surface

Lesson 4: Changing Land Surface Temperatures

1. **"GLOBE Data Entry App"**
   Link: https://www.globe.gov/globe-data/data-entry/data-entry-app
   Description: Global Learning and Observations to Benefit the Environment is an international science and education program that provides students and the public worldwide with the opportunity to participate in data collection and the scientific

process, and contribute meaningfully to our understanding of the Earth system and global environment.

2. **"Remotely sensing the cooling effects of city scale efforts to reduce Urban Heat Island"**
   Link: https://www.sciencedirect.com/science/article/abs/pii/S0360132311002472
   Description: This study is an attempt to analyze a real large scale application by observing recent vegetated and reflective surfaces in LANDSAT images of Chicago, a city which has deployed a variety of heat island combative methods over the last 15 years.

Capstone Project: Urban Heat Island City Physical Model

1. **"White Versus Greens"**
   Link: https://earthobservatory.nasa.gov/features/GreenRoof/greenroof3.php
   Description: The study in New York confirmed that white roofs—generally made with the use of a thin, light coating—absorb much less of the Sun's energy than asphalt roofs. Green roofs can range in complexity from a shallow layer of soil and plants to more elaborate rooftop garden with trees and shrubs.

VI. Data visualization & analysis activities

Lesson 1:

Climate Time Machine
- Global surface temperatures

Images of Change
- Effects of events in different places contributing to climate change

Lesson 2:

Twenty Years of Terra in Our Lives
- TERRA satellite instruments that visualize recent global climate data

Landsat
Observes and captures data of Earth's surfaces

EarthNow
- Visualize recent global climate data from Earth Science satellites

Lesson 3:

Urban Heat Island
- Factors that influence on the Urban Heat Island on different cities

EarthExplorer
- Acquire Landsat remote sensing imagery

Earth Engine App
- Analyze Urban Heat Island Intensity locations

Lesson 4:

- **GLOBE**
  - Collect land surface temperature recordings and contribute to global research data by uploading collected data

VII. NASA Office of STEM Engagement Mission and Vision alignment

This unit plan has been aligned to the mission of the NASA Office of STEM Engagement Mission as it provides a variety of opportunities for students so they can explore and discover NASA's resources including the Climate Time Machine, WorldView Platform, Images of Change, Landsat, TERRA, among other platforms which allow students to be immersed in NASA's work, enhance STEM literacy, and inspire the next generation to explore, as stated in their mission.

Furthermore, this unit plan aligns with the vision of the NASA Office of STEM Engagement as it engages students in authentic learning experiences with content that is relevant to NASA and its scientists, including topics like climate change, Urban Heat Island, surface temperatures, mitigation factors and data collection and analysis.

This unit plan involves a series of informal and formal learning experiences inside and outside the classroom where students will calculate, design, and discover its way to a new era of American innovation, which is the focus of the NASA STEM Engagement Office.

These are the objectives and strategic goals addressed throughout this unit:

Goal 1.0: Create unique opportunities for a diverse set of students to contribute to NASA's work in exploration and discovery.

Objective 1.1: Provide student work experiences that enable students to contribute to NASA's missions and programs, embedded with NASA's STEM practitioners.

Goal 2.0: *Build a diverse future STEM workforce by engaging students in authentic learning experiences with NASA's people, content and facilities.*

Objective *2.1 Develop and deploy a continuum of STEM experiences through authentic learning and research opportunities with NASA's people and work to cultivate student interest, including students from unrepresented and underserved communities, in pursuing STEM careers and foster interest in aerospace fields.*

Goal 3.0: Attract diverse groups of students to STEM through learning opportunities that spark interest and provide connections to NASA's mission and work.

Objective 3.1 Develop and deploy targeted opportunities and readily available NASA STEM engagement resources and content, to attract students to STEM.

VIII. NASA Mission Alignment

This unit plan has been aligned to NASA's mission to enhance scientific understanding of Earth as a system and its response to natural and human-induced changes and to improve our ability to predict climate, weather, and natural hazards.

This unit plan is distinctly aligned to NASA's mission as students explore land surface temperatures and how these have changed due to the Urban Heat Island Effect phenomenon. Our hands-on investigations by going outside and recording land surface temperatures on different surfaces will help us understand how singular materials and green spaces contribute to mitigation solutions in order to address city environmental concerns.

IX. NASA Strategic Objective Alignment

This unit plan is aligned with the following NASA Strategic Objective Alignment:

Strategic Objective 1.1: Understand the Sun, Earth, Solar System, and Universe

This objective Is represented through data taken from remote sensing, understanding the Earth and looking to improve life on it is highlighted throughout the lessons described below. The "Improving Life on Earth" portion of the strategy describes that students will "utilize observations from space to advance our scientific understanding of the Earth in service to the United States and the world.

By highlighting how the school's area is affected by surface heating and possible mitigation methods, the unit allows both the teacher and student to share data with the global scientific community through GLOBE and think about interventions to reduce the effects of surface heating. This is clear evidence of how "NASA shares this unique knowledge and data continuity with the global community, including members of the science, government, industry, education, and policy-maker communities.

Strategic Objective 3.3: Inspire and Engage the Public in Aeronautics, Space and Science

This project enhances the local community's response to surface heating through mitigation techniques through NASA's STEM learning experiences. The research done with Dr. Braneon together with NASA's resources contribute to the idea of diversity in STEM careers, internships and opportunities to a diverse public comprising minorities and underrepresented groups.

X. NASA SMD Decadal Survey Alignment

This unit aligns with the NASA SMD Decadal Survey in its emphasis on reducing climate uncertainty and informing societal response. It aligns with climate variability and change, as climate sets the platform and constantly influences the development of natural systems. Listed as the most important priority includes the quantification in distribution of the functional traits, functional types, and composition of vegetation and marine biomass, spatially and over time. It also addresses weather and climate as very important, where it will determine how spatial variability in surface characteristics modifies regional cycles of energy, like this unit focuses on the Urban Heat Island and their effects.

XI. Unit pre-and post-standards-based assessment with answer key

This unit's pre and post-standards are based on the Next Generation Science Standards (NGSS) for high school students. This assessment is targeted for an Earth Science class at the high school level. The purpose of this pre-assessment is to measure the student's prior knowledge on the topics and subject. This assessment includes content knowledge questions, but also includes questions from lab-skills and lab activities.

The questions in this assessment are open-ended so they can allow the teacher to have a better understanding of the student's knowledge and a better overview of where students stand in regards to the topics in this unit. This will also allow the teacher to know if there are any topics that need to be revisited and see how much students have processed the content covered in this unit. Teachers are encouraged to provide this assessment as pre-assessment and a post-assessment components of this unit plan.

Name: ________________________________ **Period:** _______ **Date:** ________

Urban Heat Island and Remote Sensing Pre & Post Assessment

Instructions: The following questions are to know how much you know about this unit's topics. Answer the following questions to the best of your ability in complete sentences.

1. What is remote sensing?

2 What is land surface temperature and what does it involve?

3. What is Landsat?

4. What is image analysis?

5. What is a satellite?

6. How have humans impacted temperatures on Earth?

7. What is the Urban Heat Island?

8. What are some of the effects of Urban Heat Island?

9. Why would an increase of population affect climate change?

10. Why is it important to know about surface temperatures and how they change?

11. What are some characteristics we might want to test for when analyzing the temperature of a city?

12. How do we access satellite data? How do we organize our data for analysis?

Rubric Category	Doesn't meet expectations	Satisfactory	Meets expectations	Exceeds expectations
Productivity	I don't follow the procedures, and don't respond to more than 6 questions in an average way.	I can follow most of the procedures, and respond to 7 or more questions in an average way.	I can follow all the procedures, successfully and respond to 10 to 12 questions in a comprehensive way.	I can efficiently follow all the procedures, and respond to all 12 questions in an exceptional way.
Understanding	I don't show a clear understanding of the scientific concepts behind climate, remote sensing, or the effects of human impacts on global climate.	I show some understanding of the scientific concepts behind climate, remote sensing and the effects of human impacts on global climate.	I show a clear understanding of the scientific concepts behind climate, remote sensing and the effects of human impacts on global climate.	I show a clear and in-depth understanding of the scientific concepts behind climate, remote sensing the effects of human impacts on global climate.

Name: ________________________________ **Period:** _______ **Date:** ________

Urban Heat Island and Remote Sensing Pre & Post Assessment *ANSWER KEY*

Instructions: The following questions are to know how much you know about this unit's topics. Answer the following questions to the best of your ability in complete sentences.

1. What is remote sensing?

Remote sensing is the process of acquiring information on the physical characteristics of an object or phenomenon by means of its reflected and/or emitted radiation without making contact with. For example, the land surface temperature. It can be measured through a satellite or an aircraft.

2 What is land surface temperature and what does it involve?

Land surface temperature is the temperature at the ground. It is calculated by analyzing the radiation of thermal energy emitted by an object. It is measured through remote sensing or other sensors to determine how hot the earth's surface is at a particular location

3. What is Landsat?

Landsat is a series of satellites equipped with sensors that observe and capture information using images of the Earth's surface and coastal regions.

4. What is image analysis?

Image analysis is the process of taking information through images using digital processing techniques.

5. What is a satellite?

A satellite is an object (like a machine) that rotates around another larger object, like the Earth and contributes to scientific research.

6. How have humans impacted temperatures on Earth?

Human activity has contributed to the change since some activities like irrigation, dams may decrease temperature. Activities such as deforestation, urbanization using asphalt concrete, burning of forest, burning of fossil fuels, and using chemicals have caused a change and altered the temperatures and global climate.

7. What is the Urban Heat Island?

An Urban Heat Island is when a city absorbs and retains more heat that the surrounding areas. For example, a city would be warmer than the rural area that surrounds it.

8. What are some of the effects of Urban Heat Island?

The increased heat in urban areas can affect human health with respiratory problems, headaches, exhaustion, and even death. The increase in the demands of the consumption of energy has contributed to changes in wind, hydrologic cycle, surface and air temperatures and air pollution levels.

9. Why would an increase of population affect climate change?

Population growth affects climate change because there is an increasing demand for oil, gas, and other fuels that are extracted from the Earth and will release CO_2 into the atmosphere, causing the effect of an enhanced greenhouse effect. Also, when there is deforestation to urbanize areas with asphalt and concrete, they cause more heat in these areas. Disease also increases due to the change in temperature. As population increases, the Urban Heat Island increases.

10. Why is it important to know about surface temperatures and how they change?

It is important to know how surface temperatures change because it helps us in understanding local climate change. The energy is taken from the sun and the greenhouse gases trap a significant fraction of that solar energy emitting it in all directions, returning part of it to the surface while maintaining thermal equilibrium. During the last years the temperature has risen.

11. What are some characteristics we might want to test for when analyzing the temperature of a city?
Temperature refers to the amount of heat that exists in an environment (city). When testing the temperature in a city it would be important to know the vegetation that is present in the city. Also, the population of citizens, reflectivity (albedo) and the number of buildings and asphalt that covers the land. All of these are factors that can influence how temperature varies within a city.

12. How do we access satellite data? How do we organize our data for analysis?
We can download free satellite imagery from different platforms. For example, Earth Explorer, is produced by USGS and NASA and anyone can access Landsat data to observe land surface temperatures.

Rubric Category	Doesn't meet expectations	Satisfactory	Meets expectations	Exceeds expectations
Productivity	I don't follow the procedures, and don't respond to more than 6 questions in an average way.	I can follow most of the procedures, and respond to 7 or more questions in an average way.	I can follow all the procedures, successfully and respond to 10 to 12 questions in a comprehensive way.	I can efficiently follow all the procedures, and respond to all 12 questions in an exceptional way.
Understanding	I don't show a clear understanding of the scientific concepts behind climate, remote sensing, or the effects of human impacts on global climate.	I show some understanding of the scientific concepts behind climate, remote sensing and the effects of human impacts on global climate.	I show a clear understanding of the scientific concepts behind climate, remote sensing and the effects of human impacts on global climate.	I show a clear and in-depth understanding of the scientific concepts behind climate, remote sensing the effects of human impacts on global climate.

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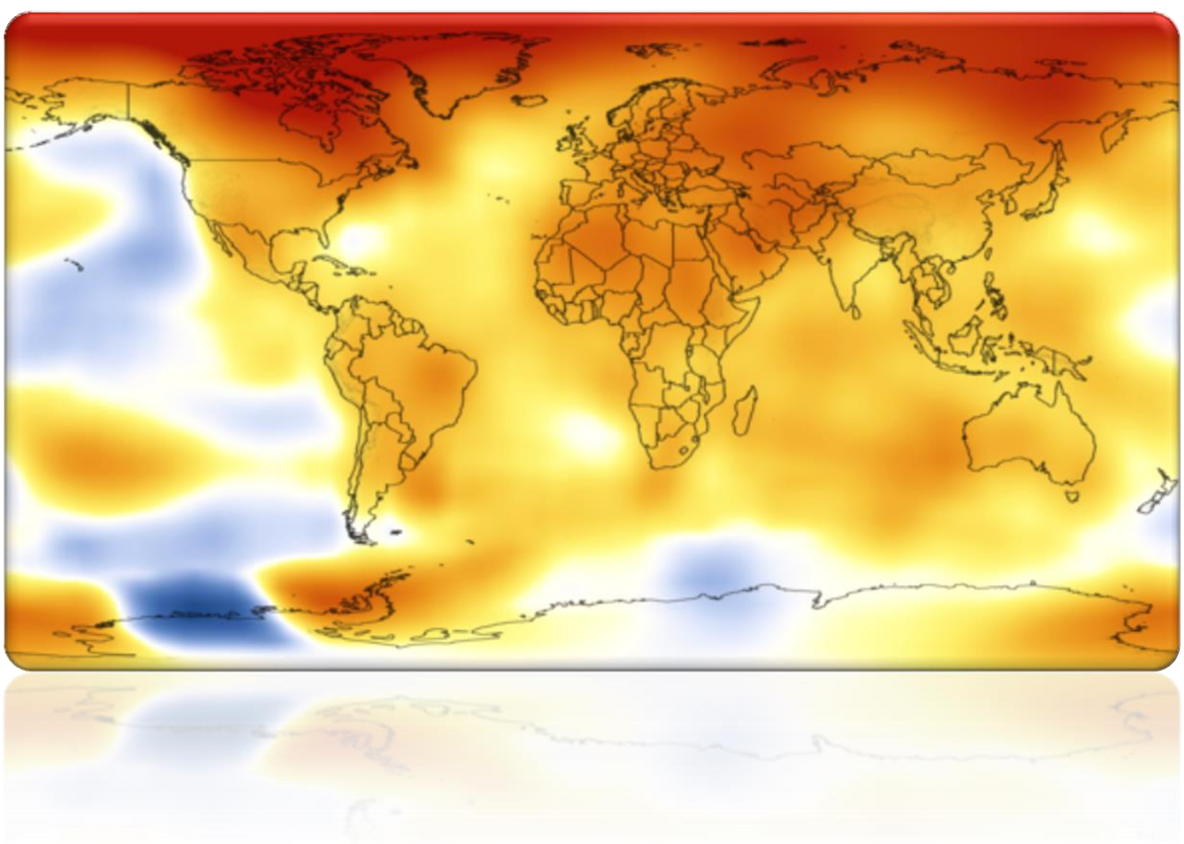
Unit Title: Land Surface Temperature in Urban Settings and the Heat Island Effect

Lesson 1 Title: "Making Earth Cool Again! What's happening to Climate?"

NASA STEM Educator / Associate Researcher: Alejandro A. Mundo

NASA PI / Mentor: Dr. Christian Braneon



XII. Lesson 1: Making Earth Cool Again! What's happening to Climate?

1. Table of Contents for lesson

2. Summary and Goals of Lesson

This lesson is titled "Making Earth Cool Again! What's happening to Climate?"" and it serves as an introduction to this unit plan which incorporates the 5E model template. It focuses on climate as well as the factors that influence it and are contributing to a changing climate on Earth.

The goals for this lesson include students to be able to:

- Define what is climate change individually and in groups.
- Discuss what is climate change in groups and as a class.
- Identify climate change evidence and explain its significance.
- Observe the evidence for global climate change.
- Create a scientific explanation about climate change factors by using a claim, climate evidence and reasoning.
- Identify how climate has been altered before and after an event in different parts of the world by observing and analyzing different satellite images.
- Interpret and analyze satellite imaging related to climate change.
- Create a poster about a location on Earth that has been affected by climate change and provide feedback on classmates' posters.

The goals for this lesson will be met throughout the activities and assignments for each part of the lesson plan.

3. CCRI Lesson Plan Content Template

*Scroll to next to see this component.

NGSS Standards & NYS Standards:	Common Core Standard:	NASA Science:
HS-ESS3-1 Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity. **HS-PS4-6** Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. **New York State Earth Science Standards (NYSES):** **2.1a** Earth systems have internal and external sources of energy, which create heat. **2.2c** A location's climate is influenced by latitude, proximity to large bodies of water, ocean currents, prevailing winds, vegetative cover, elevation, and mountain ranges. **Phenomenon:** Flow of Energy and Matter **Crosscutting concepts:** • Systems and System Models • Stability & Change • Patterns Cause and Effect	**ELA-LITERACY.RL.11-12.1**: • Cite strong and thorough textual evidence to support analysis of what the text says explicitly as well as inferences drawn from the text, including determining where the text leaves matters uncertain. **CCSS.ELA-LITERACY.RST.11-12.9** • Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible. **CCSS.ELA-LITERACY.RST.11-12.4** • Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics. **MATH.CONTENT.HSN.Q.A.3** • Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.	—Earth Science

Content Area and Grade Level	Name of Project-Based Activity or Theme:	Estimated Time Frame to Complete:
Content Area: Earth Science **Grade Level:** 11 & 12 grades	Students will analyze two different images of the same location (a before version and an after version), and describe the changes over time due to climate change.	This is the first lesson of 5 parts of this unit plan. It is estimated to take 5 days, if taught on periods of about 55 minutes a day.

Overall Investigation Question(s):	How can we use a climate simulation graph, images of change and evidence to analyze, explain and present how climate has changed over time?
Overall Project Description/Activity:	Identify how climate has been altered before and after an event in different parts of the world by observing and analyzing different satellite images.

Materials Needed to Complete Project	Stakeholders:	Hyperlinks Used:	Multimedia/Technology:	Classroom Equipment:
• Markers • Blank poster paper • Provided worksheets	–Students –Educator –Administrator	**Climate in a Box** **Link:** https://www.youtube.com/watch?v=RNoLTmBKizE **Climate Time Machine** **Link:** https://climate.nasa.gov/interactives/climate-time-machine/ **Climate Change: How Do We Know?** **Link:** https://climate.nasa.gov/evidence/ **Images of Change** **Link:** https://climate.nasa.gov/images-of-change **NASA's Mars Perseverance** **Link:** https://www.youtube.com/watch?v=6qA9iaAUo8k	• Laptops with internet connection • Laptops with PowerPoint • Smartboard	• Laptops • Printer • Smartboard

NASA System Engineering Behaviors	Category	Activities	Student Outcomes	Evaluation
Uses visuals to communicate complex interaction	Communications	Students will identify how climate has been altered before and after an event in different parts of the world by observing and analyzing different satellite images.	Work cooperatively with team members to discuss satellite images over time.	Climate change evidence
Communicates effectively through personal interaction	Communications	Students will work together in groups in order to define and discuss what is climate change.	Complete the definition of climate and climate change successfully with group members	Climate change
Builds Team Cohesion	Leadership	Students will work in harmony and assign tasks and responsibilities among peers in order to work for a common goal.	Present about the image of change and work on a climate definition.	Climate
Appreciates/Recognizes Others	Leadership	Students value each of their members in the group for their contribution and support their ideas.	Provide feedback on their classmates' posters that support the community.	
Has a comprehensive view	Attitudes & Attributes	Students will interpret satellite images in order to see how they have changed over time and explain their views according to the before and after factors.	Discuss different views and opinions about the satellite images and their importance.	Climate
Seeks information and uses the art of questioning	Attitudes & Attributes	Students will use different types of resources (evidence) in order to analyze climate change evidence and explain why it's meaningful	Use the provided resources to explain how climate has been affected by humans and other factors.	Climate change evidence
Validates facts, information and assumptions	Systems Thinking	Students will find climate change evidence and explain its significance.	Validates the evidence and puts it together in order to explain it.	Climate change evidence
Keeps the focus on mission requirements	Systems Thinking	Students will work on the assigned work and task in order to complete it by the given time.	Pay attention and follow procedures to complete the task.	
Learns from success and failures	Technical Acumen	Teacher will give feedback to students based on their performance at the activities and students will use and reflect on that feedback.	Reflects and uses feedback to do better.	
List and attach all PowerPoint presentations and supportive documents for instructional activities	**Attachments?** Yes	**List Attached Documents:** • Know and Wonder About Climate Change Worksheet • Time Machine Climate Simulation Worksheet • Scientific Explanation on Climate Change Worksheet • Images of Change Worksheet		
List and attach all rubrics for activity and assessment evaluation	**Attachments?** Yes	**List Attached Rubrics:** • Know and Wonder About Climate Change Worksheet Rubric • Time Machine Climate Simulation Worksheet Rubric • Scientific Explanation on Climate Change Worksheet Rubric • Images of Change Worksheet Rubric • Images of Change Poster Rubric for Students		

4. **Mission Alignment**
This lesson is part of this climate unit plan and aligns with NASA's Terra satellite mission. Terra explores the connections between Earth's atmosphere, land, snow and ice, ocean, and energy balance to understand Earth's climate and climate change and to map the impact of human activity and natural disasters on communities and ecosystems.

5. **Time to implement lesson**
This is the first lesson of 5 parts of this unit plan. It is estimated to take 5 days, if taught on periods of about 55 minutes a day.

6. **Materials required**
–Laptops
–Internet connection
–Printer
– Blank poster paper
–Markers
–Worksheets and supporting documents which are provided at the end of the lesson template.

7. **5E lesson model template:**

What the Teacher does	What the Students do	Time
ENGAGE **Climate Change Know and Wonder Activity** • Tell students that they will work on this task to: o Identify climate change on their own o Identify climate change as a group o Define climate change as a group o Propose questions about climate change • Model how to complete this chart to students by giving an example about NASA, like: o What I know about NASA o What we know about NASA o Our group definition of NASA o What I want to learn about NASA By doing this sample model in front of the class, students will get an idea of how the upcoming activity will occur. • Provide all students with activity worksheets • Gives instructions for the activity: o You have 2 minutes to record ideas quietly on your own on the: *"What I know About Climate Change"* part.	• Listen to the introduction of the activity. • Observe a sample of how the activity will take place. Students may be involved in this sample activity process. • Use the worksheet to record the activity work.	45 mins

◦ Then you will share your ideas during 5 minutes with the group you're sitting with. Take turns per person (1 minute per person) As your classmates share their ideas, record them in *the "What my group knows about Climate Change"* part. You should keep track of time. ◦ Later, you will brainstorm ideas from what you have shared and come up with a definition for what climate change is, then record it in the *"Our group's definition of Climate Change."* ◦ Lastly each person has 1 minute to come up with questions about climate change, discuss these questions as a group and record them in the *"What we wonder about Climate Change."* ◦ Guide the discussion in groups based on the students' responses. Facilitate the class discussion and encourage deeper thinking by having students build on each other's responses. ◦ To end this lesson, show the video called, "Climate in a Box", and tell students that in this video, they will learn more about how climate modeling requires massive computational power. Furthermore, NASA has begun to facilitate the operation of new desktop sized supercomputers, with the goal of making it substantially easier for more researchers to do meaningful work on vital and essential questions for our world. https://www.youtube.com/watch?v=RNoLTmBKizE	• Record their ideas on their own for *"What I know About Climate Change."* • Share each other's ideas (1 minute) at a time and record each other's ideas on the *"What my group knows about Climate Change."* • Discuss with their group about ideas on what climate change is. Everyone is recording the definition on the *"Our group's definition of Climate Change."* • Share questions that they wonder about climate change and record them in the *"What we wonder about Climate Change."* • Students build on each other's responses during class discussion. • Students learn more about climate modeling from the shown video.	
<u>EXPLORE</u> **Climate Time Machine Exploration** • Tell students that they will now explore more about climate change and its elements through a computer simulation known as "Time Machine." • Provide 1 laptop per group (groups of 2 students is ideal). Also provide one worksheet titled "Time Machine Climate Simulation" per student in each group.	• Listen to introduction of activity. • Use the worksheet to record the activity work and laptop to do research.	

• **Give the instructions:** ○ Go to this website: https://climate.nasa.gov/interactives/climate-time-machine/ ○ Say: *"This color-coded map shows a progression of changing global surface temperatures since 1884. Dark blue indicates areas cooler than average. Dark red indicates areas warmer than average."* ○ Remind students that they will work with their group in order to explore how climate change has progressed over time. They will then record their answers in their worksheet. ○ Tell students that they will follow the questions from the assignment, where they begin by making observations on Earth's climate during 1884, 1984, 2019 and their birthday. Model for students this process by showing the worksheet in front of the class. ○ Tell students that after they look at the Climate Time Machine, the second part of the worksheet has them look at the evidence about climate change. Where they will visit the website: https://climate.nasa.gov/evidence/ and record the evidence, explain what does the evidence suggest and also make connections to why this evidence is significant to climate change. ○ Conclude this part of the lesson by showing students a NASA video called "We Persevere" which focuses on the newest NASA's Mars, Perseverance. https://www.youtube.com/watch?v=6qA9iaAUo8k ○ Tell students that the purpose of the Perseverance rover is to search for signs of habitable conditions on Mars in the ancient past and for signs of past microbial life itself, which connects to Mars' climate and how its climate has changed over time, just like it's changing now on Earth.	• Run Climate Time Machine simulation with their group and record observations and findings on their worksheet. • Work with their groups and explore how climate change has progressed over time by examining the climate time machine. • Follow the teacher's instructions on the worksheet. • Observe at the evidence for climate change as well as explain it and make sense of its significance to climate change on the worksheet. • Watch a video about Perseverance rover, which shows how it will search for signs of habitable conditions on Mars in the ancient past and for signs of past microbial life itself, studying climate on the red planet.	45 mins

○ The teacher can consider to spend more time on the Climate Time Machine parts, like the carbon dioxide, sea level or se ice. The focus of this lesson plan is for global temperatures, but teacher can extend the activity depending on interests.		
EXPLAIN **Climate Change Scientific Explanation** • Tell students that they will now put the information they have acquired from the climate time machine, including the evidence that they have also completed in their graphic organizer. Now they will use the worksheet titled: *"Scientific Explanation on Climate Change Worksheet"* • Tell students that they will now come up with a scientific explanation. Say, "*A scientific explanation uses observations and measurements to explain something we see in the natural world. Scientific explanations should match the evidence and be logical, or they should match as much of the evidence as possible.*" • Tell students that his explanation is focused on the following question: *"Which are the 2 most convincing and clear pieces of evidence when trying to explain climate change?"* • Tell students that the scientific explanation will include three different components that they will have to complete before the actual scientific explanation: ○ **Claim**: Your answer to the question ○ **Evidence**: Quantitative Data, Graphical Interpretations ○ **Reasoning**: Conceptual Understandings: Formulas, Definitions, Laws, Theories. • Give an example of each component so that students know how to complete the graphic organizer. This could be done as a class, where students can contribute with their ideas, but they will complete this on their own. Give students about 10 minutes to complete this graphic organizer. • After students have completed their graphic organizer with claim, evidence and reasoning. They	• Listen to introduction of activity. • Listen to what is a scientific explanation. • Listen to the focus of the question that will lead to the explanation. • Examine the three different components that the scientific explanation will have. • Discuss some ideas about claims, evidence and reasoning and put them in the graphic organizer. • Complete their graphic organizer with the three columns, claim, evidence and reasoning.	60 mins

will be ready to move on to the actual scientific explanation. • Remind them that there is a word bank at the bottom of the page that you would like them to use. This word bank has important words that relate to climate change such as sea level rise, temperature, oceans, etc. • Tell students to begin writing their scientific explanation. Remind students that this is an individual activity and that it reflects their understanding and analysis of climate change and its evidence. As students are writing their scientific explanation, circulate around the room to assist students. 50 minutes is recommended for this activity, but teacher may decide to extend it based on the students. • Have dictionaries available for students who may need help assistance while writing.	• Observe the word bank at the bottom of the page to see the words they are expected to use in their scientific explanation. • Work on writing their scientific explanation individually and quietly on their own.	
<u>EXTEND</u>: **Images of Change Analysis** • Tell students that they will now move into an extended investigation activity called "Images of Change" in groups of 2 students. This activity connects to weather and climate change, where they will get to analyze two different images of the same location (a before version and an after version) and describe the changes over time. • Students will now visit the "Images of Change" https://climate.nasa.gov/images-of-change • Provide the "Images of Change" Worksheet to students. Tell them that although they are working in groups of 2 students, you want them to record their ideas and responses individually. • Tell students that they will compare the effects of physical changes based on the before-and-after images from the same location. By moving the from side to side, students can see the before and after of each location. Then, they will be able to record their observations on the graphic organizer and then reflect on how these images reflect and connect to weather and climate change.	• Listen to introduction of activity. • Access the website and explore the different images. • Students will use the slider to compare and contrast the. images of change by looking at different locations and record their observations on the graphic organizer.	30 mins

• It is important to remind students that some images are indicators of climate change and some are weather events or short-term climate variability. Climate variability tends to change slowly, it doesn't mean we don't experience shorter-term fluctuations on seasonal or multi-seasonal time scales. There are many things that can cause temperature, for example, to fluctuate around the average without causing the long-term average itself to change. • Allow students to randomly choose their own images of change (since there are many available on the website), but that they have to discuss with their classmates about the images they choose, and each record their ideas on their own worksheet.		
EVALUATE **Presentations about Images of Change** • Tell students that they will now present about one of the images of change (from previous lesson) that was meaningful to them. Have students choose an image of their list (one per student). Tell them that they will have to create a simple poster where they include the image, a description of the image and why it was meaningful to them. Students can create this digitally and print it in the classroom. • Tell students that once they have done their one-page posters, they will post them around the classroom walls because they will be doing a gallery walk. During this gallery walk, they will go around the classroom and look at their classmates' posters and leave a piece of feedback where they evaluate it according to what their classmate has created. • The feedback that students should have includes one cool feedback and one warm feedback. Explain to students that "warm feedback" is the kind of feedback that should start with a positive statement about what they see and like from their classmate's poster. On the other hand, cool feedback raises a question. Learning to ask good questions is an important part of learning to give good feedback.	• Listen to introduction of activity. • Create their one-page poster about their image-of-change where they include images, description and why it's meaningful to them. • Place posters across the classroom for the gallery walk. • Provide feedback (one warm and one cool) feedback) while participating in the class gallery walk.	60 mins

• Once everybody has their one-page posters, give a piece of paper to each student, where they will write down their feedback for their classmates' poster. Explain to students that while they're doing this gallery walk, they are walking around and providing their feedback to their classmates quietly. You may choose to give as many pieces of paper, so students can give feedback about how the image was meaningful and connects to climate change.		

8. Standards

Next Generation of Science Standards (NGSS):

HS-ESS3-1 Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.

HS-PS4-6 Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

DCI ESS2.A Earth Materials and Systems

CC Systems and System Models
Stability & Change
Patterns
Cause and Effect

New York State Earth Science Standards (NYSES):

NYSES 2.1a Earth systems have internal and external sources of energy, both of which create heat.

NYSES 2.2c A location's climate is influenced by latitude, proximity to large bodies of water, ocean currents, prevailing winds, vegetative cover, elevation, and mountain ranges.

Common Core Standards:

MATH.CONTENT.HSN.Q.A.3
Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.

ELA-LITERACY.W.9-10.9
Draw evidence from literary or informational texts to support analysis, reflection, and research.

9. NASA System Engineering Behavior Model utilized in lesson

- **Leadership**
  - Builds Team Cohesion
  - Appreciates/Recognizes Others

- **Communication**
  - Listens Effectively and Translates Information
  - Communicates Effectively Through Personal Interaction
- **Problem Solving & Systems Thinking**
  - Assimilates, Analyzes, and Synthesizes Data
  - Validates Facts, Information and Assumptions

10. Supporting Documents:

*Scroll down to see documents

Name: ______________________________ **Period:** _______ **Date:** ________

Know and Wonder About Climate Change

Instructions: First complete what you know about climate change on your own. Then discuss ideas with your group about what is climate change and record them in your handout. Later you will come up with a definition for climate change and record it. Lastly, you will write what your group wonders about climate change.

What I know about Climate Change	What my group knows about Climate Change

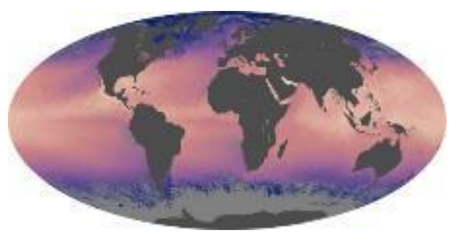


Figure 1: Earth's sea surface temperature

Our group's definition of Climate Change	What we wonder about Climate Change

Rubric Category	Doesn't meet expectations	Satisfactory	Meets expectations	Exceeds expectations
Productivity	I don't follow the procedures, struggle to record all parts of the worksheet and don't respond to all questions in an average way.	I can follow most of the procedures, record all parts of the worksheet and respond to all questions in an average way.	I can follow all the procedures, successfully record all parts of the worksheet and respond to all questions in a comprehensive way.	I can efficiently follow all the procedures, successfully record all parts of the worksheet and respond to all questions in an exceptional way.
Understanding	I don't show a clear understanding of the scientific concepts behind climate, temperature or the effects of human impacts on global climate.	I show some understanding of the scientific concepts behind climate, temperature and the effects of human impacts on global climate.	I show a clear understanding of the scientific concepts behind climate, temperature and the effects of human impacts on global climate.	I show a clear and in-depth understanding of the scientific concepts behind climate, temperature and the effects of human impacts on global climate.

National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

Name: ______________________________ **Period:** _______ **Date:** ________

Know and Wonder About Climate Change *ANSWER KEY*

Instructions: First complete what you know about climate change on your own. Then discuss ideas with your group about what is climate change and record them in your handout. Later you will come up with a definition for climate change and record it. Lastly, you will write what your group wonders about climate change.

What I know about Climate Change	What my group knows about Climate Change
I know climate change is the increase in temperature on the planet and that causes a change in the climate. *For example, I know that climate change causes the ice sheets at the poles and glaciers to melt. Furthermore, the climate around the world is changing, we see in desert areas that rain and hail.*	*My group knows that climate change alters the temperature of the Earth, causing alterations in different areas such as the glaciers at the poles, desert lands, rivers, oceans, forests, etc.* *In addition, we know that climate change can provoke changes in natural phenomena such as tornadoes, torrential rains, hurricanes.*

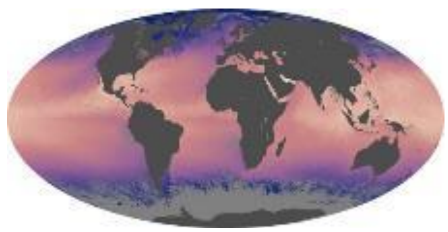


Figure 2: Earth's sea surface temperature

Our group's definition of Climate Change	What we wonder about Climate Change
Our group's definition of climate change is the increase in temperature that causes changes in the climate allowing glaciers melt, causing floods and storms. We define climate change as any change in the measures of climate lasting for a period of time. *We know that it lasts long enough periods (decades or more) until the Earth reaches a new equilibrium. Some people think it will last more than 10,000 years.*	*We wonder the following:* • *How does climate change affect the earth?* • *What factors determine climate change?* • *Is climate change related to wind patterns?* • *What can we do to stop the climate from changing?*

Rubric Category	Doesn't meet expectations	Satisfactory	Meets expectations	Exceeds expectations
Productivity	I don't follow the procedures, struggle to record all parts of the worksheet and don't respond to all questions in an average way.	I can follow most of the procedures, record all parts of the worksheet and respond to all questions in an average way.	I can follow all the procedures, successfully record all parts of the worksheet and respond to all questions in a comprehensive way.	I can efficiently follow all the procedures, successfully record all parts of the worksheet and respond to all questions in an exceptional way.
Understanding	I don't show a clear understanding of the scientific concepts behind climate, temperature or the effects of human impacts on global climate.	I show some understanding of the scientific concepts behind climate, temperature and the effects of human impacts on global climate.	I show a clear understanding of the scientific concepts behind climate, temperature and the effects of human impacts on global climate.	I show a clear and in-depth understanding of the scientific concepts behind climate, temperature and the effects of human impacts on global climate.

Name: ______________________________ **Period:** _______ **Date:** ________

Time Machine Climate Simulation Worksheet

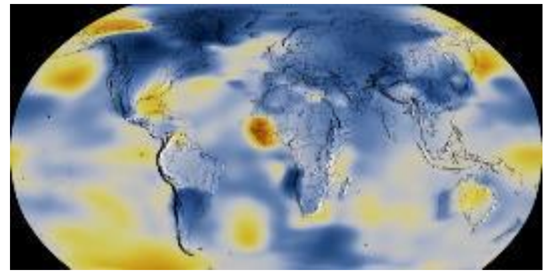


Figure 1: Global temperatures in 1884

Procedure:

1. *Go to the Climate Time Machine website: https://climate.nasa.gov/interactives/climate-time-machine/*
2. *Read the bottom description under the time machine for climate change.*
3. *Answer* the analysis questions below.

Analysis Questions:

1. Make observations about Earth's climate during 1884 and describe it below.

2. After 100 years since the first record in the climate time machine, describe how Earth's climate looked during 1984.

3. Find the year when you were born in the time machine and describe how Earth's climate looked during that year? Was it hottest or coldest? Have patterns changed? Include your birth year.

4. Make observations about Earth's climate during 2019 and describe it below.

5. Now you will further explore the different types of evidence for climate change on this site: https://climate.nasa.gov/evidence/ Then, you will complete the following table about climate change evidence and explaining why that evidence is significant to the Earth's climate.

Name of evidence	What is the evidence for climate change?	Why is this significant to Earth's climate and the environment?

Rubric Category	Doesn't meet expectations 🛰	Satisfactory 🛰 🛰	Meets expectations 🛰 🛰 🛰	Exceeds expectations 🛰 🛰 🛰 🛰
Productivity	I don't follow the procedures, struggle to record all parts of the worksheet and don't respond to all questions in an average way.	I can follow most of the procedures, record all parts of the worksheet and respond to all questions in an average way.	I can follow all the procedures, successfully record all parts of the worksheet and respond to all questions in a comprehensive way.	I can efficiently follow all the procedures, successfully record all parts of the worksheet and respond to all questions in an exceptional way.
Understanding	I don't show a clear understanding of the scientific concepts behind climate and the evidence and significance of climate change factors over time.	I show some understanding of the scientific concepts behind climate and the evidence and significance of climate change factors over time.	I show a clear understanding of the scientific concepts behind climate and the evidence and significance of climate change factors over time.	I show a clear and in-depth understanding of the scientific concepts behind climate and the evidence and significance of climate change factors over time.

Name: _______________________________ **Period:** _______ **Date:** ________

Time Machine Climate Simulation Worksheet

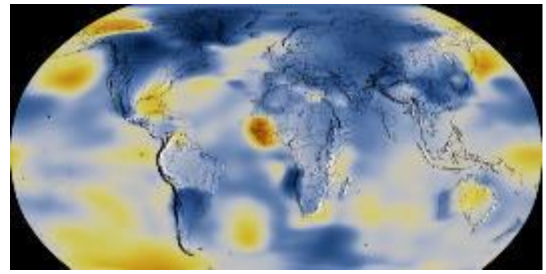


Figure 1: Global temperatures in 1884

Procedure: ***ANSWER KEY***

1. *Go to the Climate Time Machine website:* *https://climate.nasa.gov/interactives/climate-time-machine/*
2. *Read the bottom description under the time machine for climate change.*
3. *Answer* the analysis questions below.

Analysis Questions:

1. Make observations about Earth's climate during 1884 and describe it below.

   In 1884, the map shows North America and Europe were cooler than average areas and some western regions of Africa were warmer than average. Most continental areas were cooler.

2. After 100 years since the first record in the climate time machine, describe how Earth's climate looked during 1984.

   After 100 years, North America was warmer, Europe was warmer and some parts of Mediterranean North Africa were cooler than average, as was Greenland.

3. Find the year when you were born in the time machine and describe how Earth's climate looked during that year? Was it hottest or coldest? Have patterns changed? Include your birth year.

   In 2004, the map shows all continents were warmer than average but Alaska, Europe and some parts of Africa were warmer. The patterns show that it has been getting warmer because the colors have changed to yellow and red which demonstrate warmer temperatures.

4. Make observations about Earth's climate during 2019 and describe it below.

   In 2019, all continents were warmer than average, but Alaska, Europe and Asia were much hotter than the average. Polar regions were warming the fastest in later years.

Continues on next page.

5. Now you will further explore the different types of evidence for climate change on this site: https://climate.nasa.gov/evidence/ Then, you will complete the following table about climate change evidence and explaining why that evidence is significant to the Earth's climate. ***ANSWER KEY***

Name of evidence	What is the evidence for climate change?	Why is this significant to Earth's climate and the environment?
Glacier Retreat	*Glaciers are retreating almost everywhere around the world including in the Alps, Himalayas, Andes, Rockies, Alaska and Africa.*	*Sea level and global temperature rise due to thawing.* *The temperature has increased and this has overheated the poles and this causes the glaciers to be thawing.*
Sea Level Rise	*Global sea level rose about 8 inches in the last century. The rate in the last two decades, however, is nearly double that of the last century and is accelerating steadily over years. Warmer water expands further increasing sea level rise and near to sea level when storms occur.*	*Regarding the extra water that is flowing in the ocean due to the melting of the glaciers, it increases every time and is expected to increase in the coming years due to the loss of ice in the Antarctic.* *Furthermore, this could cause flooding problems for countries that are below sea level and those that are at sea level.*
Ocean Acidification	*Since the beginning of the Industrial Revolution, the acidity of surface ocean waters has increased by about 30 percent. This increase is the result of humans emitting more carbon dioxide into the atmosphere and hence more being absorbed into the oceans. The amount of carbon dioxide absorbed by the upper layer of the oceans is increasing by about 2 billion tons per year as well as warmer oceans.*	*Acidification and water contamination are due to the high concentration of carbon dioxide in the air generated by human activity.* *Ocean acidity causes serious damage to marine life causing death in various species, affecting coral reefs, and degradation of the ecosystem.*
Extreme Events	*The number of record high temperature events in the United States has been increasing, while the number of record low temperature events has been decreasing, since 1950. The U.S. has also witnessed increasing numbers of intense rainfall events.*	*Global warming has produced great changes meteorologically such as hurricanes, cyclones, rains, extreme droughts or floods.* *In desert places torrential rains fall and in places where it is not snowing now snow falls.*
Shrinking Ice Sheets	*The Greenland and Antarctic ice sheets have decreased in mass. Data from NASA's Gravity Recovery and Climate Experiment show Greenland lost an average of 286 billion tons of ice per year between 1993 and 2016, while Antarctica lost about 127 billion tons of ice per year during the same time period. The rate of Antarctica ice mass loss has tripled in the last decade.*	*The ice sheets in Greenland and Antarctic are important as each melting layer that reaches the sea contributes to sea level rise.* *It is believed that if the entire Greenland ice sheet was to weaken and melt, the sea level would change and rise by about 7 meters.*
Global Temperature Rise	*The planet's average surface temperature has risen about 1.62 degrees Fahrenheit (0.9 degrees Celsius) since the late 19th century, a change driven largely by increased carbon dioxide and other human-made emissions into the atmosphere.* *Most of the warming occurred in the past 35 years, with the six warmest years on record taking place since 2014. Not only was 2016 the warmest year on record, but eight of the 12 months that make up the year —from January through September, with the exception of June — were the warmest on record for those respective months.*	*The Earth's atmosphere is made up of different gases whose function is to maintain a specific temperature for life. This is called the greenhouse effect.* *However, human activities that have caused this warming are the use of fertilizers, chemical activity, the burning of fossil fuels, transportation, heating, and deforestation to construct buildings. These activities have increased the production of these gases, causing so-called global warming, the main cause of climate change.* *Human beings are responsible for climate change and its greenhouse gas emissions that heat the planet. The best known gas is CO2, causing 63%.of total warming.*

Name: ______________________________ **Period:** _______ **Date:** ________

Scientific Explanation on Climate Change Worksheet (Part 1 of 2)

Instructions: You will now create a scientific explanation about climate change based on the question shown below. Before you create your scientific explanation, you will complete the following graphic organizer. First, complete the "Claim" with details that explain that claim. Then complete the "Evidence" part, with pieces of evidence that can support your claim. Then you will talk about the reasoning that supports the evidence or the claim. Include words from the word bank below in your graphic organizer below.

Question: Which are the 2 most convincing and clear pieces of evidence when trying to explain climate change?

CLAIM ***You draw a conclusion about the question above.***	**EVIDENCE** ***Addresses the question, such as quantitative data, graphical interpretations.***	**REASONING** ***Logically links the evidence with conceptual understanding such as formulas, definitions, law, or theories***

Word Bank

Climate change | Satellites | Sea level | Oceans | Warming temperatures | Snow | Rain

Name: ________________________________ **Period:** _______ **Date:** ________

Scientific Explanation of Climate Change Worksheet (Part 2 of 2)

Instructions: Now that you have completed the graphic organizer about **Claim, Evidence** and **Reasoning** from the previous page, you will write a **scientific explanation** where you include your **Claim Evidence** and **Reasoning**.

Question: Which are the 2 most convincing and clear pieces of evidence when trying to explain climate change?

Rubric Category	Doesn't meet expectations	Satisfactory	Meets expectations	Exceeds expectations
Productivity	I don't follow the procedures, struggle to record the parts for climate change evidence and don't respond to the climate change questions in an average way.	I can follow most of the procedures, record the parts for climate change evidence and respond to the climate change questions in an average way.	I can follow all the procedures, successfully record all parts for climate change evidence and respond to the climate change questions in a comprehensive way.	I can efficiently follow all the procedures, successfully record all parts for climate change evidence and respond to all climate change questions in an exceptional way.
Understanding	I don't show a clear understanding of the scientific concepts behind climate and don't show the evidence and significance of climate change.	I show some understanding of the scientific concepts behind climate and the evidence and significance of climate change.	I show a clear understanding of the scientific concepts behind climate and the evidence and significance of climate change.	I show a clear and in-depth understanding of the scientific concepts behind climate and the evidence and significance of climate change.
Claim	I don't make a claim at all.	I can make an accurate and complete claim, but don't address the research question.	I can make an accurate but incomplete claim that answers the original question.	I can make an accurate and complete claim that answers the original question.
Evidence	I don't provide any evidence.	I can provide appropriate and some evidence to support the claim, but it doesn't include specific data examples.	I can provide evidence to partially support the claim, which includes specific data examples.	I can provide appropriate and sufficient evidence to support the claim, which includes specific data examples.
Reasoning	I don't provide any reasoning	I provide some reasoning that explains how the evidence supports the claim, but reasoning is somewhat clear.	I can provide appropriate reasoning that clearly explains how the data cunts as evidence to link with and supports some of the claim.	I can provide reasoning that clearly explains how the data counts as evidence to link with an support the claim.
Vocabulary	I cannot use any academic vocabulary words clearly from the word bank or correctly in my explanation.	I can use between 2 to 3 academic vocabulary words clearly from the word bank and correctly in my explanation.	I can use at least 4 academic vocabulary words clearly from the word bank and correctly in my explanation.	I can successfully use 4 or more academic vocabulary words clearly from the word bank and correctly in my explanation.

Name: ________________________________ **Period:** _______ **Date:** _________

Scientific Explanation on Climate Change Worksheet (Part 1 of 2) *ANSWER KEY*

Instructions: You will now create a scientific explanation about climate change based on the question shown below. Before you create your scientific explanation, you will complete the following graphic organizer. First, complete the "Claim" with details that explain that claim. Then complete the "Evidence" part, with pieces of evidence that can support your claim. Then you will talk about the reasoning that supports the evidence or the claim. Include words from the word bank below in your graphic organizer below.

Question: Which are the 2 most convincing and clear pieces of evidence when trying to explain climate change?

CLAIM ***You draw a conclusion about the question above.***	**EVIDENCE** ***Addresses the question, such as quantitative data, graphical interpretations.***	**REASONING** ***Logically links the evidence with conceptual understanding such as formulas, definitions, law, or theories***
• *The 2 most convincing and clear pieces of evidence when trying to explain climate change are:* *Rising sea levels → clear* *Land ice sheets melting → convincing*	• *Land ice melt rates* • *How much ice melts per year.* • *"Antarctica has lost 127 billion tons of ice in the span of 1993 to 2016."* • *How many inches sea has risen in 'x' amount of years.* • *NASA's climate facts also state that the seas have risen eight inches in the last century.*	• *When people think climate change, they think of rising temperatures* • *Land ice sheets melting shows a direct result of increasing heat → as temps. Have increased so has the melt rate.* • *Sea levels rising also shows the impacts of temperature increase → the melting land ice leads to higher sea levels*

Word Bank

Climate change | Satellites | Sea level | Oceans | Warming temperatures | Snow | Rain

National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

Name: ________________________________ **Period:** _______ **Date :** ________ ***ANSWER KEY***

Scientific Explanation of Climate Change Worksheet (Part 2 of 2)

Instructions: Now that you have completed the graphic organizer about **Claim, Evidence** and **Reasoning** from the previous page, you will write a **scientific explanation** where you include your **Claim Evidence** and **Reasoning**.

Question: Which are the 2 most convincing and clear pieces of evidence when trying to explain climate change?

Climate change is one of the most pressing issues the world faces today. Oceans, forests, and life on Earth are endangered due to its harmful effects. However, in order to go about solving this issue, scientists must find a way to convince the public, policymakers, and stakeholders that it does in fact pose a threat significant enough to invest in. In order to best convince people of climate change, scientists should use melting ice sheets and sea level rise as examples because they clearly demonstrate the consequences of temperature rise.

Land ice sheets around the world have been melting which has had negative impacts on the polar climates they are located in. Worst of all, the ice has been melting at an increasingly high rate. According to NASA's climate facts, Greenland loses 279 bill metric tons per year compared to Antarctica which loses 149 bill metric tons per year. The data highlights such drastic ice sheet loss which is bound to convince people that these rising temperatures do in fact pose a threat to polar ecosystems. The fact that land ice sheet melt has such clear evidence pointing to the impacts of temperature increase makes it a very compelling example of climate change.

Sea level rise is another pressing issue that has significantly worsened due to climate change Rising sea levels put coastal regions and islands at high risk of flooding if this issue worsens in the coming years. NASA's climate facts also state that the seas have risen eight inches in the last century. The explanation for this additional water is the melting of sea ice which is another clear effect of warming temperatures. The sea ice could have only melted because the temperatures have increased. Having such blatant evidence is important when it comes to convincing people because it provides logical and irrefutable evidence that climate change is having an impact.

In addition, there are many ways to go about proving climate change, and most examples can be supported by very persuading evidence. However, it is important to keep in mind what will convince people the most while considering any personal beliefs they may have. Climate change has always been a delicate subject as it often clashes with people's political or religious views. It is the job of scientists to use the most persuading yet sensitive evidence when publicizing such large findings.

For that reason, I believe the examples of ice sheet melt and rising sea levels are the best because they not only clearly demonstrate direct results of increasing temperatures, they also propose evidence that is much harder to be dismissed due to feelings (i.e. not believing in warming oceans because they don't physically feel any warmer).

Overall, although scientists have found lots of proof that climate change does in fact pose a threat, not all evidence is as comprehensive to people outside of the scientific community as others. The largest effect of climate change people think of is temperature rise. Following that logic, one should use the most direct evidence of temperature increase to then prove climate change. Since ice sheet melt and sea level rise are very clear evidence of melting as a result of warming temperatures, they are the best and most compelling ways to demonstrate the danger this issue poses. In all, climate change will always be challenging to prove, but there is evidence that can persuade people faster, and scientists must use that evidence so that the threat is realized before it becomes irreversible.

Rubric Category	Doesn't meet expectations 🛰	Satisfactory 🛰 🛰	Meets expectations 🛰 🛰 🛰	Exceeds expectations 🛰 🛰 🛰 🛰
Productivity	I don't follow the procedures, struggle to record the parts for climate change evidence and don't respond to the climate change questions in an average way.	I can follow most of the procedures, record the parts for climate change evidence and respond to the climate change questions in an average way.	I can follow all the procedures, successfully record all parts for climate change evidence and respond to the climate change questions in a comprehensive way.	I can efficiently follow all the procedures, successfully record all parts for climate change evidence and respond to all climate change questions in an exceptional way.
Understanding	I don't show a clear understanding of the scientific concepts behind climate and don't show the evidence and significance of climate change.	I show some understanding of the scientific concepts behind climate and the evidence and significance of climate change.	I show a clear understanding of the scientific concepts behind climate and the evidence and significance of climate change.	I show a clear and in-depth understanding of the scientific concepts behind climate and the evidence and significance of climate change.
Claim	I don't make a claim at all.	I can make an accurate and complete claim, but don't address the research question.	I can make an accurate but incomplete claim that answers the original question.	I can make an accurate and complete claim that answers the original question.
Evidence	I don't provide any evidence.	I can provide appropriate and some evidence to support the claim, but it doesn't include specific data examples.	I can provide evidence to partially support the claim, which includes specific data examples.	I can provide appropriate and sufficient evidence to support the claim, which includes specific data examples.
Reasoning	I don't provide any reasoning	I provide some reasoning that explains how the evidence supports the claim, but reasoning is somewhat clear.	I can provide appropriate reasoning that clearly explains how the data cunts as evidence to link with and supports some of the claim.	I can provide reasoning that clearly explains how the data counts as evidence to link and support the claim.
Vocabulary	I cannot use any academic vocabulary words clearly or correctly in my explanation.	I can use between 2 to 3 academic vocabulary words clearly and correctly in my explanation.	I can use at least 4 academic vocabulary words clearly and correctly in my explanation.	I can successfully use 4 or more academic vocabulary words clearly and correctly in my explanation.

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Goddard Institute for Space Studies
New York, N.Y.

Name: ________________________________ **Period:** _______ **Date:** ________

Images of Change Worksheet

Instructions: You will look at the Images of Change on this website: https://climate.nasa.gov/images-of-change. After, you have to choose an image of change that is appealing to you (use the slider to see before and after) Then complete the chart below, including a description and how it connects to climate change.

Name of image of change	Observations and descriptions about image of change using the slider	How does this image reflect and connect to climate change or climate variability?

Rubric Category	Doesn't meet expectations	Satisfactory	Meets expectations	Exceeds expectations
Productivity	I don't follow the procedures, struggle to record all parts of the worksheet and don't respond to all questions in an average way.	I can follow most of the procedures, record all parts of the worksheet and respond to all questions in an average way.	I can follow all the procedures, successfully record all parts of the worksheet and respond to all questions in a comprehensive way.	I can efficiently follow all the procedures, successfully record all parts of the worksheet and respond to all questions in an exceptional way.
Understanding	I don't show a clear understanding of the scientific concepts behind climate and the evidence and significance of climate change factors over time.	I show some understanding of the scientific concepts behind climate and the evidence and significance of climate change factors over time.	I show a clear understanding of the scientific concepts behind climate and the evidence and significance of climate change factors over time.	I show a clear and in-depth understanding of the scientific concepts behind climate and the evidence and significance of climate change factors over time.

Name: ______________________________ **Period:** _______ **Date:** ________

Images of Change Worksheet ***ANSWER KEY***

Instructions: You will look at the Images of Change on this website: https://climate.nasa.gov/images-of-change. After, you have to choose an image of change that is appealing to you (use the slider to see before and after) Then complete the chart below, including a description and how it connects to climate change.

Name of image of change	Observations and descriptions about image of change using the slider	How does this image reflect and connect to climate change or climate variability?
Drought Shrinks Chile's El Yeso Reservoir.	*I can observe with the slider that before, this reservoir shows, it held 7,734 million cubic feet (219 million cubic meters) of water in 2016. Later, in the year 2020 image, it had lost more than half of volume, leaving only 3,496 million cubic feet (99 million cubic meters). The cause is a drought that has plagued central Chile for more than a decade.*	*This image connects to the lack of ice on the mountains. Furthermore, as the phenomenon of global warming becomes more visible on our planet, longer droughts are seen, due to the acceleration of melting glaciers and drastic changes in precipitations and snow patterns.*
Rains Douse Fires, Cause Floods in New South Wales, Australia.	*I can observe with the slider that before torrential rains brought Australians relief from catastrophic wildfires. These storms also swamped parched lands and made rivers overflow, leading to muddy floods in many coastal regions. Later, in February image shows flooded land around farming communities in the state of New South Wales.*	*This image connects to higher temperatures of the atmosphere, the greater the content of water vapor that it can hold and the precipitating systems have more available water and the greater the probability of torrential rains. In addition, with global warming, heavy rainfall is repeated more severely.*
Iceland's Ok Glaciers Melts Away.	*I can observe with the slider that before 1901 geological maps estimated that Okjökull ("Jökull"is Icelandic for "glacier") spanned about 15 square miles (38 square kilometers). Later, in 1978, aerial photography showed the glacier had shrunk to about 1 square mile (3 square kilometers). Today, less than half a square mile (less than 1 square kilometer) remains.*	*This image connects to glaciers melting and shrinking, therefore leading to sea level rise.* *This is result from warming. It's the product from higher GHG's.*
Heat Wave turns Europe brown.	*I can observe with the slider that in 2017 Denmark, Sweden, the Netherlands, Germany and Poland showed green and snowy portions. Later, in 2018 the same region, much of this part of the world turned brown in just a month, during which several countries experienced record high temperatures and low precipitations. The United Kingdom experienced its driest first half of summer (June 1 to July 16) on record.*	*This image connects to higher temperature, less rainfall, droughts and floods caused by changes in the length of seasons, and therefore heat waves increase. This event is more of a climate variability, than climate change.*
Hurricane Maria's Damage to Puerto Rico's Forest.	*I can observe with the slider that in 2017 the image, taken before the hurricane struck, showed a big forest. Later, in September of the same year, these images show the impact of Hurricane Maria in Puerto Rico. The forests were reduced to a tangle of fallen trees and isolated survivors.*	*This image connects to the rising temperature of the sea causing hurricanes to become more violent. In addition, at higher temperatures, more hurricanes, with all the problems they entail: destruction of cities and crops.*

Student One-Page Image of Change Student Sample Poster

Title: "***Hurricane Maria's Damage to Puerto Rico's Forest."***

By: *Student*

Image description and its relation to Climate:
I can observe with the slider that in 2017 the image taken before the hurricane struck, showed a big forest. Later, in September of the same year, these images show the impact of Hurricane Maria in Puerto Rico. The forests were reduced to a tangle of fallen trees and isolated survivors.

This image connects to the rising temperature of the sea causing hurricanes to become more violent. In addition, at higher temperatures, more hurricanes, with all the problems they entail: destruction of cities and crops.

Image before hurricane Maria:

Image after hurricane Maria:

Why this image is meaningful to me:
This image was significant for me because my family lived in Puerto Rico for a long time and saw the great disaster that Hurricane Maria left. The great forests were destroyed in their entirety, knocking down houses and claiming many human lives.

This Hurricane category 4 with winds of up 155 miles per hour affected the forest. An estimated 20 to 40 million trees were damaged or killed when they were stripped of foliage, snapped in half or ripped from the ground. In addition, loss in forests and nature takes years to recover.

Images of Change Poster Rubric For Students

Rubric Category	Doesn't meet expectations 🛰️	Satisfactory 🛰️🛰️	Meets expectations 🛰️🛰️🛰️	Exceeds expectations 🛰️🛰️🛰️🛰️
Images	I don't include two images that reflect the before and after of the location with good descriptive titles.	I can include two images that reflect the before and after of the location with titles.	I can efficiently include two images that reflect the before and after of the location with good descriptive titles.	I can efficiently include two images that reflect the before and after of the location with creative descriptive titles.
Description of Image	I can't describe the images to reflect what exactly happened in this location.	I can describe the images in ways that reflect what exactly happened in this location.	I can describe the images in-depth and in descriptive ways that reflect what exactly happened in this location.	I can describe the images in-depth and in very descriptive ways that reflect what exactly happened in this location.
Meaningfulness	I can't describe why these images are meaningful to me and in any way.	I can describe why these images are meaningful to me in very descriptive way.	I can describe why these images are meaningful to me and in a very descriptive way.	I can describe why these images are meaningful to me and in-depth and in very descriptive way.
Productivity	I don't follow the procedures, struggle to record all parts of the worksheet and don't respond to all questions in an average way.	I can follow most of the procedures, record all parts of the worksheet and respond to all questions in an average way.	I can follow all the procedures, successfully record all parts of the worksheet and respond to all questions in a comprehensive way.	I can efficiently follow all the procedures, successfully record all parts of the worksheet and respond to all questions in an exceptional way.
Understanding	I don't show a clear understanding of the scientific concepts behind climate and the evidence and significance of climate change factors over time.	I show some understanding of the scientific concepts behind climate and the evidence and significance of climate change factors over time.	I show a clear understanding of the scientific concepts behind climate and the evidence and significance of climate change factors over time.	I show a clear and in-depth understanding of the scientific concepts behind climate and the evidence and significance of climate change factors over time.

Websites used in this lesson:

Climate Time Machine: https://climate.nasa.gov/interactives/climate-time-machine/

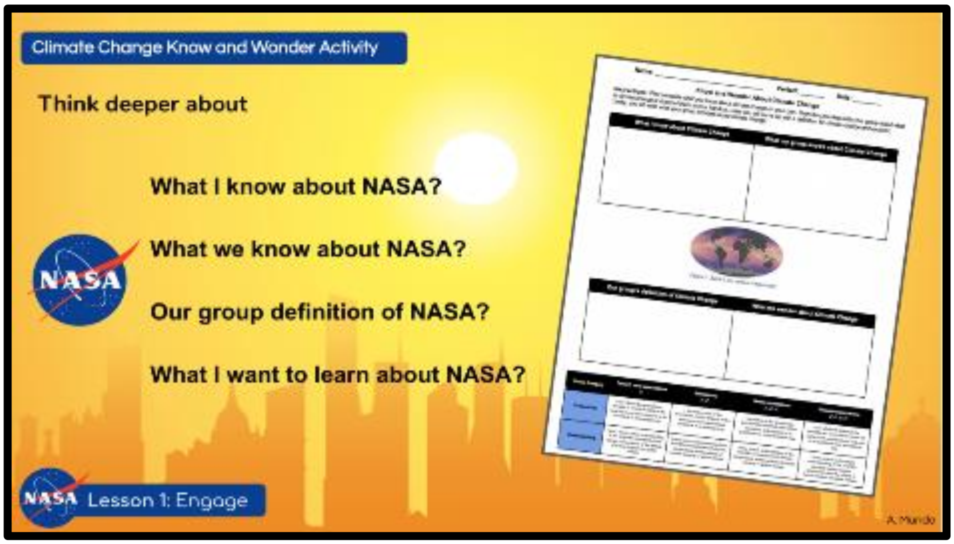
Climate Change Evidence: https://climate.nasa.gov/evidence/

Images of Change: https://climate.nasa.gov/images-of-change

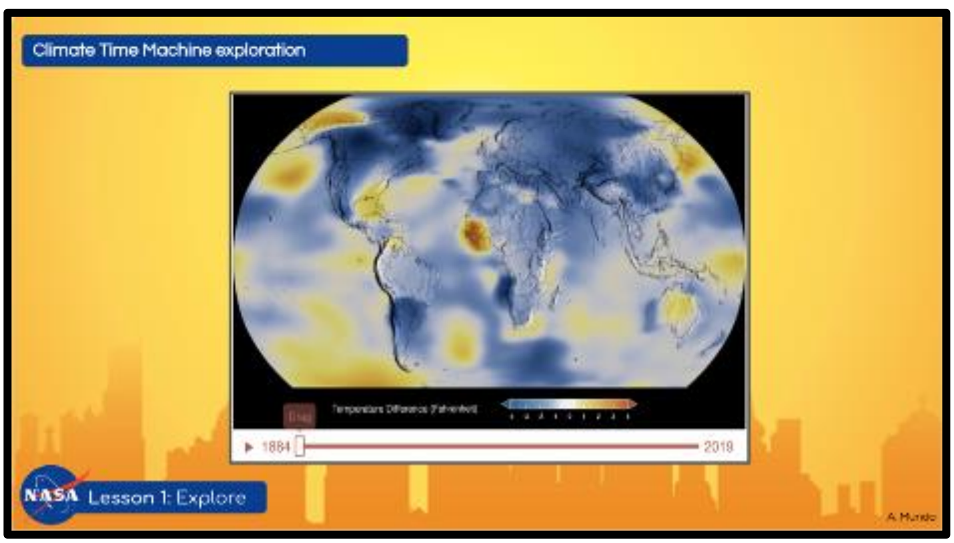
We Persevere Video: https://www.youtube.com/watch?v=6qA9iaAUo8k

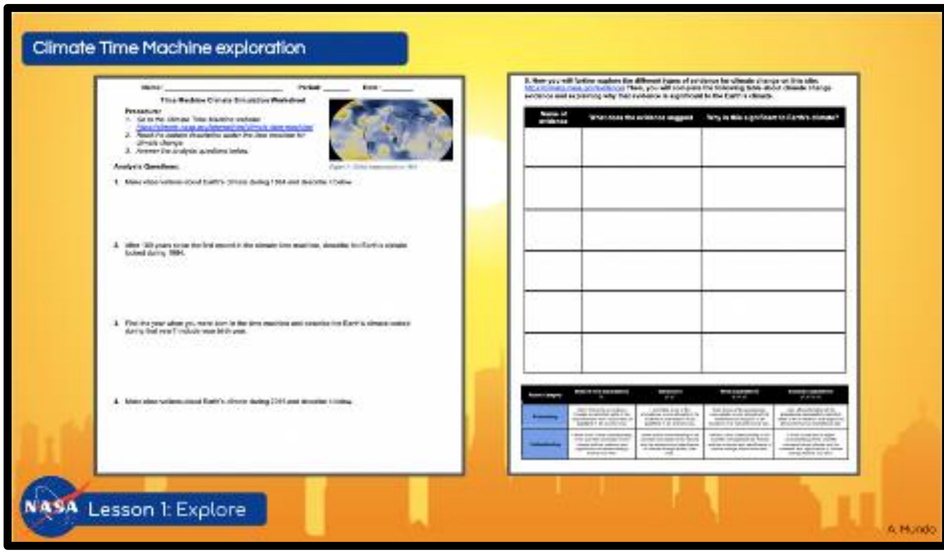
Lesson Presentation Slides:

ENGAGE:



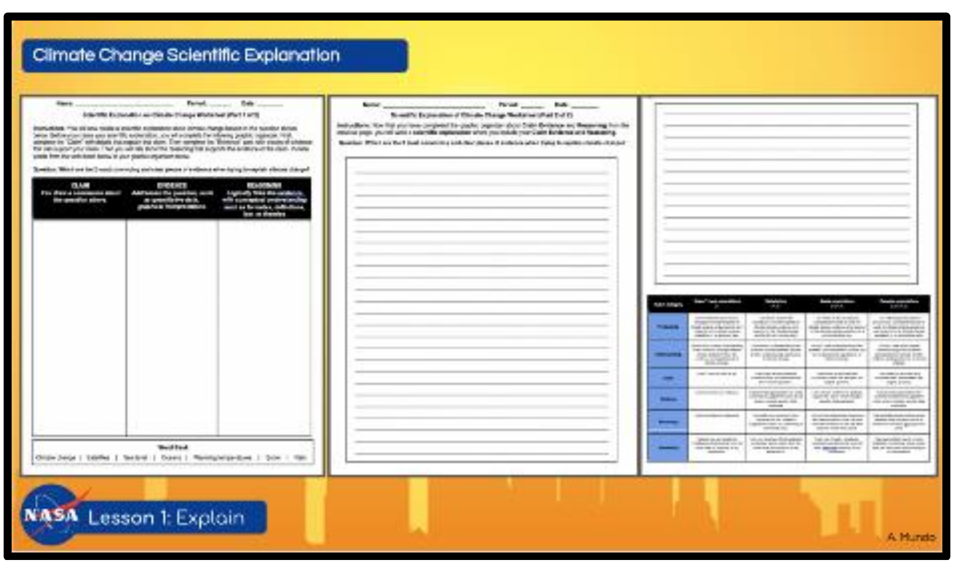
EXPLORE:




Climate Time Machine exploration
NASA
Lesson 1: Explore
A. Mundo

EXPLAIN:

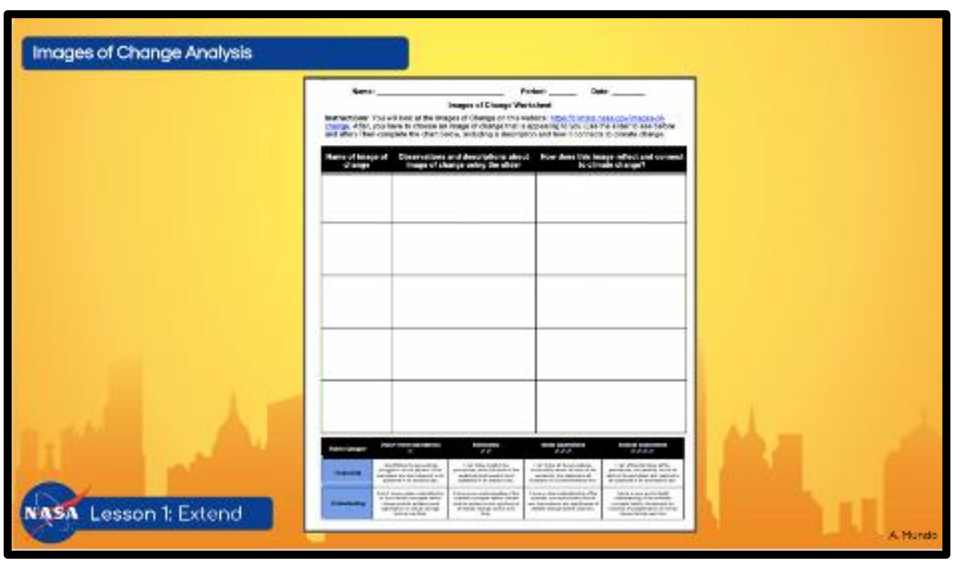

Climate Change Scientific Explanation
Instructions for activity:
1. Use the worksheet titled: "Scientific Explanation on Climate Change Worksheet".
2. You will now create a scientific explanation.
3. You will create a scientific explanation using: Claim, Evidence, and Reasoning.
4. Complete this graphic organizer and use the word bank.
5. Write your scientific explanation.
NASA
Lesson 1: Explain
A. Mundo


Climate Change Scientific Explanation
NASA
Lesson 1: Explain
A. Mundo

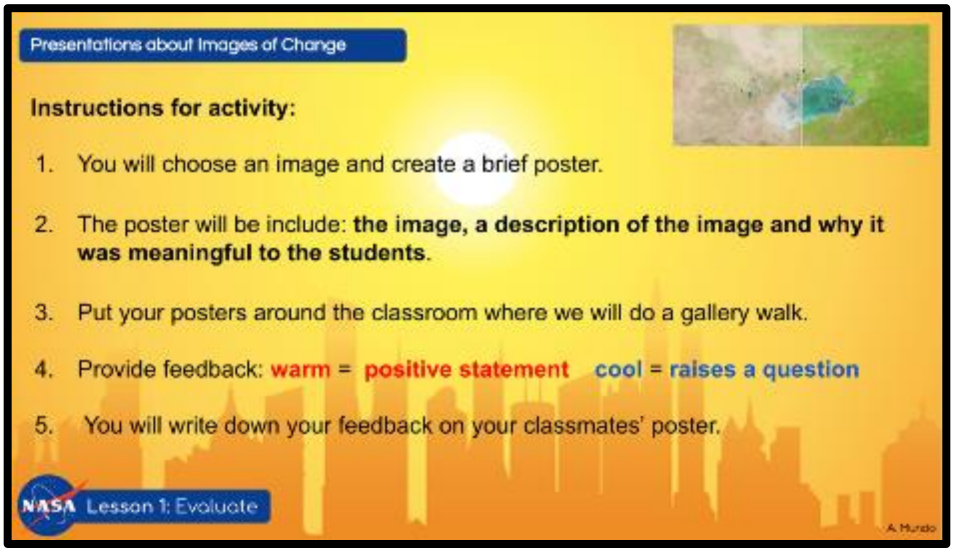
EXTEND:

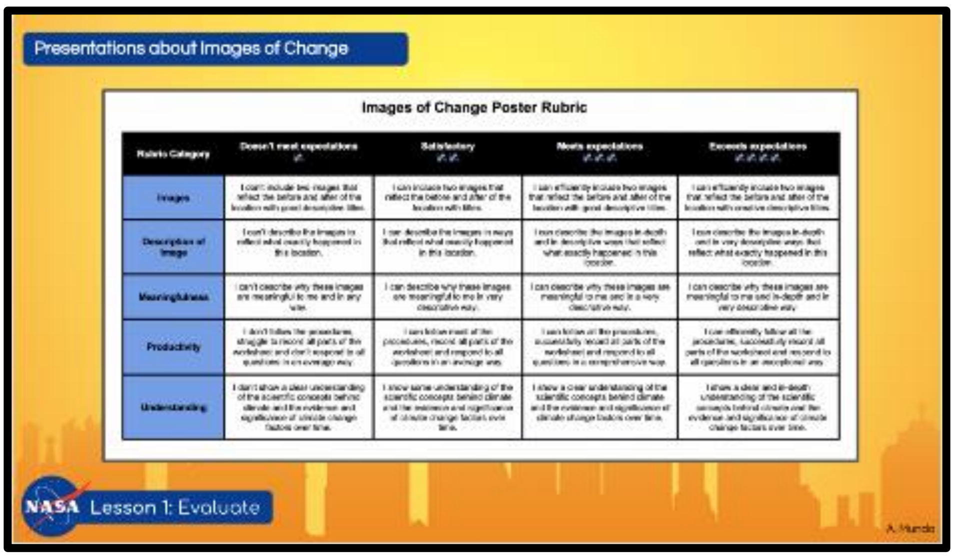

Images of Change Analysis
Instructions for activity:
1. In groups of 2 students, you will analyze 2 different images of the same location before and after.
2. Go to this website: https://climate.nasa.gov/images-of-change
3. Record the ideas and responses.
4. Compare the effects of climate change based on the before-and-after images from the same.
5. Record your observations on the graphic organizer.
Lesson 1: Extend


Images of Change Analysis
Images of Change
James River Floods in South Dakota
Lesson 1: Extend


Images of Change Analysis
Images of Change Worksheet
Lesson 1: Extend

EVALUATE:





Differentiated instruction activities

This lesson includes instructional activities that promote differentiation in the following ways:

- Students learn new content in multiple ways including orally (through groups and class discussions), visually (through the use of videos and images), data analysis (through infographics and graphs) and reflection.
- Students use graphic organizers that help them process and organize their understanding of the new content.
- Lessons include graphic organizers with sentence starters that benefit English Language Learners and Special Education students to organize their ideas in better ways.
- Every lesson is adaptable to the personal learning plans of students.

11. Conclusion, Assessment Quantification and linkage to next lesson:

This has been the first lesson of this climate unit plan which had a focus on climate change and its effects at a global scale. During this first lesson, students had the opportunity to engage in authentic learning experiences through discovery, research and exploration by defining what is climate change individually and in groups. In addition, they had the opportunity to discuss climate change in groups and as a class, identify climate change evidence and climate variability and explain its significance. In addition, students observe the evidence for global climate change by creating a scientific explanation about climate change factors and identify how the environment has been altered before and after an event in different parts of the world. Furthermore, students observe and analyze different satellite images related to climate and create a poster about a location on Earth that has been affected by climate change and provided feedback on classmates' posters. The completion of all worksheets, tasks and activities with a high rubric grade demonstrates assessment quantification of student's learning. In the next lesson, students will learn more about remote sensing, specifically satellite imagery, and its use in order to study climate factors.

National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

NASA Climate Change Research Initiative

Applied Research STEM Curriculum Portfolio

CCRI Unit Plan Template

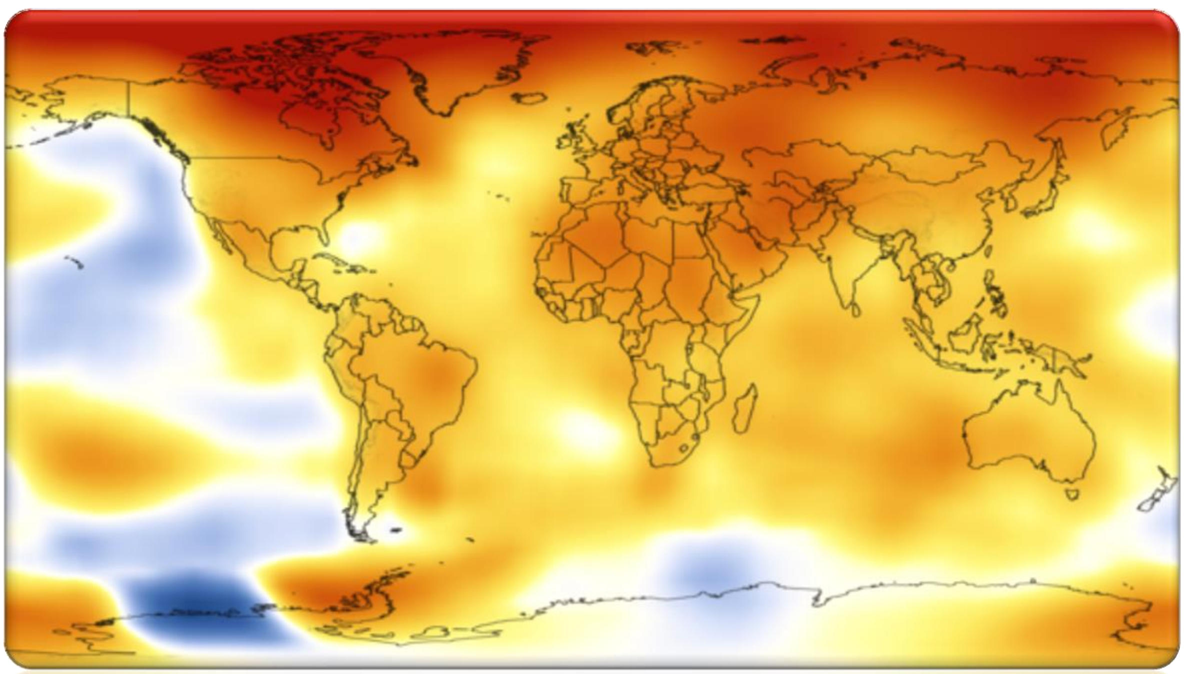
NASA Science Mission Directorate | Earth Sciences Division
NASA Goddard Institute for Space Studies
NASA Goddard Space Flight Center | Office of STEM Engagement

Unit Title: Land Surface Temperature in Urban Settings and the Heat Island Effect

Lesson 2 Title: Seeing From Another View Through Satellites

NASA STEM Educator / Associate Researcher: Alejandro Mundo

NASA PI / Mentor: Dr. Christian Braneon



XIII. Lesson 2: Seeing From Another View Through Satellites

1. Table of Contents for lesson

2. Summary and Goals of Lesson

This lesson is titled "Seeing From Another View Through Satellites" and it serves as lesson 2 of this unit plan which incorporates the 5E model template. It focuses on remote sensing as well as satellites and their instruments to better understand how scientific research uses these resources to study Earth's climate.

The goals for this lesson include students to be able to:

- Simulate ground-based and satellite surface temperature recordings
- Discuss the different methods to record physical characteristics of Earth's surface
- Define remote sensing and its advantages
- Read and reflect on TERRA and Landsat satellites and its instruments
- Present about TERRA and Landsat satellites and their instruments
- Investigate on climate satellites from Earth Now and analyze and explain their contribution to climate research
- Investigate TERRA satellites from Earth Now and analyze their instruments and explain their contribution to climate research
- Evaluate their knowledge by matching satellites and their instruments with their descriptions

The goals for this lesson will be met throughout the activities and assignments for each part of the lesson plan.

3. CCRI Lesson Plan Content Template

*Scroll down to see content

HS-ESS2-2 Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.

HS-PS4-6 Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

New York State Earth Science Standards (NYSES):
NYSES 2.1g Weather variables can be represented in a variety of formats including radar and satellite images, weather maps (including station models, isobars, and fronts), atmospheric cross-sections, and computer models.

NYSES 1.1b The Earth is orbited by one moon and many artificial satellites.

Phenomenon: Flow of Energy and Matter

Crosscutting concepts:

- Systems and System Models
- Interdependence of Science, Engineering, and Technology Patterns
- Energy and matter

ELA-LITERACY.RL.11-12.1:

- Cite strong and thorough textual evidence to support analysis of what the text says explicitly as well as inferences drawn from the text, including determining where the text leaves matters uncertain.

CCSS.ELA-LITERACY.RST.11-12.9

- Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.

CCSS.ELA-LITERACY.W.11-12.2
Write informative/explanatory texts to examine and convey complex ideas, concepts, and information clearly and accurately through the effective selection, organization, and analysis of content.

—Earth Science

Content Area and Grade Level	Name of Project-Based Activity or Theme:	Estimated Time Frame to Complete:
Content Area: Earth Science **Grade Level:** 11 & 12 grades	Students will analyze two different images of the same location (a before version and an after version), and describe the changes over time due to climate change.	This is the first lesson of 5 parts of this unit plan. It is estimated to take 5 days, if taught on periods of about 55 minutes a day.

Overall Investigation Question(s):	How do we learn more about climate satellites and their instruments and how do we use remote sensing to study Earth's climate like elements?
Overall Project Description/Activity:	Learn about climate satellites and their instruments through different platforms and use remote sensing to study Earth's climate like elements i.e. temperature.

Materials Needed to Complete Project	Stakeholders:	Hyperlinks Used:	Multimedia/Technology:	Classroom Equipment:
• Provided worksheets	–Students –Educator –Administrator	**Twenty Years of Terra in Our Lives** **Link:** https://terra.nasa.gov/news/twenty-years-of-terra-in-our-lives **ASTER** **Link:** https://terra.nasa.gov/about/terra-instruments/aster **CERES** **Link:** https://terra.nasa.gov/about/terra-instruments/ceres **MISR** **Link:** https://terra.nasa.gov/about/terra-instruments/misr **MODIS** **Link:** https://terra.nasa.gov/about/terra-instruments/modis **Landsat** **Link:** https://landsat.gsfc.nasa.gov/about/ **Earth Now** **Link:** https://climate.nasa.gov/earth-now/	• Laptops with internet connection • Laptops with PowerPoint • Smartboard	• Laptops • Smartboard

NASA System Engineering Behaviors	Category	Activities	Student Outcomes	Evaluation
Uses visuals to communicate complex interaction	Communications	Students will identify how climate satellites like TERRA have its own instruments that have a specific purpose to study Earth's climate.	Work cooperatively with team members to discuss Landsat and TERRA's instruments	Remote sensing
Communicates effectively through personal interaction	Communications	Students will work together in groups in order to present about the different instruments in TERRA satellite	Complete their definitions and descriptions about the different types of instruments it has.	Remote sensing
Builds Team Cohesion	Leadership	Students will work in harmony and assign tasks and responsibilities among peer in order to work for a common goal.	Present about the different instruments that TERRA has as well as Landsat.	Climate and temperature
Appreciates/Recognizes Others	Leadership	Students value each of their members in the group for their contribution and support their ideas.	Provide feedback on their classmates' presentations and supports them.	
Has a comprehensive view	Attitudes & Attributes	Students will choose their own climate satellites and work with their partners to discuss their missions and descriptions.	Discuss different views and opinions about the satellites they choose and why they're important.	Remote sensing
Seeks information and uses the art of questioning	Attitudes & Attributes	Students will use different types of resources (evidence) in order to analyze remote sensing and explain why it's meaningful in climate research.	Use the provided resources to explain what remote sensing is and its importance in research.	Remote sensing
Validates facts, information and assumptions	Systems Thinking	Students will find satellite instruments from Worldview platform and validating their functions.	Validates the evidence and put it together in order to explain it.	Climate
Keeps the focus on mission requirements	Systems Thinking	Students will work on the assigned work and task in order to complete it by the given time.	Pay attention and follow procedures to complete the task.	
Learns from success and failures	Technical Acumen	Teacher will give feedback to students based on their performance at the activities and students will use and reflect on that feedback.	Reflects and uses feedback to do better.	
	Attachments?	**List Attached Documents:**		
List and attach all PowerPoint presentations and supportive documents for instructional activities	Yes	• Temperature Recording from National Park Activity Worksheet • Twenty Years of Terra in Our Lives Worksheet • Earth-Now General Satellites and their Instruments Worksheet • TERRA Satellites Matching Satellites Activity Worksheet		
	Attachments?	**List Attached Rubrics:**		
List and attach all rubrics for activity and assessment evaluation	Yes	• Temperature Recording from National Park Activity Worksheet Rubric • Twenty Years of Terra in Our Lives Worksheet Rubric • Earth-Now General Satellites and their Instruments Worksheet Rubric • TERRA Satellites Matching Satellites Activity Worksheet Rubric		

4. **Mission Alignment**
   This lesson is part of this climate unit plan and aligns with NASA's Terra satellite mission. Terra explores the connections between Earth's atmosphere, land, snow and ice, ocean, and energy balance to understand Earth's climate and climate change and to map the impact of human activity and natural disasters on communities and ecosystems. It also aligns with Landsat satellite mission, whose groundbreaking series of repetitive imaging of Earth's land at a spatial resolution that shows human interaction with the environment.

5. **Time to implement lesson**
   After the first lesson and before the third lesson in this unit plan.
   This can be implemented without the first lesson in this unit plan.

6. **Materials required.**
   –Computers
   –Worksheets and supporting documents are provided at the end the lesson template.

7. **5 E lesson model template:**

What the Teacher does	What the Students do	Time
<u>**ENGAGE**</u> **Outside Temperature Recordings Activity** • Tell students that they will work on this task called "Park Ranger and Scientist" to simulate temperature recording of national parks. The purpose of this activity is to allow students to get an introduction on what is remote sensing and why satellites are important for data recording. Refrain from telling the purpose of the activity to students so the activity is more meaningful to them while doing it. • The teacher begins the class by taking the students outside the classroom to a grassy area. The park could be from 50 feet square or bigger. • Once outside, tell students to lie down on their stomachs on the grass. Tell students that in this task, they are interns at a national park (you can choose a national park name) and that they have been assigned to count the park's thermometers which record temperatures in different parts of the park. • Throw a random number of colored push pins in different parts that represent the thermometers (at least 15).	• Listen to introduction of activity. • Go outside of the classroom as a class. • Students go outside of the classroom to the designated place to do the activity.	40 mins

• After students have counted the thermometers (colored push pins) at eye-level, have them stand up and count the push pins. Then, have students come back to the classroom and reflect on the activity by writing a response to the question, "*As a scientist and park ranger, would you prefer to study the park from the ground or the air? What if you're studying temperatures like surface temperatures? Explain why."*
 	
• Then guide the class in a discussion in order to promote deeper thinking, by asking questions such as:
  ○ *What are some complications that can emerge while studying physical characteristics from above?*
  ○ *What connections can you make between the physical world and this activity?*
  ○ *What could be another physical characteristic aspect that could be monitored besides temperature?*
  ○ *What are advantages of remote sensing (above observations like satellites) than ground-based instruments?*
	• Students are writing the different ways how they would prefer to study the national park and then discussing their ideas among their groups.
	
	• Students are engaged in a class discussion about remote sensing where they reflect on the activity and think deeper in the bigger concept of remote sensing.	

EXPLORE **Terra NASA Climate Research Satellite** • Tell students that they will now find out more about remote sensing with Terra *(a multi-national NASA scientific research satellite)*. This article (attached below) is called "Twenty Years of Terra in Our Lives" which also provides information about its instruments such as ASTER, CERES, MISR, MODIS, MOPITT and satellite LANDSAT. • During this article reading, students will explore how Terra has been doing remote sensing for the last 20 years. The satellite's five instruments concurrently observe Earth's atmosphere, ocean, land, snow and ice, providing insights into Earth systems such as the water, carbon and energy cycles. The MODIS and ASTER instruments onboard also	• Listen to introduction of activity. • Students will read an article about remote sensing with Terra and how it works called, *"Twenty Years of Terra in Our Lives"* by NASA.	45 mins

provide critical information for assessing and managing natural disasters and other emergencies. • The teacher may choose to take a group of students to read on their own to a side of the classroom. This would be a differentiation strategy to help those with reading disorders or English Language Learners. • Then, after students have finished their independent readings, the teacher will assist groups in completing the graphic organizer as they explore about Terra's remote sensing while circulating around the classroom.	• Students will complete a graphic organizer where they will reflect on the text and record their findings about satellites and remote sensing.	
<u>EXPLAIN</u> **Terra Satellite Presentations** • The teacher will put students in groups of 4 students. These groups will create a series of small 4-minute oral presentations about what is remote sensing and how Terra has worked over the last decades. • You may choose to put students in homogeneous grouping, by distributing students who function at similar academic, social, and emotional levels, in the same cooperative learning group together. This is a way of differentiating education students or English Language Learners. • Assign one instrument from Terra to each group which they will present about between: ASTER, CERES, MISR, MODIS, MOPITT, and Landsat satellite. Students can use the whiteboard, PowerPoint, etc. to consolidate their thoughts and explain the theme and purpose of their satellite instrument. • Students can find further information on the satellites and their instruments, if needed, on the following websites: https://terra.nasa.gov/about/terra-instruments/aster https://terra.nasa.gov/about/terra-instruments/ceres https://terra.nasa.gov/about/terra-instruments/misr https://terra.nasa.gov/about/terra-instruments/modis	• Listen to introduction of activity. • Students will present their analysis of the article with their groups. Purpose, Method, Analysis, and Conclusions will be the expected discussion points for each reading. They can take notes in their graphic organizers. The presentation should be no longer than 4 minutes.	40 mins

https://terra.nasa.gov/about/terra-instruments/mopitt https://landsat.gsfc.nasa.gov/about/ • Tell students that each student in the group will be required to participate in the presentation process. This presentation will be a formative assessment, as the teacher can, in the process of visiting each group, determine the participation and analysis of each student, plus their understanding of remote sensing. • At the end of each presentation, allow 1-2 minutes for questions that their classmates can make about their remote sensing presentation.	• After each presentation, other students will get 1-2 minutes to ask questions about their peers' presentation.	
EXTEND **Earth Now Climate Satellites and Terra Analysis** • Tell students that they will now work in groups of 2 students to investigate about other satellites that do climate research on NASA's Earth-Now Platform. Earth Now is an application that visualizes recent global climate data from Earth Science satellites. The visualized data include surface air temperature, carbon dioxide, carbon monoxide, ozone, and water vapor, as well as gravity and sea-level variations. It can be accessed here: https://climate.nasa.gov/earth-now/ • Tell students that they will have the opportunity to describe the satellites presented at Earth Now. Students will have the freedom to choose among the different satellites. Then they will further investigate that satellite by analyzing its dataset and recording observations and explanations on the worksheet called "Earth-Now General Satellites and Its Instruments." Remind students that each student will turn in their individual worksheet. • After students have completed the first part about satellites on Earth Now like GPM, GRACE-FO1, Jason-3, ICESat-2, etc. Then they will focus on the TERRA satellite and	• Listen to introduction of activity. • Access Earth-Now platform and investigate about the different climate satellites. • Make observations about the climate satellites, analyze dataset of each satellite and record the observations as well as explain what it means on the worksheet, individually. • Make observations about the TERRA satellite, analyze dataset of each satellite and record the observations as	60 mins

further investigate its instruments including ASTER, CERES, MISR, MODIS and MOPITT, where they will describe the satellites as well as explain their importance to global climate research. Remind students that each student will turn in their individual worksheet.	well as explain its instruments importance to global climate research	
EVALUATE **Terra and Landsat Satellite Instruments Sorting** • Tell students that they will now evaluate their knowledge about the satellites that they have been learning about, including Landsat and TERRA and its instruments like ASTER, CERES, MISR, MODIS and MOPITT. • The purpose of this activity is to cut the images and key characteristics and mix them up. Then have students work in groups of 2 in order to match the image and name with the description based on their knowledge of previous readings on remote sensing satellites and its instruments. Then, guide students in a discussion about their matches. • Suggested class discussion questions: ○ If you could work on using remote sensing for climate analysis and could use one of these instruments, which one would you choose? ○ What's the purpose of remote sensing versus ground-based measurements? ○ When acquiring data from these instruments, what steps would you follow in order to analyze land surface temperatures? ○ How does a Landsat satellite differentiate between objects on Earth's surface? • The last part of this activity ends with an individual reflection in which students respond to the following question in writing:	• Listen to introduction of activity. • Students will work together to read the descriptions of what satellites do and the different types of features they analyze on Earth. Then, working with their groups, they have to classify the satellites. • Participate in a discussion with their groups and class where they reflect on what they have focused on satellites and its instruments. • Write about their knowledge and understanding of remote sensing, its importance for climate research and explain how remote sensing data can	60 mins

• Explain what is remote sensing and why it is important for climate research. Then explain how remote sensing data can be used to monitor human activity. Provide at least two examples and an example of an instrument or satellite that is important in this process. You can have them look at the sensor(s) that it's observing now. • Have dictionaries available for students who may need assistance while writing. • In addition, tell students that they will now get to investigate about a NASA's "James Webb Telescope" and its instruments, which will be the premier observatory of the next decade since it will study every phase in the history of our Universe, ranging from the first luminous glows after the Big Bang, to the formation of solar systems capable of supporting life on planets like Earth, to the evolution of our own Solar System. • You can find more information about the NIRCam, NIRSpec, MIRI, and FGS/NIRISS instruments on James Webb Telescope instruments website here: https://www.nasa.gov/mission_pages/webb/instruments/index.html • Tell students that now it's their time to build their own satellite through a simulation game presented by the James Webb Telescope. This will be a homework assignment, so tell students that they will have to access the following website (which works on computers, phones and tablets). The website has the steps on how to build their own satellite based on the features students choose to focus on: https://jwst.nasa.gov/content/features/educational/buildItYourself/index.html • Have students share their satellites to you via email or print it out, so that you can see their satellite products. This is a fascinating way to end this lesson about remote sensing and how satellites and its instruments help us do research.	be used to monitor human activity. • Learn about NASA's James Webb Telescope and its instruments. • Build their own telescope by following the steps on the website and by the features they choose. • Share the results of their created telescope in NASA's James Webb Telescope website.	

8. Standards:

Next Generation of Science Standards (NGSS):

HS-ESS2-2	Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.
HS-PS4-6	Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.
DCI ESS2.A	Earth Materials and Systems
CC	Energy and matter
	Interdependence of Science, Engineering, and Technology

New York State Earth Science Standards (NYSES):

NYSES 2.1g	Weather variables can be represented in a variety of formats including radar and satellite images, weather maps (including station models, isobars, and fronts), atmospheric cross-sections, and computer models.
NYSES 1.1b	The Earth is orbited by one moon and many artificial satellites.

Common Core Standards:

ELA-LITERACY.RL.11-12.1 Cite strong and thorough textual evidence to support analysis of what the text says explicitly as well as inferences drawn from the text, including determining where the text leaves matters uncertain.

ELA-LITERACY.W.11-12.2 Write informative/explanatory texts to examine and convey complex ideas, concepts, and information clearly and accurately through the effective selection, organization, and analysis of content.

9. NASA System Engineering Behavior Model utilized in lesson

- **Leadership**
  - Builds Team Cohesion
  - Appreciates/Recognizes Others
- **Communication**
  - Listens Effectively and Translates Information
  - Communicates Effectively Through Personal Interaction
- **Problem Solving & Systems Thinking**
  - Validates Facts, Information and Assumptions
  - Has the Ability to Find Connections and Patterns Across the System
  - Draws on Past Experiences

10. Supporting Documents:

Name: ______________________________ **Period:** _______ **Date:** ________

Temperature Recording from National Park Activity

Instructions: You will complete the following chart by answering the question in the black box below. Make sure that you answer in full sentences.

Question: As a scientist and park ranger, would you prefer to study the park from the ground or the air? What if you're studying temperatures? Explain why.

Figure 1: Torres del Paine National Park, in Chile's Patagonia region during Summer

Rubric Category	Doesn't meet expectations	Satisfactory	Meets expectations	Exceeds expectations
Productivity	I don't follow the procedures, struggle to record all parts of the worksheet and don't respond to all questions in an average way.	I can follow most of the procedures, record all parts of the worksheet and respond to all questions in an average way.	I can follow all the procedures, successfully record all parts of the worksheet and respond to all questions in a comprehensive way.	I can efficiently follow all the procedures, successfully record all parts of the worksheet and respond to all questions in an exceptional way.

Name: ________________________________ **Period:** _______ **Date:** ________

Temperature Recording from National Park Activity ***ANSWER KEY***

Instructions: You will complete the following chart by answering the question in the black box below. Make sure that you answer in full sentences.

Question: As a scientist and park ranger, would you prefer to study the park from the ground or the air? What if you're studying temperatures? Explain why.

I would like to study the park both by ground and by air. Because I can closely analyze the environment, animals and the ecosystem.

By air, if there is a problem, maybe I would use a drone that would give me a broader view of the environment in general.

If I am studying the temperatures, it would be useful to be close to the ground using thermometers to measure the temperature of the ground surface and analyze the changes that are registered.

I think that satellites could detect an anomaly in the park and would help me to solve the problem. For example, if there is a fire and the temperature is higher, this could put the animals and the ecosystem in danger.

Figure 1: Torres del Paine National Park, in Chile's Patagonia region during summer.

Rubric Category	Doesn't meet expectations	Satisfactory	Meets expectations	Exceeds expectations
Productivity	I don't follow the procedures, struggle to record all parts of the worksheet and don't respond to all questions in an average way.	I can follow most of the procedures, record all parts of the worksheet and respond to all questions in an average way.	I can follow all the procedures, successfully record all parts of the worksheet and respond to all questions in a comprehensive way.	I can efficiently follow all the procedures, successfully record all parts of the worksheet and respond to all questions in an exceptional way.

Name: ______________________________ **Period:** _______ **Date:** ________

Twenty Years of Terra in Our Lives

Instructions: You will read the following text to learn more about Terra satellite and the different instruments that it has. As you read, make sure to annotate the text by using the following symbols:

***** = important | __ = keyword | **?** = I don't understand | ○ = unfamiliar word | **!** = I'm surprised | ∞ = made a connection

Twenty years ago, many of us connected to the internet listening to the tones of the dial-up modem. We stressed about how Y2K was going to impact our increasingly computer-dependent lives on New Year's Eve, 2000.
But we survived Y2K and now we scroll through the internet silently on our phones.

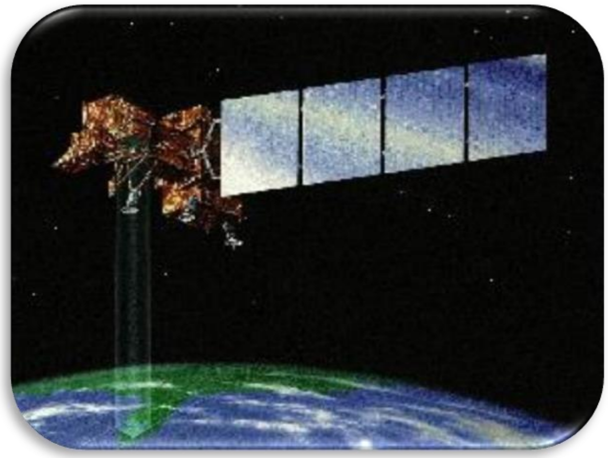


Figure 1: Landsat 7 takes high-resolution imagery of the earth's surface

There is no question that technology has changed. But, at the same time that our lives on Earth were being shaped by our access to technology, 705 kilometers above us, a satellite was changing how we understood our planet. Designed and built in the 1980s and 90s, NASA and Lockheed Martin engineers set out to build a satellite that could take simultaneous measurements of Earth's atmosphere, land, and water. Its mission – to understand how Earth is changing and to identify the consequences for life on Earth. For 20 years,

Terra, the flagship Earth observing satellite, has chronicled those changes. Season after season, Terra data continue to help us understand how the evolving systems of our planet affect our lives – and how we can use that data to benefit society.

Breathing clean air is important to sustaining healthy lives. Three of Terra's instruments – the Multi-angle Imaging Spectroradiometer (MISR), Moderate Imaging Spectroradiometer (MODIS), and Measurements of Pollution in the Troposphere (MOPITT) – track air quality across the globe, identifying and measuring harmful sources and helping people take precautions on poor air quality days. MODIS, with its daily global observations, combined with MISR's detailed views of airborne particles, produce imagery and data products used to track pollutants through the atmosphere as well as to monitor poor air quality days.

Terra data are giving us a reason to breathe a little easier, showing us that air quality in many parts of the world is improving. For example, MISR air quality data in Southern California from 2000-2015, have been able to separate sulfate, nitrate, organic carbon, and elemental carbon particles, showing dramatic reductions in the level of harmful human-caused airborne particles, providing evidence that environmental policy changes worked.

In addition to Terra, for over 40 years, the Landsat satellite has offered the longest continuous global record of the Earth's surface; it continues to deliver visually stunning and scientifically valuable images of our planet.

Rubric Category	Doesn't meet expectations	Satisfactory	Meets expectations	Exceeds expectations
Productivity	I don't follow the procedures, struggle to read the article and annotate the parts of the reading in an average way.	I can follow most of the procedures, read the article and annotate most parts of the reading in an average way.	I can follow all the procedures, read the article and annotate all parts of the reading in an exceptional way..	I can efficiently follow all the procedures, read the article and successfully annotate all parts of the reading outstandingly.

Name: ________________________________ **Period:** _______ **Date:** ________

Twenty Years of Terra in Our Lives ***ANSWER KEY***

Note: Student reading annotations are independent and should reflect the student's choice of annotations, this are just sample annotations that serve as a guide.

Instructions: You will read the following text to learn more about Terra satellite and the different instruments that it has. As you read, make sure to annotate the text by using the following symbols:

* = important | __ = keyword | ? = I don't understand | o = unfamiliar word | ! = I'm surprised | ∞ = made a connection

Twenty years ago, many of us connected to the internet listening to the tones of the dial-up modem. We stressed about how Y2K was going to impact our increasingly computer-dependent lives on New Year's Eve, 2000.

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Breathing clean air is important to sustaining healthy lives. Three of Terra's instruments – the Multi-angle Imaging Spectroradiometer (MISR), Moderate Imaging Spectroradiometer (MODIS) and Measurements of Pollution in the Troposphere (MOPITT) – track air quality across the globe, identifying harmful sources and helping people take precautions on poor air quality days.

MODIS, with its daily global observations, combined with MISR's detailed views of airborne particles, produce imagery and data products used to track pollutants through the atmosphere as well as to forecast poor air quality days.

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Name: ________________________________ **Period:** _______ **Date:** ________

Earth-Now General Satellites and Its Instruments (Page 1 of 3)

Instructions: You will now visit the following Earth-Now site: https://climate.nasa.gov/earth-now/ in order to learn more about the different satellites and its instruments. Then you will describe the satellites (and satellite instruments) including their function as well as provide an example of its dataset and explain its meaning.

Name of satellite:	
Description about your satellite and its instruments:	Example of this satellite's dataset and its meaning

Name of satellite:	
Description about the satellite or instrument:	Example of this satellite's dataset and its meaning

Name of satellite:	
Description about your satellite and its instruments:	Example of this satellite's dataset and its meaning

Name of satellite:	
Description about your satellite and its instruments:	Example of this satellite's dataset and its meaning

Name: ________________________________ **Period:** _______ **Date:** ________

TERRA Satellite and Its Instruments (Page 2 of 3)

Instructions: You will continue to explore the Earth-Now site: https://climate.nasa.gov/earth-now/ that you have worked on before. This time you will focus on learning specifically about TERRA satellite instruments ASTER, CERES, MISR, MODIS and MOPITT. You will describe these satellite instruments including their characteristics and importance in climate research.

TERRA satellite instrument: ASTER	
Description about TERRA's instrument:	Importance to global climate research and to you:

TERRA satellite instrument: CERES	
Description about TERRA's instrument:	Importance to global climate research and to you:

TERRA satellite instrument: MISR	
Description about TERRA's instrument:	Importance to global climate research and to you:

National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

Name: ______________________________ **Period:** _______ **Date:** ________

TERRA Satellite and Its Instruments (Page 3 of 3)

TERRA satellite instrument: MODIS	
Description about TERRA's instrument:	Importance to global climate research and to you:

TERRA satellite instrument: MOPITT	
Description about your satellite and its instruments:	Importance to global climate research and to you:

Rubric Category	Doesn't meet expectations	Satisfactory	Meets expectations	Exceeds expectations
Productivity	I don't follow the procedures, struggle to describe the satellites and its instruments, can't describe its importance to global climate research or respond to all questions in an average way.	I can follow most of the procedures, describe the satellites and its instruments, describe its importance to global climate research and respond to all questions in an average way.	I can follow all the procedures, successfully describe the satellites and its instruments, describe its importance to global climate research and respond to all questions in a comprehensive way.	I can efficiently follow all the procedures, successfully describe the satellites and its instruments, describe its importance to global climate research and respond to all questions in an exceptional way.
Understanding	I don't show a clear understanding of climate satellites, TERRA instruments and their function and their importance to global climate.	I show some understanding of climate satellites, TERRA instruments and their function and their importance to global climate.	I show a clear understanding of climate satellites, TERRA instruments and their function and their importance to global climate.	I show a clear and in-depth understanding of climate satellites, TERRA instruments and their function and their importance to global climate.

Name: ________________________________ **Period:** _______ **Date:** ________

Earth-Now General Satellites and Its Instruments (Page 1 of 3) *ANSWER KEY*

Name of satellite: ***Aqua***

Description about your satellite and its instruments:

- *Time in orbit: 18 years 73 days.*

Collecting information on:

- *Ocean evaporation.*
- *Atmospheric water vapor*
- *Clouds*
- *Precipitation*
- *Soil moisture*
- *Sea and Land ice*
- *Snow cover*

Instruments:

- *AIRS*
- *AMSU*
- *CERES*
- *MODIS*
- *AMSR-E*

Example of this satellite's dataset and its meaning

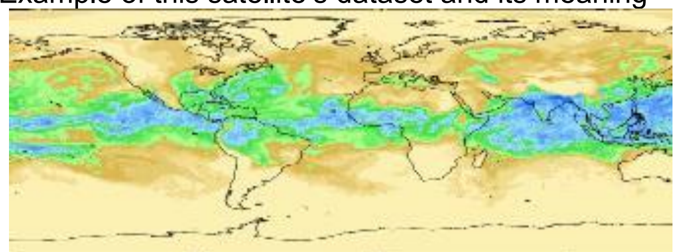


Figure 3 Aqua satellite showing water vapor

- Thanks to the Satellite Aqua, I can observe the water vapor around the Earth.
- Blue colored areas denote higher concentration of water vapor.
- Tanner colored areas denote lower concentration of water vapor.

Name of satellite: ***OCO-2***

Description about the satellite or instrument:

- *Time in orbit: 6 years 14 days.*
- *Studying atmospheric carbon dioxide*
- *The mission's goal is to improve understanding of the carbon cycle and the processes that regulate atmospheric CO2 concentration.*

Instruments:

- *Uses diffraction grating to separate the inbound light energy into a spectrum of multiple component colors.*

Example of this satellite's dataset and its meaning

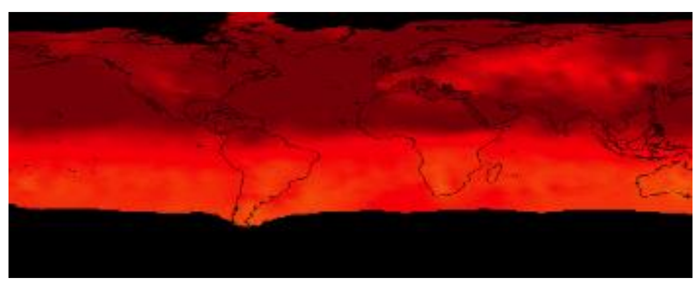
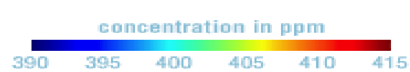


Figure 4 OCO-2



- *Red and yellow areas indicate higher concentration of CO2, while blue areas indicate lower concentrations.*
- *CO2 distribution is measurement in ppm (parts per million).*

Name: ________________________________ **Period:** _______ **Date:** ________

Earth-Now General Satellites and Its Instruments (Page 2 of 2) *ANSWER KEY—CONTINUATION*

Name of satellite: ***JASON-3***

Description about your satellite and its instruments:

- *Time in orbit: 4 years 180 days.*
- *Measuring variation in ocean-surface height.*
- *Understanding of ocean circulation patterns.*
- *Global and regional sea-level changes, and*
- *Climate change*

Instruments:

- *A radar altimeter.*

Example of this satellite's dataset and its meaning

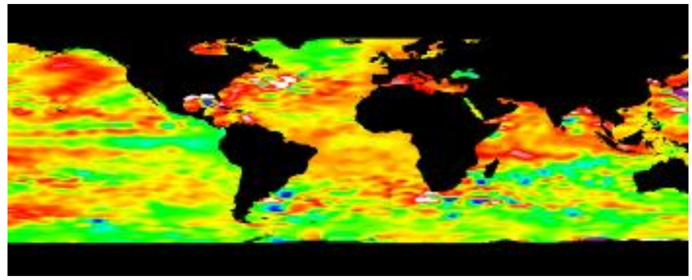


Figure 5 Caption

- *Yellow and red areas indicate regions of the sea levels greater than average, while blue and Purple areas indicate lower than average. Warmer water expands leading to higher levels while cooler water is cooler.*
- *As temperatures increase, so does melting of ice at higher altitudes/latitudes, further raising sea levels.*

Name of satellite: ***Suomi NNP***

Description about your satellite and its instruments:

- *Time in orbit: 8 years 262 days.*
- *Monitoring the environment on Earth and the planet's climate.*
- *Measuring will be used to map land cover and monitor changes in vegetation productivity.*
- *Tracking atmospheric ozone and aerosols.*
- *Taking sea and land surface temperatures.*
- *Monitoring sea ice, land ice and glaciers around the world.*

Instruments:

- *The Visible/Infrared Imager Radiometer Suite (VIIRS).*
- *The Cross-Track Infrared Sounder (CrIS).*
- *The Advanced Technology Microwave Sounder (ATMS).*
- *The Ozone Mapping and Profiler Suite (OMPS).*
- *The Clouds and the Earth Radiant Energy System (CERES).*

Example of this satellite's dataset and its meaning

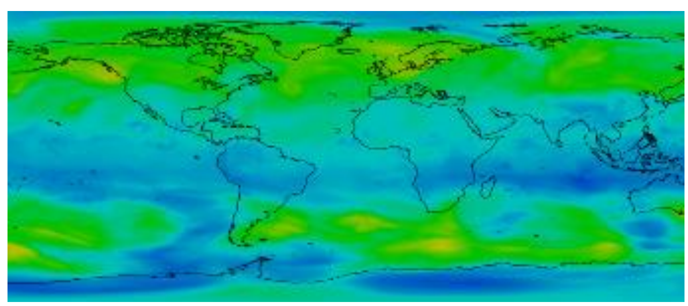


Figure 6: Dobson

- *Pink and white regions represent higher concentration of ozone, while bluer colors represent lower concentration.*
- *One Dobson unit is equal to a layer of pure ozone 0.01 mm thick at 0 degrees Celsius and 1 atm pressure.*

Name: ________________________________ **Period:** _______ **Date:** ________

TERRA Satellite and Its Instruments (Page 3 of 3) *ANSWER KEY*

Instructions: You will continue to explore the Earth-Now site: https://climate.nasa.gov/earth-now/ that you have worked on before. This time you will focus on learning specifically about TERRA satellite instruments ASTER, CERES, MISR, MODIS and MOPITT. You will describe these satellite instruments including their characteristics and importance in climate research.

TERRA satellite instrument: ASTER	
Description about TERRA's instrument: • *Advanced Spaceborne Thermal Emission and Reflection Radiometer.* • *Obtain high-resolution images of the Earth in 14 different wavelengths.*	Importance to global climate research and to you: • *ASTER data is used to create detailed maps of Earth's temperature, emissivity, reflectance, and elevation.* • *This image was meaningful to me because through this instrument we can locate fires in the Earth.*

TERRA satellite instrument: CERES	
Description about TERRA's instrument: • *There are two identical CERES instruments aboard Terra.* • *One CERES instrument operates in a cross-track scan mode and the other in a biaxial scan mode.* • *The cross track mode essentially continues the measurements of the earth Radiation Budget Experiment (ERBE) and the Tropical Rainfall Measuring Mission (TRMM).*	Importance to global climate research and to you: • *The biaxial scan mode provides information about the Earth's radiation balance.* • *This image was meaningful to me because through this instrument we can measure the total radiation and evaluate the radiation flow through the clouds.*

TERRA satellite instrument: MISR	
Description about TERRA's instrument: • *MISR is a new type of instrument designed to see Earth with cameras pointed at nine different angles.* • *One camera points toward the nadir, and the others provide forward and backward viewing angles, on Earth's surface, of 26.1 °, 45.6 °, 60.0°, and 70.5 °.*	Importance to global climate research and to you: • *MISR data can distinguish different types of clouds, aerosol particles, and surfaces.* • *This image was meaningful to me because through this instrument equipped with its nine cameras you can capture the eruption of a volcano and the amount, types, and heights of clouds.*

<table>
<tr><th colspan="2">TERRA satellite instrument: MODIS</th></tr>
<tr><td>Description about TERRA's instrument:
• MODIS measures the photosynthetic activity of land and marine plants (phytoplankton) to yield better estimates of how much of the greenhouse gas is being absorbed and used in plant productivity.
• MODIS has observed the impacts El Niño and La Niña have on the microscopic marine plant.
• MODIS measurements of the biosphere are helping to track carbon dioxide sources and sinks in response to climate change.</td><td>Importance to global climate research and to you:
• The sensor observes where and when disasters strike—such as volcanic eruptions, floods, severe storms, droughts, and wildfires—and will hopefully help people get out of harm's way.
• This image was meaningful to me because through this instrument you can track carbon dioxide sources that are responsible to climate change.</td></tr>
</table>

<table>
<tr><th colspan="2">TERRA satellite instrument: MOPITT</th></tr>
<tr><td>Description about your satellite and its instruments:
• It is an instrument designed to enhance our knowledge of the lower atmosphere and to observe how it interacts with the land and ocean biosphere.
• MOPITT is one of the earliest satellite sensors to use gas correlation spectroscopy.
• The sensor measures emitted and reflected radiation from the Earth in three spectral bands.</td><td>Importance to global climate research and to you:
• The sensor helps to track the gas to its sources.
• This image was meaningful to me because through this instrument measures of pollution in the troposphere can be made.</td></tr>
</table>

TERRA Satellites Matching Satellites Activity

Teacher Instructions: The next page has TERRA satellite and its instruments including MOPITT, MODIS, ASTER, MISR as well as Landsat satellite. By now, students have already learned about these satellites from the text, the EarthNow Platform, as well as an article reading.

The purpose of this activity is to cut the images and key characteristics and mix them up. Then have students work in groups of 2 in order to match the image and name with the description based on their knowledge of previous readings on remote sensing satellites and its instruments. Then, guide students in a discussion about their matches.

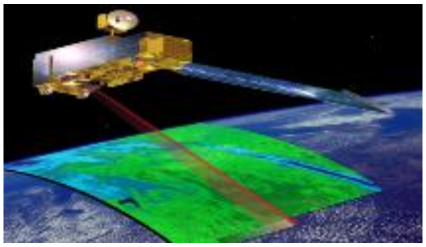
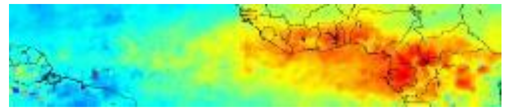
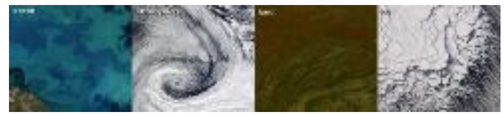
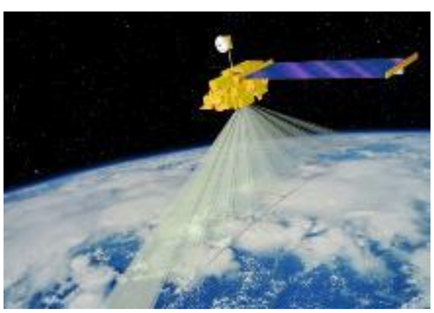
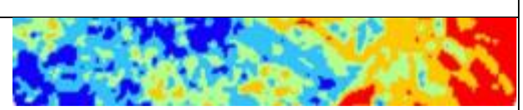
Suggested discussion questions:

- If you could work on using remote sensing for climate analysis and could use one of these instruments, which one would you choose?
- What's the purpose and benefits of remote sensing versus ground-based measurements?
- When acquiring data from these instruments, what steps would you follow in order to analyze land surface temperatures?
- How does a Landsat satellite differentiate between objects on Earth's surface?

The last part of this activity ends with an individual reflection in which students respond to the following question in writing:

- Explain what is remote sensing and why it is important for climate research. Then explain how remote sensing data can be used to monitor human activity. Provide at least two examples and an example of an instrument or satellite that is important in this process.

TERRA Satellites Matching Satellites Activity *(See previous page for instructions)*

 **MOPITT**	**Key characteristics:**  • Measures pollution in the troposphere from 9 different angles. • It has a sensor that uses gas correlation spectroscopy. • Measures the radiation emitted and reflected from Earth.
 **MODIS**	**Key characteristics:**  • The sensor observes volcanic eruptions, floods, severe storms, droughts. • Its detectors measure 36 spectral bands. • Records the resolution-small changes of the ocean, land and ice atmosphere.
 **ASTER**	**Key characteristics:**  • It uses thermal infrared energy. • It can locate fires on the Earth. • Obtains high-resolution images of the Earth in 14 different wavelengths.
 **MISR**	**Key characteristics:**  • Measures the properties of clouds. • This instrument is equipped with nine cameras. • It has a spectroradiometer.
 **LANDSAT**	 • It collects spectral information from Earth's surface. • The sensors detect natural changes. • Its data report on human health, agriculture, climate, energy, urban growth, ecosystems, forest management, etc.

TERRA Satellites Matching Satellites Student Answers

Title: "**TERRA Satellites Matching Satellites Student**"

By: *Student*

Explain what is remote sensing and why it is important for climate research. Then explain how remote sensing data can be used to monitor human activity. Provide at least two examples and an example of an instrument or satellite that is important in this process.

The term remote sensing refers to obtaining information about an object or area from distance, from aircraft or satellites in this case.

Remote sensing can be used to monitor different human activity, such as carbon dioxide, which is a greenhouse gas derived from human and natural events which slow the escape of heat into space.

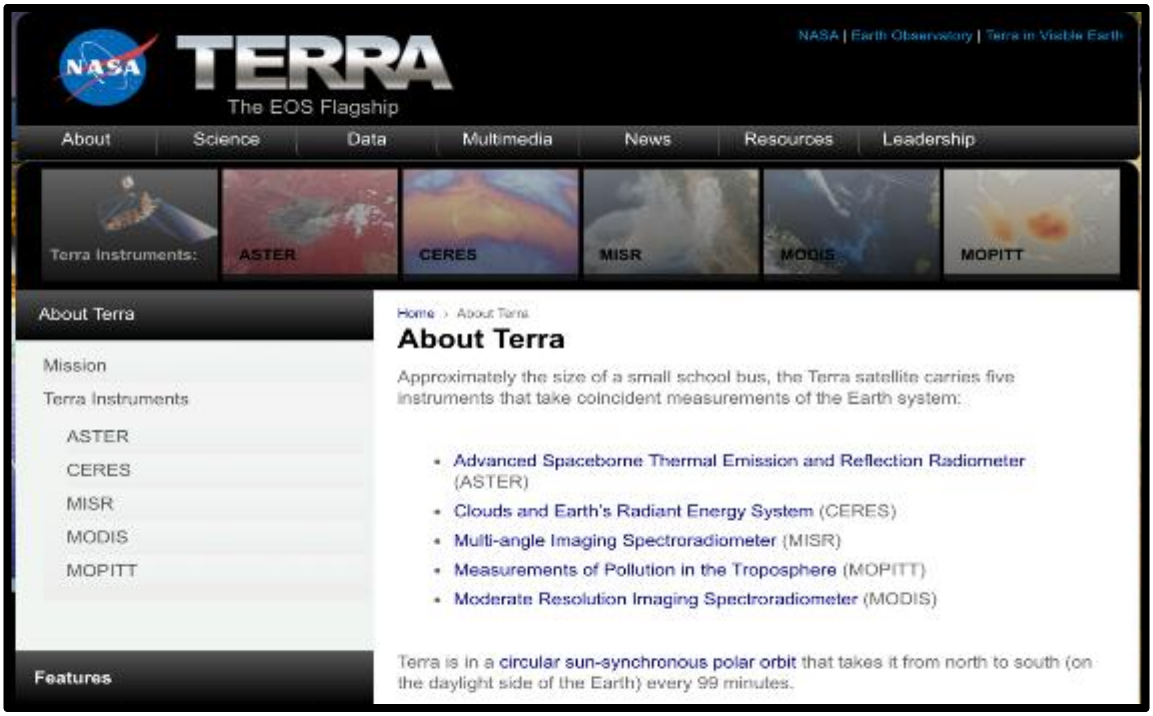
Burning fossil fuels emitting carbon dioxide enters the atmosphere through the burning of fossil fuels (coal, natural gas, and oil), solid waste, trees, and other biological materials; as a result of certain chemical reactions (for example, cement manufacturing). OCO-2 is the spacecraft dedicated to studying atmospheric carbon dioxide, which is linked to global warming and climate change.

Another example of remote sensing is monitoring Earth's atmosphere to map the impact of human activity and natural disasters on communities and ecosystems. For example, by looking at how cities have overtaken over fields and ecosystems that have been forced due to civilization.

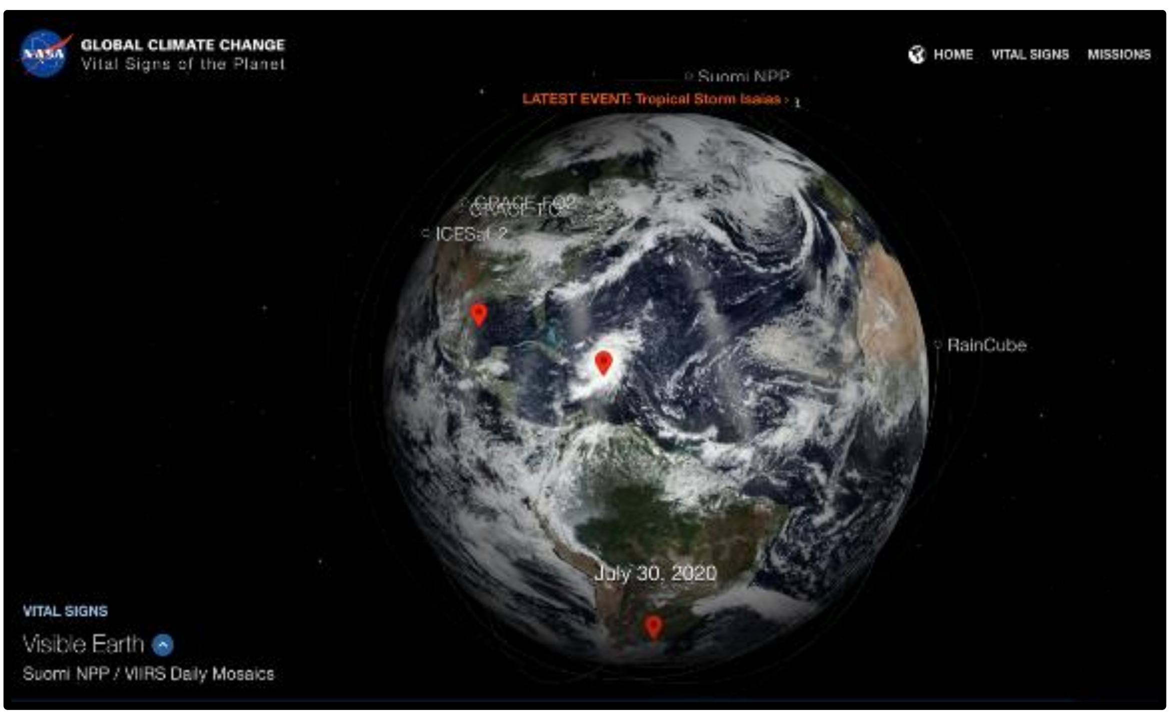
TERRA and its instrument ASTER explore the connections between Earth's atmosphere, land, snow and ice, ocean, and energy balance to understand Earth's climate and climate change.

Websites used in this lesson:

TERRA instruments: https://terra.nasa.gov/about



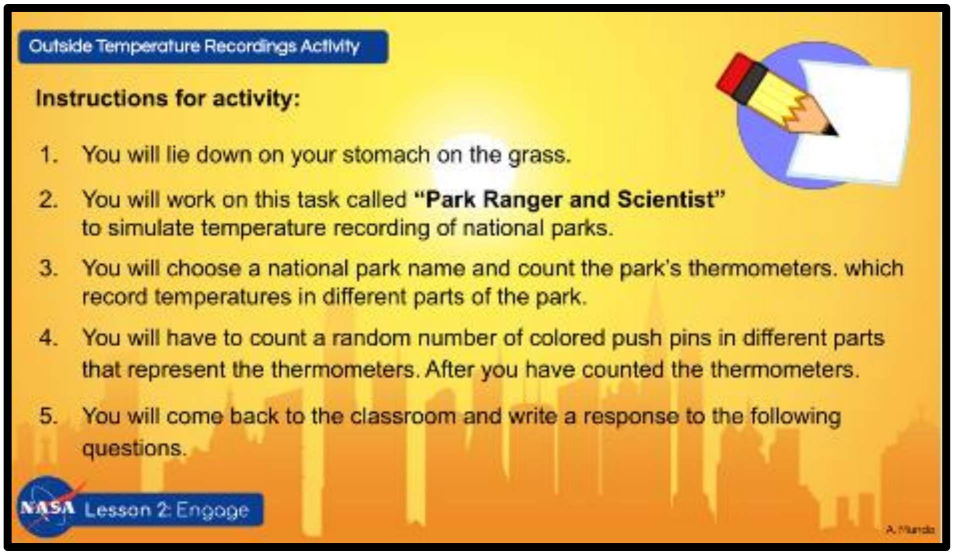
NASA Earth Now: https://climate.nasa.gov/earth-now/#/

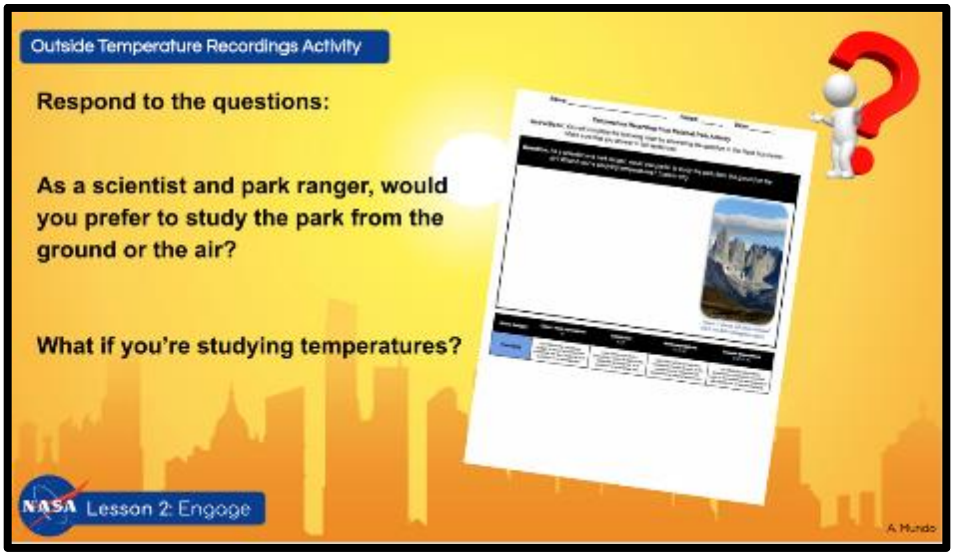


James Webb Space Telescope:
https://www.nasa.gov/mission_pages/webb/instruments/index.html

Lesson Presentation Slides:

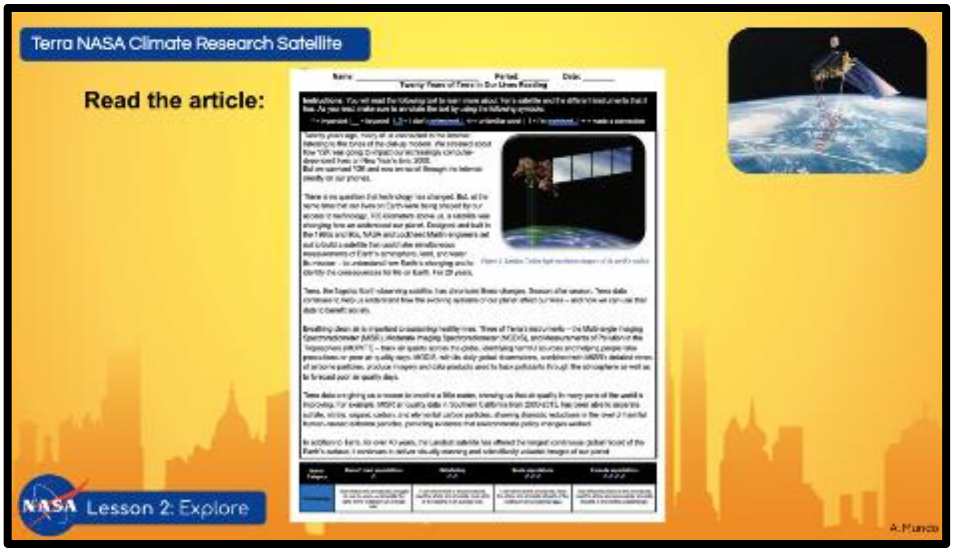
ENGAGE:


Outside Temperature Recordings Activity
Instructions for activity:
1. You will lie down on your stomach on the grass.
2. You will work on this task called "Park Ranger and Scientist" to simulate temperature recording of national parks.
3. You will choose a national park name and count the park's thermometers. which record temperatures in different parts of the park.
4. You will have to count a random number of colored push pins in different parts that represent the thermometers. After you have counted the thermometers.
5. You will come back to the classroom and write a response to the following questions.
NASA Lesson 2: Engage
A. Mundo

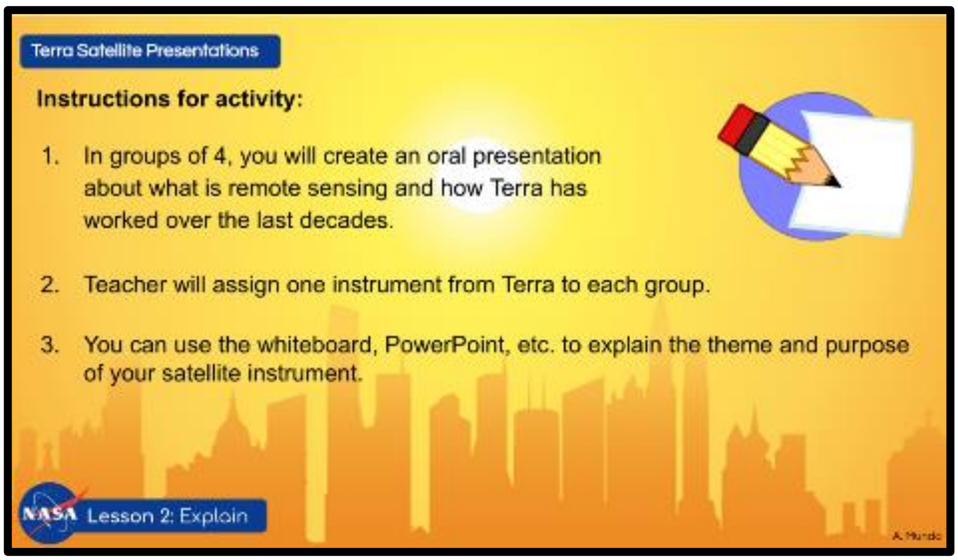

Outside Temperature Recordings Activity
Respond to the questions:
As a scientist and park ranger, would you prefer to study the park from the ground or the air?
What if you're studying temperatures?
NASA Lesson 2: Engage
A. Mundo

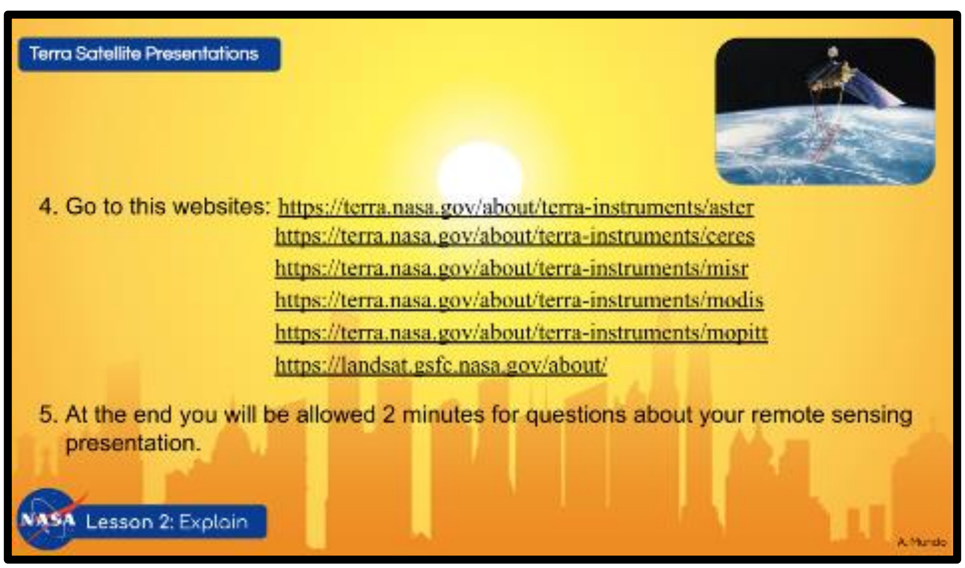
EXPLORE:


Terra NASA Climate Research Satellite
Instructions for activity:
1. You will read the article: "Twenty Years of Terra in Our Lives".
2. You will explore how Terra has been doing remote sensing for the last 20 years.
3. You will learn about the satellite's five instruments concurrently observing Earth's atmosphere, ocean, land, snow and ice, providing insights into Earth systems such as the water, carbon and energy cycles.
4. You will complete the graphic organizer.
NASA Lesson 2: Explore
A. Mundo


Terra NASA Climate Research Satellite
Read the article:
Lesson 2: Explore
A. Mundo

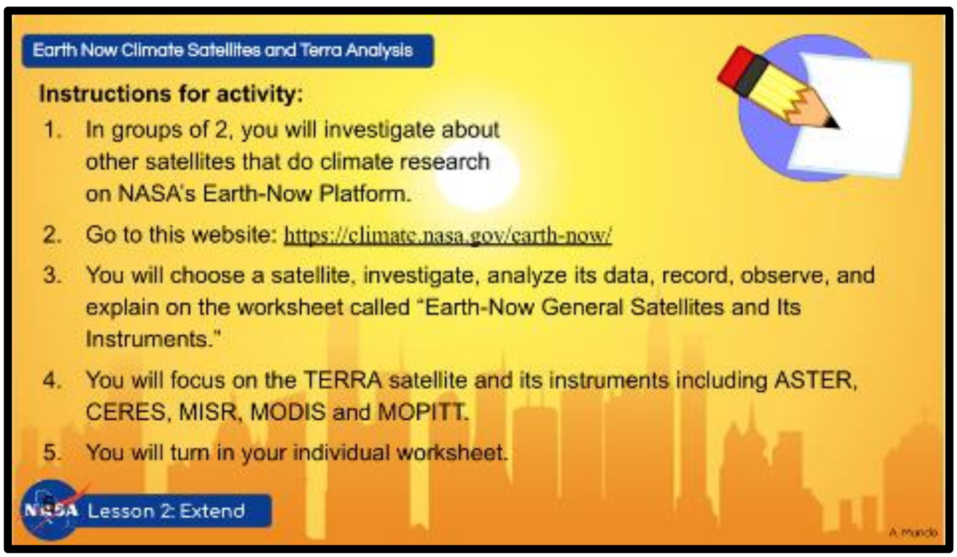
EXPLAIN:

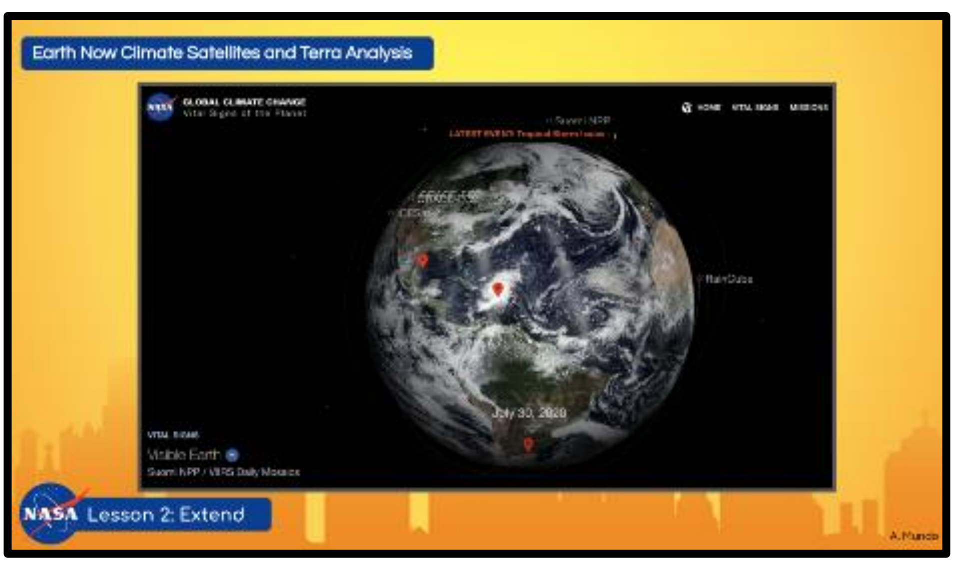

Terra Satellite Presentations
Instructions for activity:
1. In groups of 4, you will create an oral presentation about what is remote sensing and how Terra has worked over the last decades.
2. Teacher will assign one instrument from Terra to each group.
3. You can use the whiteboard, PowerPoint, etc. to explain the theme and purpose of your satellite instrument.
Lesson 2: Explain
A. Mundo

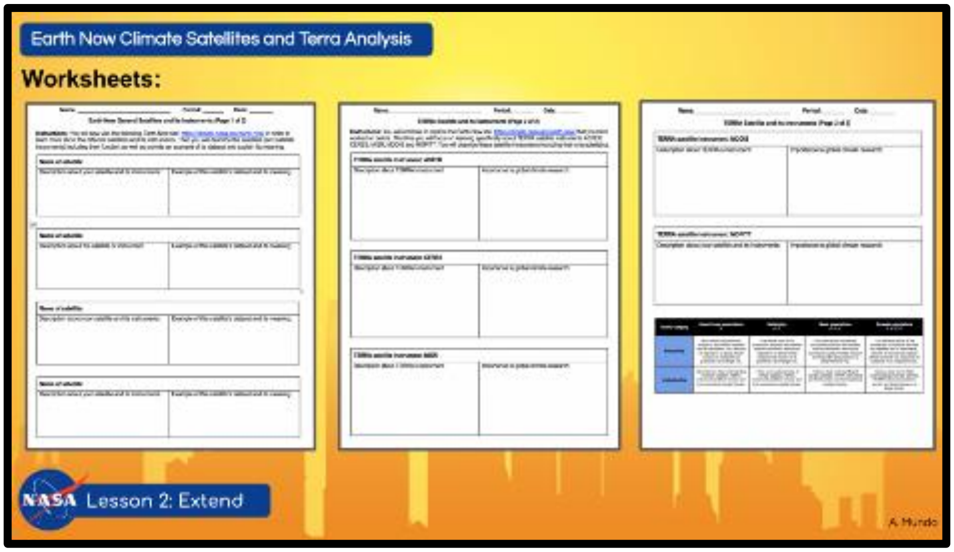

Terra Satellite Presentations
4. Go to this websites: https://terra.nasa.gov/about/terra-instruments/aster
https://terra.nasa.gov/about/terra-instruments/ceres
https://terra.nasa.gov/about/terra-instruments/misr
https://terra.nasa.gov/about/terra-instruments/modis
https://terra.nasa.gov/about/terra-instruments/mopitt
https://landsat.gsfc.nasa.gov/about/
5. At the end you will be allowed 2 minutes for questions about your remote sensing presentation.
Lesson 2: Explain
A. Mundo


Terra Satellite Presentations
TERRA
The EOS Flagship
About Terra
Lesson 2: Explain
A. Mundo

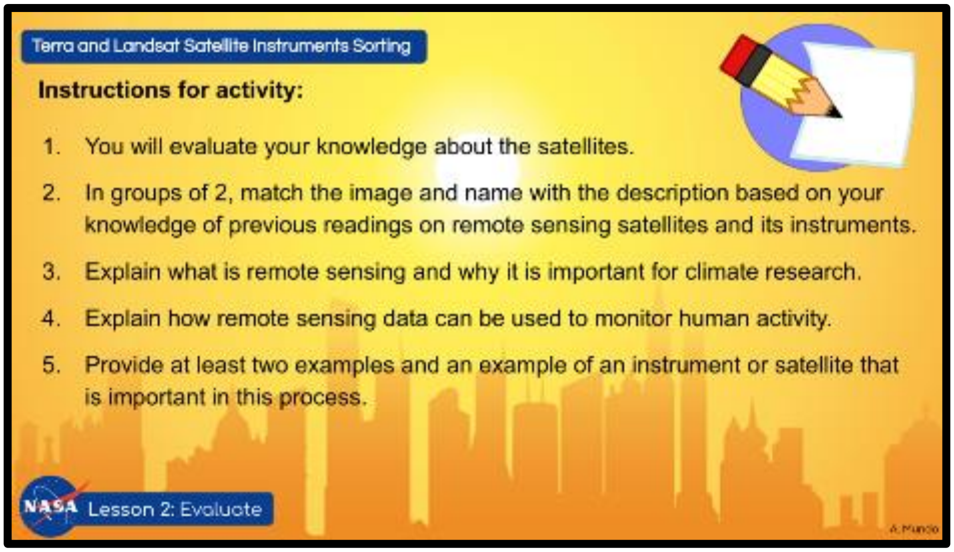
EXTEND:

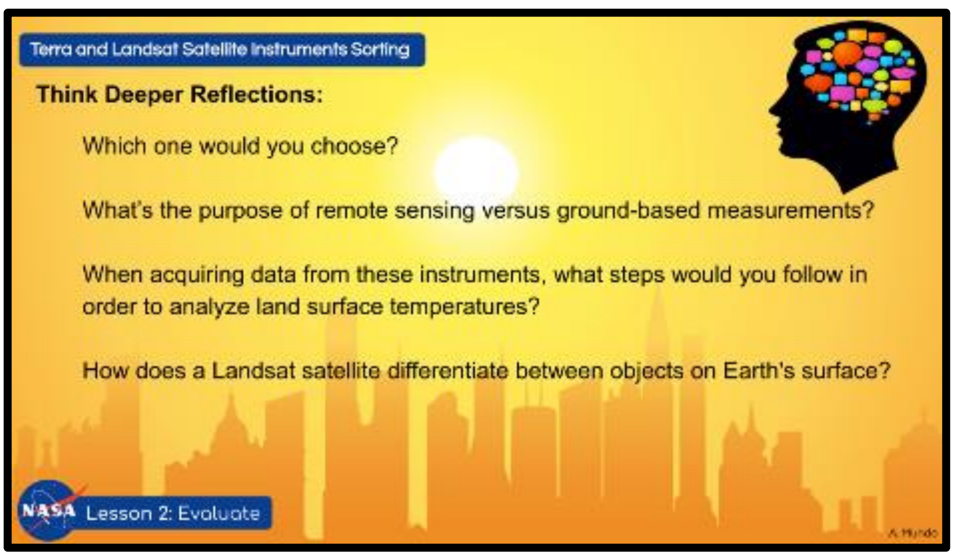

Earth Now Climate Satellites and Terra Analysis
Instructions for activity:
1. In groups of 2, you will investigate about other satellites that do climate research on NASA's Earth-Now Platform.
2. Go to this website: https://climate.nasa.gov/earth-now/
3. You will choose a satellite, investigate, analyze its data, record, observe, and explain on the worksheet called "Earth-Now General Satellites and Its Instruments."
4. You will focus on the TERRA satellite and its instruments including ASTER, CERES, MISR, MODIS and MOPITT.
5. You will turn in your individual worksheet.
Lesson 2: Extend
A. Mundo


Earth Now Climate Satellites and Terra Analysis
GLOBAL CLIMATE CHANGE
July 30, 2020
Lesson 2: Extend
A. Mundo


Earth Now Climate Satellites and Terra Analysis
Worksheets:
Lesson 2: Extend
A. Mundo

EVALUATE:


Terra and Landsat Satellite Instruments Sorting
Instructions for activity:
1. You will evaluate your knowledge about the satellites.
2. In groups of 2, match the image and name with the description based on your knowledge of previous readings on remote sensing satellites and its instruments.
3. Explain what is remote sensing and why it is important for climate research.
4. Explain how remote sensing data can be used to monitor human activity.
5. Provide at least two examples and an example of an instrument or satellite that is important in this process.
Lesson 2: Evaluate
A. Mundo


Terra and Landsat Satellite Instruments Sorting
Think Deeper Reflections:
Which one would you choose?
What's the purpose of remote sensing versus ground-based measurements?
When acquiring data from these instruments, what steps would you follow in order to analyze land surface temperatures?
How does a Landsat satellite differentiate between objects on Earth's surface?
Lesson 2: Evaluate
A. Mundo

Differentiated instruction activities

This lesson includes instructional activities that promote differentiation in the following ways:

- Students learn new content in multiple ways including orally (through groups and class discussions), visually (through the use of videos and images), data analysis (through infographics and graphs) and reflection.
- Students use graphic organizers that help them process and organize their understanding of the new content.
- Lessons include graphic organizers with sentence starters that benefit English Language Learners and Special Education students to organize their ideas in better ways.
- Every lesson is adaptable to the personal learning plans of students.

11. Conclusion and linkage to next lesson:

This has been the second lesson of this climate unit plan which had a focus on remote sensing, satellites and instruments. During this second lesson, students had the opportunity to engage in authentic learning experiences through discovery, research and exploration by simulating ground-based and satellite surface temperature recordings. Furthermore, they had the opportunity to discuss the different methods to record physical characteristics of Earth's surface, define remote sensing and its advantages, read and reflect on TERRA and Landsat satellites and their instruments, and present about TERRA and Landsat satellites and their instruments. In addition, students investigate climate satellites from Earth Now and analyze and explain its contribution to climate research, investigate TERRA satellites from Earth Now platform and analyze their instruments and explain their contribution to climate research as well as evaluate their knowledge by matching satellites and their instruments with their descriptions. The completion of all worksheets, tasks and activities with a high rubric grade demonstrates an assessment quantification of student's learning. In the next lesson, students will learn more about the Urban Heat Island phenomenon and their effects on cities around the world.

National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

NASA Climate Change Research Initiative
Applied Research STEM Curriculum Portfolio

CCRI Unit Plan Template

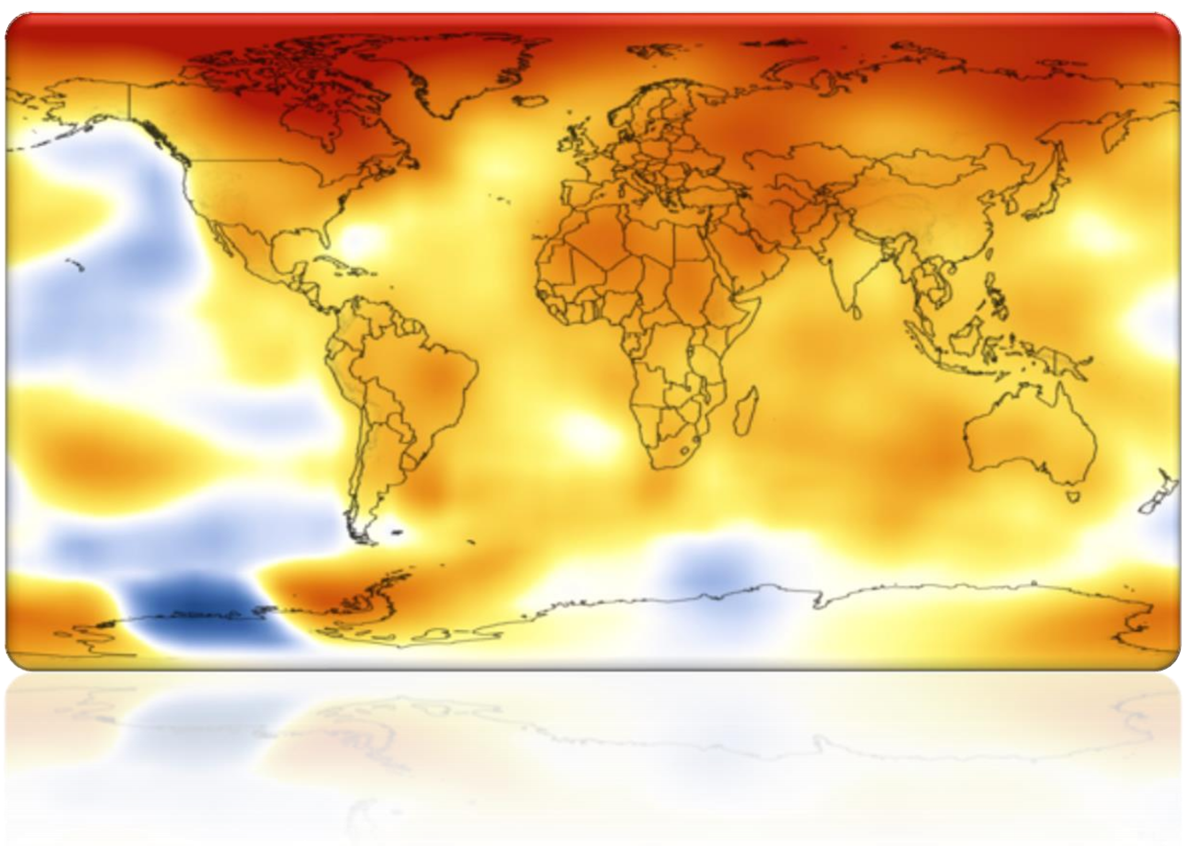
NASA Science Mission Directorate | Earth Sciences Division
NASA Goddard Institute for Space Studies
NASA Goddard Space Flight Center | Office of STEM Engagement

Unit Title: Land Surface Temperature in Urban Settings and the Heat Island Effect

Lesson 3 Title: “When Heat Is Trapped and Urban Heat Island Takes Over”

NASA STEM Educator / Associate Researcher: Alejandro A. Mundo

NASA PI / Mentor: Dr. Christian Braneon



XIV. Lesson 3: "When Heat Is Trapped and Urban Heat Island Takes Over"

1. Table of Contents for lesson

2. Summary and Goals of Lesson

This lesson is titled "When Heat Is Trapped and Urban Heat Island Takes Over" and it serves as lesson 3 of this climate unit which incorporates the 5E model template. It focuses on the Urban Heat Island phenomenon and its effects on urban settings.

The goals for this lesson include students to be able to:

- Observe remote sensing imagery from different cities.
- Discuss and make connections about temperature and vegetation in different locations.
- Read about the Urban Heat Island phenomenon.
- Create a poster and explain what is the Urban Heat Island and its effects.
- Investigate, access and download remote sensing imagery from EarthExplorer for New York City and a city of their choice.
- Analyze remote sensing imagery from EarthExplorer and reflect on the process and imagery characteristics.
- Calculate the land surface temperatures from the Earth Engine Apps specifications.

The goals for this lesson will be met throughout the activities and assignments for each part of the lesson plan.

3. CCRI Lesson Plan Content Template

*Scroll to next to see this component.

NGSS Standards & NYS Standards:	Common Core Standard:	NASA Science:
HS-ESS2-2 Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems. **HS-PS4-6** Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. **New York State Earth Science Standards (NYSES):** **NYSES 2.1g** Weather variables can be represented in a variety of formats including radar and satellite images, weather maps (including station models, isobars, and fronts), atmospheric cross-sections, and computer models. **NYSES 1.1b** The Earth is orbited by one moon and many artificial satellites. **Phenomenon:** Flow of Energy and Matter **Crosscutting concepts:** • Systems and System Models • Interdependence of Science, Engineering, and Technology Patterns • Energy and matter	**ELA-LITERACY.RL.11-12.1**: • Cite strong and thorough textual evidence to support analysis of what the text says explicitly as well as cite inferences drawn from the text, including determine where the text leaves matters uncertain. **ELA-LITERACY.RST.11-12.3** • Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text. **CCSS.ELA-LITERACY.RST.11-12.9** • Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible. **CCSS.ELA-LITERACY.W.11-12.2** Write informative/explanatory texts to examine and convey complex ideas, concepts, and information clearly and accurately through the effective selection, organization, and analysis of content.	—Earth Science

Content Area and Grade Level	Name of Project-Based Activity or Theme:	Estimated Time Frame to Complete:
Content Area: Earth Science **Grade Level:** 11 & 12 grades	Students will analyze what is the Urban Heat Island phenomenon and the effects it has over urban settings.	This is the third lesson of 5 parts of this unit plan. It is estimated to take 5 days, if taught on periods of about 55 minutes a day.

Overall Investigation Question(s):	What is the Urban Heat Island and how is it caused?
Overall Project Description/Activity:	Learn about the Urban Heat Island phenomenon and its effect on cities and climate as a whole.

Materials Needed to Complete Project	Stakeholders:	Hyperlinks Used:	Multimedia/Technology:	Classroom Equipment:
• Markers • Blank poster paper • Provided worksheets	–Students –Educator –Administrator	**NASA Urban Heat Islands** **Link:** https://www.youtube.com/watch?v=lnBO4vX82Fs **Urban Heat Islands** **Link:** https://mynasadata.larc.nasa.gov/basic-page/urban-heat-islands **Earth Explorer** **Link:** https://earthexplorer.usgs.gov/ **Google Earth Engine App** **Link:** https://yceo.users.earthengine.app/view/uhimap	• Laptops with internet connection • Laptops with PowerPoint • Smartboard	• Laptops • Smartboard

NASA System Engineering Behaviors	Category	Activities	Student Outcomes	Evaluation
Uses visuals to communicate complex interaction	Communications	Students will discuss about different maps belonging to different cities including a vegetation map and brightness temperature map.	Work cooperatively with team members to discuss connections between maps and climate..	Climate
Communicates effectively through personal interaction	Communications	Students will work together in groups in order to present about the connections between maps	Complete their definitions and descriptions about the different types of instruments it has.	Remote sensing
Builds Team Cohesion	Leadership	Students will work in harmony and assign tasks and responsibilities among peer in order to work for a common goal.	Present about the different instruments that TERRA has as well as Landsat.	Climate and temperature
Appreciates/Recognizes Others	Leadership	Students value each of their members in the group for their contribution and support their ideas.	Provide feedback on their classmates' presentations and supports them.	
Has a comprehensive view	Attitudes & Attributes	Students will choose their own climate satellites and work with their partners to discuss their missions and descriptions.	Discuss different views and opinions about the satellites they choose and why they're important.	Climate
Seeks information and uses the art of questioning	Attitudes & Attributes	Students will use different types of resources (evidence) in order to analyze remote sensing and explain why its meaningful in climate research.	Use the provided resources to explain what remote sensing is and its importance in research.	Remote sensing
Validates facts, information and assumptions	Systems Thinking	Students will find satellite instruments from Worldview platform and validating fvideits functions.	Validates the evidence and put it together in order to explain it.	Climate
Keeps the focus on mission requirements	Systems Thinking	Students will work on the assigned work and task in order to complete it by the given time.	Pay attention and follow procedures to complete the task.	
Learns from success and failures	Technical Acumen	Teacher will give feedback to students based on their performance at the activities and students will use and reflect on that feedback.	Reflects and uses feedback to do better.	

	Attachments?	List Attached Documents:
List and attach all PowerPoint presentations and supportive documents for instructional activities	Yes	• Urban Heat Island and Its Effects Worksheet • Urban Heat Island Poster Guidelines for Students • EarthExplorer Remote Sensing Imagery Analysis Worksheet

	Attachments?	List Attached Rubrics:
List and attach all rubrics for activity and assessment evaluation	Yes	• Urban Heat Island and Its Effects Worksheet Rubric • Urban Heat Island Poster Guidelines for Students Rubric • EarthExplorer Remote Sensing Imagery Analysis Worksheet Rubric

4. Mission Alignment

This lesson is part of this climate unit plan and aligns with NASA's Landsat satellite mission, whose groundbreaking series of repetitive imaging of Earth's land at a spatial resolution shows human interaction with the environment.

5. Time to implement lesson

This is the third lesson of 5 parts of this unit plan. It is estimated to take 5 day, if taught on periods of about 55 minutes a day.

6. Materials required.

–Computers
–Markers
–Poster paper
–Worksheets and supporting documents which are provided at the end the lesson template.

7. 5 E lesson model template:

What the Teacher does	What the Students do	Time
<u>**ENGAGE**</u> **Temperatures and Vegetation Map Activity** • Tell students that they will now take a closer look at remote sensing images for different locations on Earth. All images appear below in the worksheet section. The first page shows images of New York City, followed by the next page which has images of Atlanta, Baltimore and the last page shows images of Providence. The maps in the following pages represent temperature, vegetation maps and climate. The idea is that students will have to observe them and come up with conclusions on what they see and make connections to vegetation and temperature. • You will provide one set of images to each group. There are three sets, and it's fine if you have multiple groups observing the same type of image. Have each group work together to come up with observations and connections to climate change. Allow 5 minutes for groups to talk among each other discussing their ideas. These are some of the questions that you can post to guide the conversation o What do you see? o Where is this at? o What connections can you make?	• Listen to introduction of activity. • Work in groups to observe the assigned remote sensing images and discuss with their group members about connections to climate change and relationships that they see in their images.	40 mins

◦ Have you seen a map like this before? ◦ Why is it important to have these maps? How does it connect to the topic we are talking about? • As the groups are discussing their ideas, circulate around the classroom. Remind students that they will have an opportunity to share their ideas in a few minutes. • After students have discussed their ideas with their groups, allow students to share out their ideas, findings and connections to the class. The idea is to lead the conversation by image. First have the group(s) that had the same image talk about it first. Then move on the next image and so on. This purpose is to have students make connections to vegetation and temperature, meaning that where there is more vegetation, the temperature appears to be less warm than where there are buildings in a city. • Then, show this NASA video called "Urban Heat Islands: https://www.youtube.com/watch?v=lnBO4vX82Fs • As the introduction to today's activity, this video explains the usage of remote sensing in analyzing how metropolitan areas tend to be hotter than the neighboring regions. Some suggested questions that the teacher can ask after the video as a class discussion: • Why do you think NYC or any city is hotter than its surrounding area? • Why do you propose an urban area is called a Heat Island? • What do you think are consequences of this heating?	• Share their group ideas in the class discussion and listen to the other groups in the classroom that got a different set of images than them to see if the connections can also be applied there. • Watch the video about the phenomenon "Urban Heat Island" • Engage in a group discussion in order to discuss possible reasons and consequences of surface temperature changes in urban cities like New York.	
<u>EXPLORE</u> **Urban Heat Island Article** • Tell students that they will now explore about the phenomenon known as the "Urban Heat Island" in order to find out more about its characteristics. While reading this article, students will also annotate, as suggested in the reading.	• Listen to introduction of activity.	

• The reading can be done independently, in groups, silent reading, or in any way according to your classroom needs.
 	
• The teacher may choose to take a group of students to read on their own to a side of the classroom. This would be a differentiation strategy to help those with reading disorders or English Language Learners.
 	
• After students have finished reading, facilitate a class conversation that reflects on the following questions:
  ○ What is the Urban Heat Island and its effects?
  ○ What are some factors that influence the Urban Heat Island in different cities?
  ○ What is the relationship between energy and the Urban Heat Island?
 	
• Teacher may add further questions that relate to the article and promote critical thinking.
	• Get a copy of the article called "Urban Heat Island Effect" which they will read as well as annotate independently.
	
	• Share their ideas in a class discussion and build on each other's ideas from the text they just read about the Urban Heat Island and its effects.
		30 mins

<u>EXPLAIN</u>
 	
Urban Heat Island Poster
 	
• Tell students that they will now work in groups of four (or teacher can choose a number) in order to create a poster where they will explain what is the Urban Heat Island and its effects, based on the article they have read previously. In addition, students will also have to make a sketch of how the Urban Heat Island effects are represented on a city and similar environments.
 	
• Encourage students to work on the following guidelines, which are also present on the "Urban Heat Island Effect Poster" handout.
 	
• Guidelines:
  ○ A clear and complete definition of what is the Urban Heat Island and its effects
  ○ Clear connection to climate
  ○ Includes how NASA is contributing to this topic
  ○ Should be readable from about 10 feet away
	• Listen to introduction of activity.
	
	• Work on a poster in which they have to explain what is the heat island effect and how heat is represented on the cities and different environments
	
	• Students will use the poster guidelines to create their poster together with their group members. All students should be active during the whole time.
		90 m

◦ Include at least one Urban Heat Island city ◦ Has a title that is short and draws interest ◦ Text is clear and to the point (minimum 50 words) ◦ Use of bullets, numbering, and headlines make it easy to read ◦ Effective use of graphics, color and designs ◦ Consistent and clean layout ◦ Includes acknowledgments, your name and your group's names • The teacher may choose to do this activity as a pamphlet, to see individual projects.		
<u>EXTEND</u> **EarthExplorer Remote Sensing Imagery** • Tell students that they will now further investigate about the concept of remote sensing imagery for Landsat where they will get to explore imagery of different locations including New York City, Durban and a location of their choice. Tell students that scientists actually use the Earth Explorer platform in order to get satellite imagery. Satellite imagery can help us analyze the Earth in different ways. For example, we can analyze surface temperatures to study the Urban Heat Island and its effects on different locations. • Provide the steps for accessing remote sensing imagery from Earth Explorer to students: https://earthexplorer.usgs.gov/ The instructions have been included in the document called: "EarthExplorer Manual" The teacher may model how to do the steps as a class and students can follow on their computers, if preferred. • Ask students to individually complete the worksheet called "EarthExplorer Remote Sensing Imagery Analysis" where they will reflect about the process of acquiring remote sensing imagery and follow a task.	• Listen to introduction of activity. • Work on a lab for EarthExplorer in order to get remote sensing imagery from different locations including Durban, New York, and a city of their choice. • Follow the manual's instructions as well as the steps provided on the worksheet. • Follow teacher's model how to access remote sensing imagery, if teacher chooses to do this as a class. • Complete the task assigned on the worksheet individually.	60 m

• Tell students that while they are not physically extracting remote sensing data and doing calculations, they are analyzing remote sensing imagery that can be extracted by using a coding and programming like "R" or "Python" and "ArcGIS" and Landsat satellites.		
<u>EVALUATE</u> **Urban Heat Island Intensity and Earth Engine App** • Tell students that they will now get to use a platform known as Google Earth Engine App, which has the purpose of tracking the range of Urban Heat Island intensity data, year by year, for a 14-year time span. Students will now observe the data, analyze it and try to find correlations between the urban environments and intensity in the locality. • Provide students with the following steps, which also appear in the document called "Earth Engine App and Urban Heat Island Intensity" below: • *Go to Earth Engine App's website:* *https://yceo.users.earthengine.app/view/uhimap* • *At the top, there is a search bar where you will type in the name of your city.* • *Once you have searched and selected your city, the map will take you to the city.* • *Select a part of the city by clicking on top of the map. In order to get a valid data map, make sure you click on an area that has colored pixels on top.* • *On the right side, you will be able to see the data including annual daytime UHI, annual nighttime UHI, summer daytime UHI, summer nighttime UHI, winter daytime, winter nighttime as well as long-term and seasonal UHI intensity graphs.* • *Record the values in your table, as requested. In order to calculate the range of intensity, you will subtract the lowest summer daytime intensity from the highest summer daytime intensity.* • *Complete the table on the worksheet with the required information.* **Teacher's task for next class**: The teacher needs to watch and complete the E-training modules on "Intro To	• Listen to introduction of activity. • Follow steps how to access the Google Earth Engine App in order to acquire the range of Urban Heat Island intensity data. • Analyze and Interpret the Urban Heat Island intensity data on the provided worksheet.	

Atmosphere," "Clouds," and "Surface Temp" on the GLOBE training website: https://www.globe.gov/get-trained/protocol-etraining https://www.globe.gov/get-trained/protocol-etraining/etraining-modules/16867642/12267 Teacher should allow at least one week to complete these modules.		

8. Standards

Next Generation of Science Standards (NGSS):

HS-ESS2-2. Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.

HS-PS4-6 Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

DCI ESS2.A Earth Materials and Systems

CC Energy and matter: Energy drives the cycling of matter within and between systems. (HS-ESS2-3)

Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible. (HS-ESS2-1)

New York State Earth Science Standards (NYSES):

NYSES 2.1a Earth systems have internal and external sources of energy, both of which create heat.

NYSES 2.2c A location's climate is influenced by latitude, proximity to large bodies of water, ocean currents, prevailing winds, vegetative cover, elevation, and mountain ranges.

NYSES 2.1g Weather variables can be represented in a variety of formats including radar and satellite images, weather maps (including station models, isobars, and fronts), atmospheric cross-sections, and computer models.

Common Core Standards:

MATH.CONTENT.HSN.Q.A.3
Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.

ELA-LITERACY.W.9-10.9
Draw evidence from literary or informational texts to support analysis, reflection, and research.

9. NASA System Engineering Behavior Model utilized in lesson

- **Leadership**
  - Builds Team Cohesion
  - Appreciates/Recognizes Others

- **Attitudes and Attributes:**
  - Seeks Information and Uses the Art of Questioning

- **Communication**
  - Listens Effectively and Translates Information
  - Communicates Effectively Through Personal Interaction

- **Problem Solving & Systems Thinking**
  - Assimilates, Analyzes, and Synthesizes Data
  - Validates Facts, Information and Assumptions
  - Has the Ability to Find Connections and Patterns Across the System

10. Supporting Documents:

*Scroll down to see documents

Remote Sensing Images Activity

Teacher Instructions: The following three pages provide remote sensing images of different locations around the Earth. The first page shows images of New York City, followed by the next page which has images of Atlanta, Baltimore and the last page shows images of Providence.

The maps in the following pages represent temperature and vegetation maps. The idea is that students will have to observe them and come up with conclusions on what they see and make connections between vegetation and temperature.

You will provide one set of images to each group. There are three sets, and it's fine if you have multiple groups observing the same type of image. Have each group work together to come up with observations and connections to climate change. Allow 5 minutes for groups to talk among each other discussing their ideas. These are some of the questions that you can post to guide the conversation

Class discussion questions:

- What do you see?
- Where is this at?
- What connections can you make between vegetation and temperature?
- Have you seen a map like this before?
- Why is it important to have these maps? How does it connect to the topic we're talking about?

As the groups are discussing their ideas, circulate around the classroom. Remind students that they will have an opportunity to share their ideas in a few minutes.

After students have discussed their ideas with their groups, allow students to share out their ideas, findings and connections to the class. The idea is to lead the conversation by image. First have the group(s) that had the same image talk about it first. Then move on the next image and so on. This purpose is to have students make connections to vegetation and temperature, meaning that where there is more vegetation, the temperature appears to be less warm than where there are buildings in a city.

Students' sample discussion answers: ****ANSWERS****

What do you see?

I see two maps that show Landsat satellite data on temperature and vegetation.

Where is this at?
These images are from New York City.

What connections can you make between vegetation and temperature?
One connection I can make in this map has to do with the vegetation, as when the vegetation is dense, its temperature is somewhat warm, but where the vegetation is sparse the temperature is hot.

Have you seen a map like this before?
No, I have not seen one like it before.

Why is it important to have these maps? How does it connect to the topic we're talking?
Because it helps us to be aware of the problem of the high temperatures that are registered in the city and to look for possible solutions to reduce this phenomenon of the Urban Heat Island.

Furthermore, it improves the impact of the effects experienced by high temperatures. The purple color on the images represent hot temperatures while pink represents warm temperatures in New York City.

The dark green color represents more dense vegetation while yellow color represent the sparse vegetation.

Remote Sensing Images

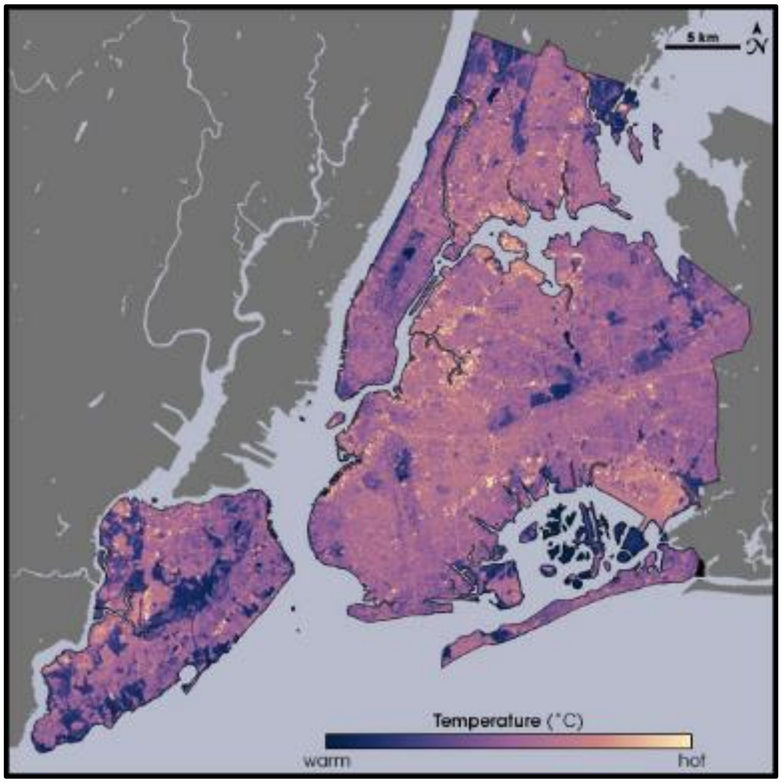


Figure 1: New York City temperature map in Summer 2002 | NASA Landsat

Figure 2: New York City vegetation map NASA in Summer 2002 | NASA Landsat

Remote Sensing Images (Continuation)

Figure 3: Atlanta aerial map on September 28, 2000 | NASA Landsat

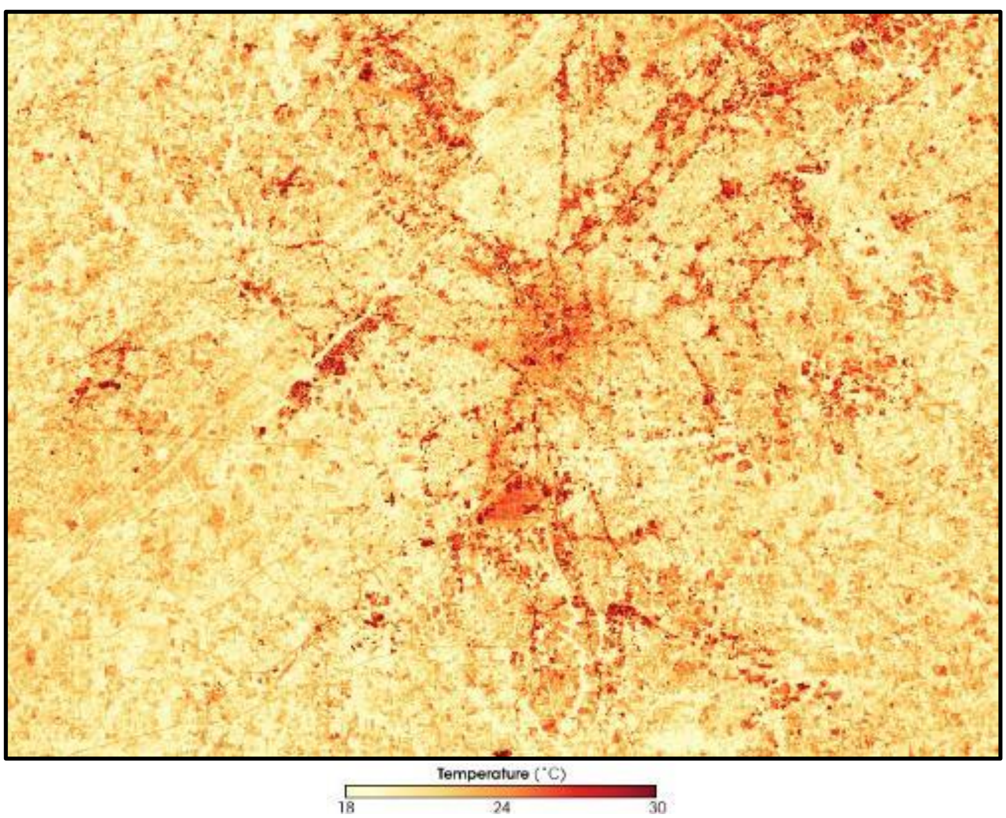


Figure 4: Atlanta land surface temperature map September 28, 2000 | NASA Landsat

Remote Sensing Images (Continuation)

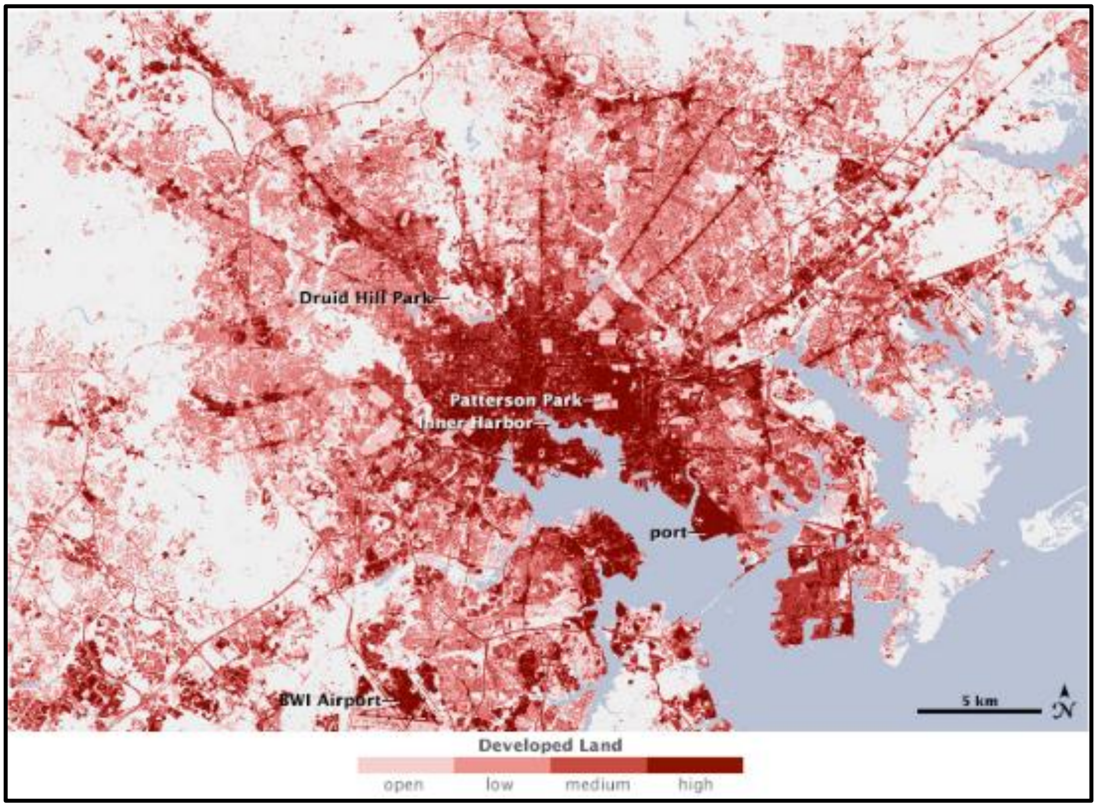


Figure 5: Baltimore land surface temperature map on August 2, 2001 | NASA Landsat

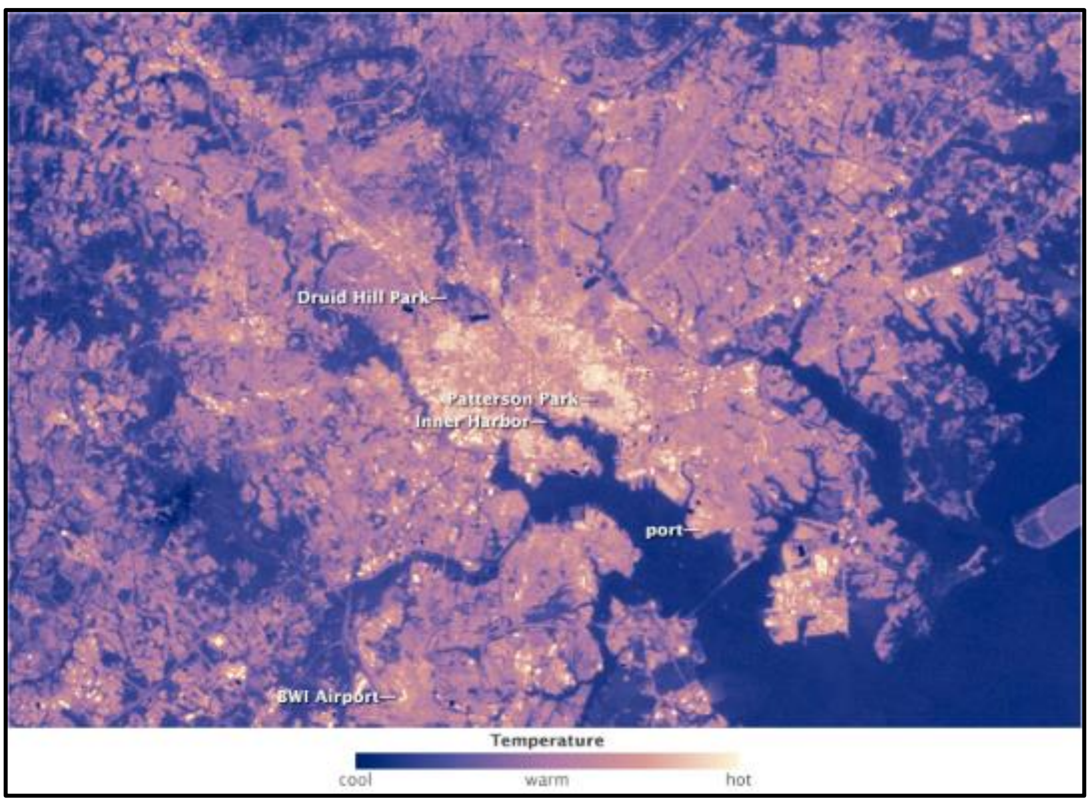


Figure 6: Baltimore brightness temperature map on August 2, 2001 | NASA Landsat

Figure 7: Aerial map of Providence, Rhode Island on July 31, 2002 | NASA Landsat

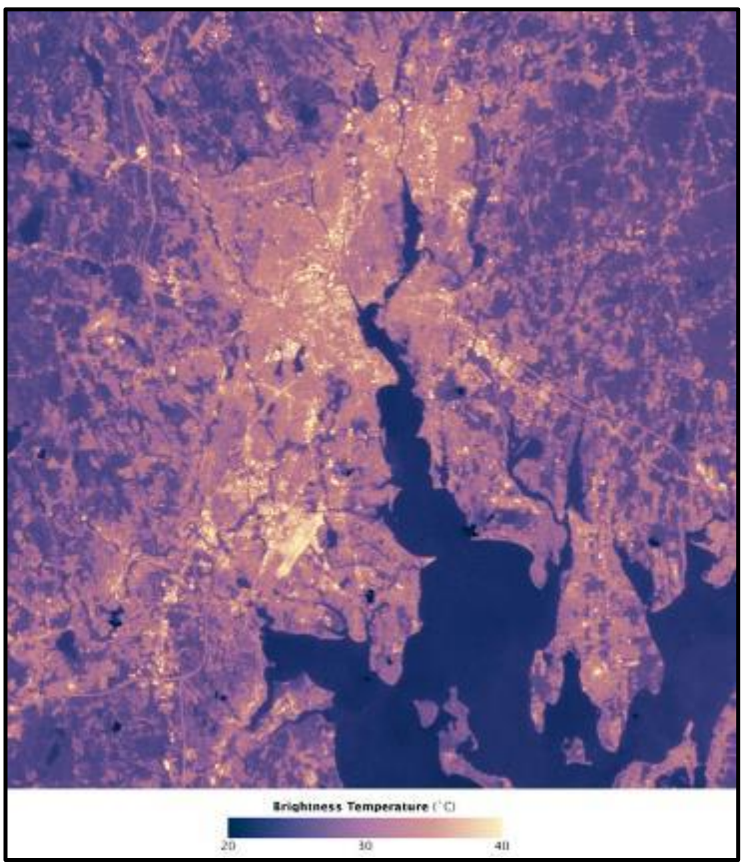


Figure 8: Providence, Rhode Island brightness temperature map on July 31, 2002 | NASA Landsat

National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

Name: ______________________________ **Period:** _______ **Date:** ________

Urban Heat Island and Its Effects

You will now read the following text to learn more about the phenomenon known as the Urban Heat Island and its effects. As you read, make sure to annotate the text by using the following symbols:

***** = important | __ = keyword | **?** = I don't understand | ○ = unfamiliar word | **!** = I'm surprised | ∞ = made a connection

What Are Urban Heat Islands?

An Urban Heat Island is a phenomenon that is best described when a city experiences much warmer temperatures than in nearby rural areas. The sun's heat and light reach the city and the country in the same way. The difference in temperature between urban and less-developed rural areas has to do with how well the surfaces in each environment absorb and hold heat.

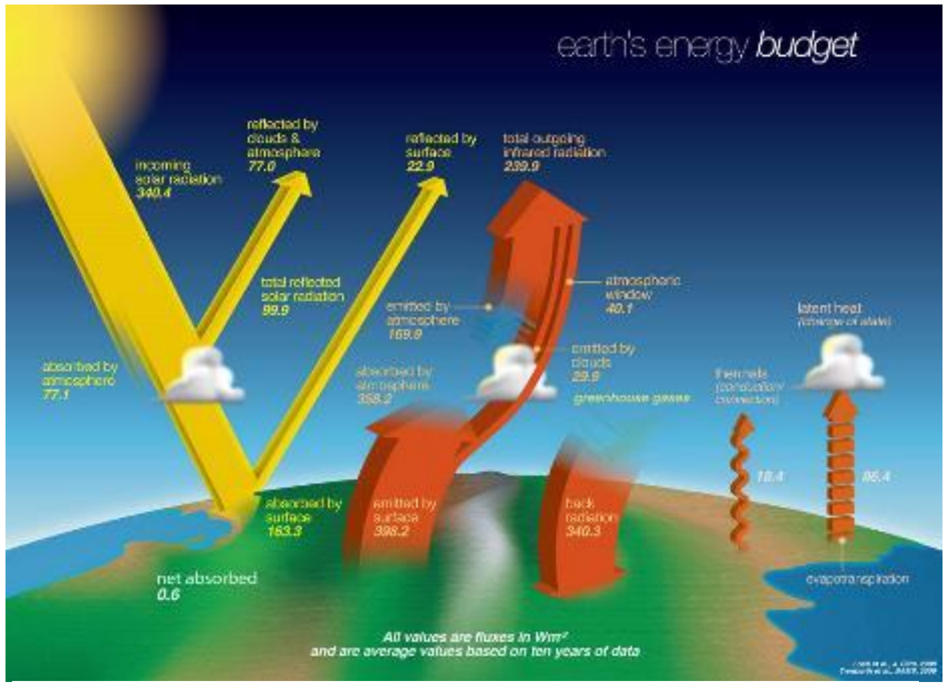


Figure 1: Earth's Energy budget representation of energy absorption and emmitance

Shown to the top-right is a diagram displaying Earth's Energy Balance. To understand what is happening in the diagram, let's start with the radiation emitted by the Sun, represented by the yellow arrows. Radiation from the Sun can be absorbed or reflected. This is why some of the yellow arrows point right back to space, showing reflection. About 50% of the radiation from the sun that reaches the Earth is absorbed by the surface. The surface absorbs the Sun's radiation and gains energy, warming the surface.

The surface eventually releases some of this energy to the atmosphere above. Much of the energy is released as infrared radiation, which is detected as heat, like the warmth felt from a fire. This is shown by the red arrows. As the temperature of a surface warms, it will release more infrared radiation, regardless of what materials make up the object.

Another way that energy is released from the surface is through conduction and convection, shown by the curvy red arrow. Conduction transfers heat to cooler air that directly touches the hot surface. Convection occurs when air warmed by the surface rises upward, moving heat away from the surface. Convection from hot pavement is the reason that the air above a hot road on a summer day appears to shimmer. Both convection and conduction remove energy from the surface faster when the surface is much warmer than the air above.

A third way by which energy is transferred from Earth's surface is through evaporation, which is shown by the dashed red arrow. Evaporation is the changing of liquid water to an invisible gas called water vapor. This change requires energy, and evaporation is the reason that you cool off when you sweat. The surface of the Earth also "sweats". When water evaporates from Earth's surface, it transfers energy away from the surface, keeping it cool.

Earth's energy is often referred to as a "budget" or "balance". This is because the Earth is releasing the same amount of energy that it is gaining on average. The processes of conduction, convection, infrared radiation, and evaporation are all responsible for this balance. When something changes to throw off the balance, some of all of these processes respond.

To talk about the movement of heat and energy, scientists use a theoretical object that is a perfect absorber (and hence perfect emitter) of heat and energy. They call this a blackbody because it absorbs all light and would appear completely black to us.

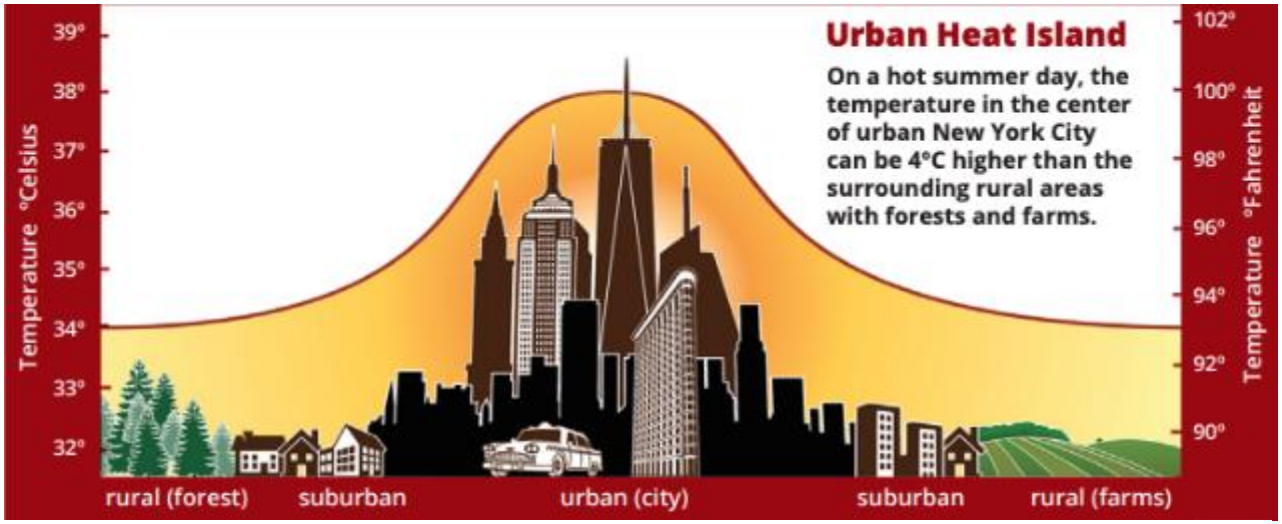


Figure 2: Urban Heat Island Profile of New York City and surrounding areas

Where Do Urban Heat Islands Form?

The hottest places on Earth have a few traits in common. They are full of rock and stone, they do not have a lot of water, plants, or trees, and they are full of dark colors. Cities are full of these rocky surfaces — asphalt, brick, and concrete — that absorb heat by day and release it at night. These materials are used to make the sidewalks, parking lots, roads, and basketball courts of urban areas. Urban Heat Islands form because humans replace cooler natural surfaces with rocky surfaces.

These hard and dark-colored surfaces contribute to the Urban Heat Island effect in two ways. First, these surfaces have a low albedo, which increases the amount of energy from solar radiation they absorb. Second, these surfaces do not contain much water to evaporate, meaning that less of the absorbed energy evaporates water, and more goes into warming the surface and releasing energy by conduction, convection, or radiation. The combination of these factors means that cities and other highly developed areas are hotter than the plant-covered countryside.

Urban areas often see temperatures sometimes rise 6°C (10°F) hotter than the surrounding suburbs and rural areas. Cities tend to be hotter than their surrounding areas at all times of the day and at all times of the year. However, a variety of factors influence the Urban Heat Island. Bigger cities tend to have stronger heat-trapping capacities than smaller cities. Cities surrounded by forest have more pronounced heat islands than do cities in arid environments, since replacing forests with paved surfaces in urban areas has much more of a warming effect than replacing dry sand and rock with pavement.

Why are Urban Heat Islands a Problem?

Urban Heat Islands are one of the easiest ways to see how human impact can change our planet. Sidewalks, parking lots and skyscrapers wouldn't exist if humans weren't there to build them. And although these structures are essential to city living, the heat islands they create can be dangerous for humans.

In the summer, New York City is about 7°F (4°C) hotter than its surrounding areas. That doesn't seem like much, but these higher temperatures can cause people to become dehydrated or suffer from heat exhaustion. The hot temps also require more energy to operate fans and air conditioners. This can lead to power outages and a serious danger to public health.

Think about what you just read!

1. In your own words, what are some of the Urban Heat Island effects on big cities such as New York City?

2. Describe the process of incoming solar radiation, reflectance and terrestrial radiation and how it relates to urban cities as black bodies.

Rubric Category	Doesn't meet expectations 🛰	Satisfactory 🛰 🛰	Meets expectations 🛰 🛰 🛰	Exceeds expectations 🛰 🛰 🛰 🛰
Productivity	I don't follow the procedures, struggle to annotate all parts of the reading and don't respond to all questions in an average way.	I can follow most of the procedures, annotate all parts of the reading and respond to all questions in an average way.	I can follow all the procedures, successfully annotate all parts of the reading and respond to all questions in a comprehensive way.	I can efficiently follow all the procedures, successfully annotate all parts of the reading and respond to all questions in an exceptional way.
Understanding	I don't show a clear understanding of the scientific concepts behind energy, temperature and the effects of Urban Heat Island on cities.	I show some understanding of the scientific concepts behind energy, temperature and the effects of Urban Heat Island on cities.	I show a clear understanding of the scientific concepts behind energy, temperature and the effects of Urban Heat Island on cities.	I show a clear and in-depth understanding of the scientific concepts behind energy, temperature and the effects of Urban Heat Island on cities.

National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

Urban Heat Island and Its Effects Worksheet *ANSWER KEY*

Note: Student reading annotations are independent and should reflect the student's choice of annotations, this are just sample annotations that serve as a guide.

Urban Heat Island and Its Effects

You will now read the following text to learn more about the phenomenon known as the Urban Heat Island and its effects. As you read, make sure to annotate the text by using the following symbols:

* = important | __ = keyword | ? = I don't understand | ○ = unfamiliar word | ! = I'm surprised | ∞ = made a connection

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Urban Heat Island and Its Effects Worksheet *ANSWER KEY*

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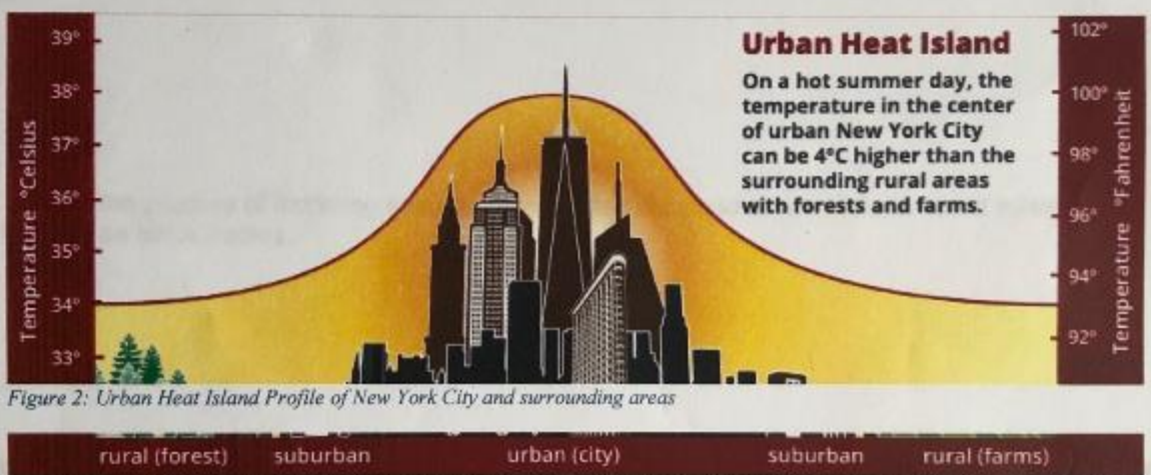
Where Do Urban Heat Islands Form?

The hottest places on Earth have a few traits in common. They are full of rock and stone, they do not have a lot of



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Think about what you just read!

1. In your own words, what are some of the Urban Heat Island effects on big cities such as New York City?

Some of the Urban Heat Island effects on big cities, like NYC are:

- *Extensive heat causing dehydration and heat exhaustion and even death*
- *Respiratory difficulties and heat cramps.*
- *Warmer air temperatures at night.*
- *Land surface temperatures are hotter.*
- *Increased energy demand.*
- *Power outages*

2. Describe the process of incoming solar radiation, reflectance and terrestrial radiation and how it relates to urban cities as black bodies.

Radiation emitted by the Sun is absorbed by tall buildings, dark roofs, sidewalks, streets, parking lots, asphalt, and concrete.

A black body absorbs all the radiation that reaches it without reflecting the same radiation, the same radiation that it receives will increase its energy and, therefore, its temperature. In addition, the molecules and atoms that form it emit new radiation to maintain thermal equilibrium.

Buildings can be somewhat black bodies as they absorb all the radiation that falls on them, but are capable of emitting radiation and raising the temperature. This is related to the phenomenon of the Urban Heat Island.

Furthermore, the city absorbs almost 90% of the light and they are able to reflect 10% of that radiation to the atmosphere. Absorbed light is converted into thermal energy and emitted as heat.

Buildings absorb all wavelengths of light energy and convert them to heat, causing the object to heat up.

Urban Heat Island Poster Guidelines for Students:

Your poster should have:

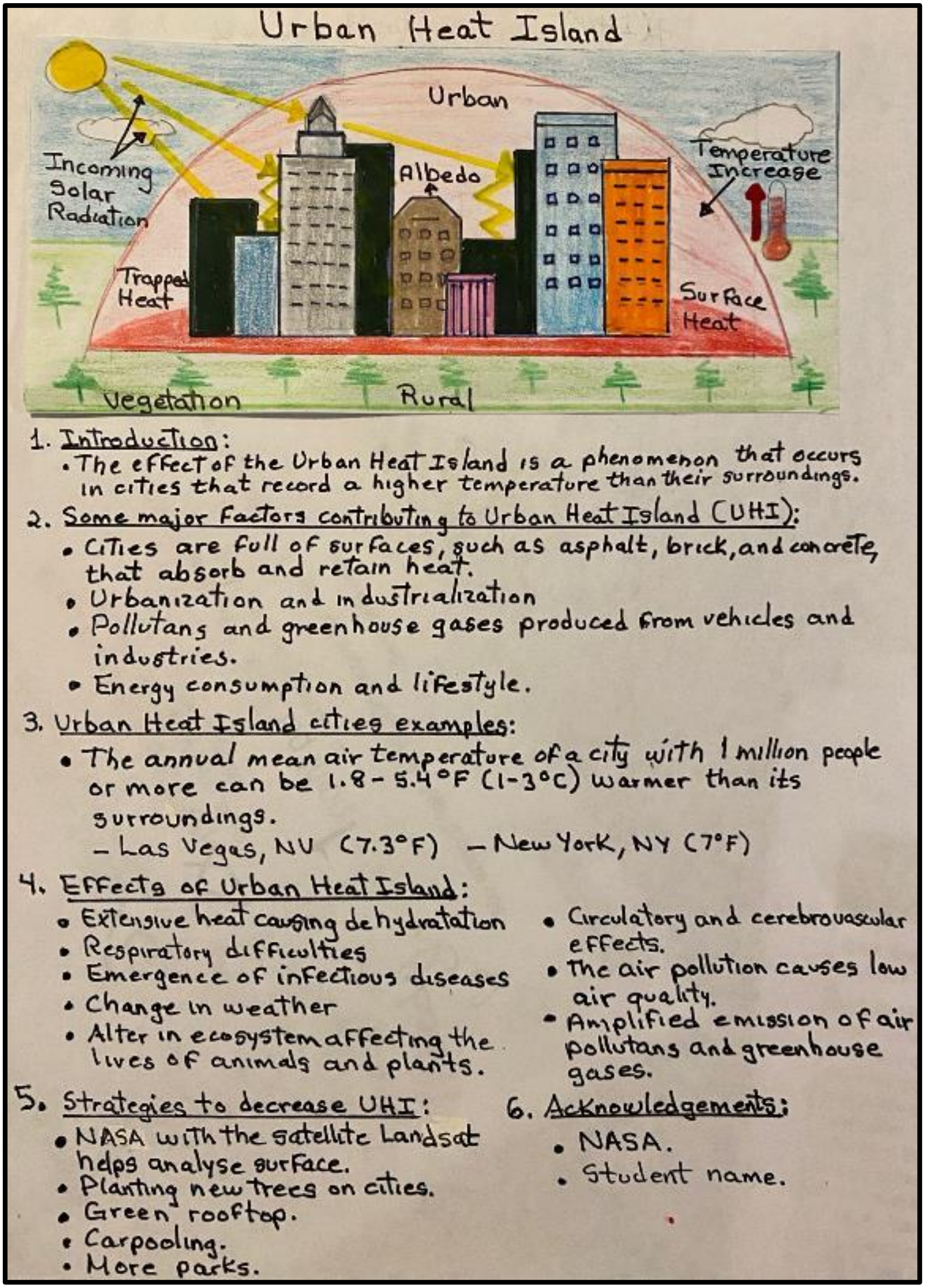
- A clear and complete definition of what is the Urban Heat Island and its effects
- Clear connection to climate
- Includes how NASA is contributing to this topic
- Should be readable from about 10 feet away
- Include at least one Urban Heat Island city example
- Has a title that is short and draws interest
- Text is clear and to the point (minimum 50 words)
- Use of bullets, numbering, and headlines make it easy to read
- Effective use of graphics, color and designs
- Consistent and clean layout
- Include acknowledgments, your name and your group's names

You will be graded according to the following rubric:

Urban Heat Island Poster Rubric

Rubric Category	Doesn't meet expectations	Satisfactory	Meets expectations	Exceeds expectations
Infographics	I don't include any graphics that demonstrates the Urban Heat Island effects.	I can include one graphic that demonstrates the Urban Heat Island effects.	I can efficiently include two graphics that demonstrate the Urban Heat Island effects.	I can efficiently include more than two graphics that demonstrate the Urban Heat Island effects.
Connection to climate	I can't describe how the Urban Heat Island and its effects connect to climate.	I can clearly describe on average how the Urban Heat Island and its effects connect to climate.	I can clearly describe satisfactorily how the Urban Heat Island and its effects connect to climate.	I can clearly describe in-depth how the Urban Heat Island and its effects connect to climate.
Strategies to decrease Urban Heat Island	I can't clearly identify and explain multiple strategies to decrease the Urban Heat Island and its effects.	I can identify and explain multiple strategies to decrease the Urban Heat Island and its effects.	I can clearly identify and explain multiple strategies to decrease the Urban Heat Island and its effects.	I can clearly identify and explain multiple strategies to decrease the Urban Heat Island and its effects.
Graphics and design	I can't I include at least 1 visual including graphs, sketches or illustrations that represent and connect to the Urban Heat Island phenomenon.	I include at least 1 visual including graphs, sketches or illustrations that represent and connect to the Urban Heat Island phenomenon.	I include at least 2 visuals including graphs, sketches or illustrations that represent and connect to the Urban Heat Island phenomenon.	I include more than 2 visuals including graphs, sketches or illustrations that represent and connect to the Urban Heat Island phenomenon.
Productivity	I don't follow the procedures, can't create a poster or follow all the guidelines in an average way.	I can follow most of the procedures, create a poster and follow all the guidelines in an average way.	I can follow all the procedures, successfully create a poster and follow all the guidelines in a comprehensive way.	I can efficiently follow all the procedures, successfully create a poster and follow all the guidelines in an exceptional way.
Understanding	I don't show a clear understanding of the scientific concepts behind the Urban Heat Island phenomenon and its effects on an urban setting and climate.	I show some understanding of the scientific concepts behind the Urban Heat Island phenomenon and its effects on an urban setting and climate.	I show a clear understanding of the scientific concepts behind the Urban Heat Island phenomenon and its effects on an urban setting and climate.	I show a clear and in-depth understanding of the scientific concepts behind the Urban Heat Island phenomenon and its effects on an urban setting and climate.

Note: The following is a sample poster for teacher reference only. Students should have the freedom to creatively put their poster together, by following the guidelines on the previous page and rubric. ***ANSWER KEY***



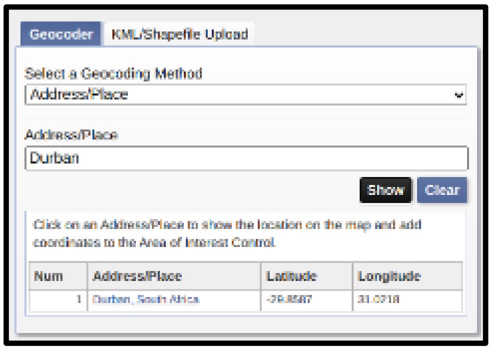
Steps for acquiring remote sensing imagery data from NASA and USGS's EarthExplorer platform

Note: You will need a computer with internet access for accessing remote sensing imagery.

EarthExplorer Manual

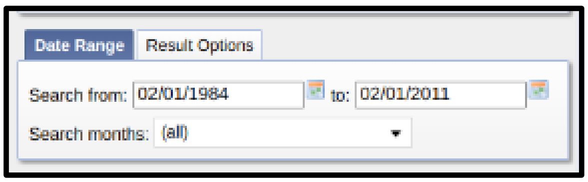
You need to visit the EarthExplorer Website: https://earthexplorer.usgs.gov/

Step One: Input your location



Type in your desired location in the "Address/Place" section and press "show." The location you looked up should then pop up. Click on it.

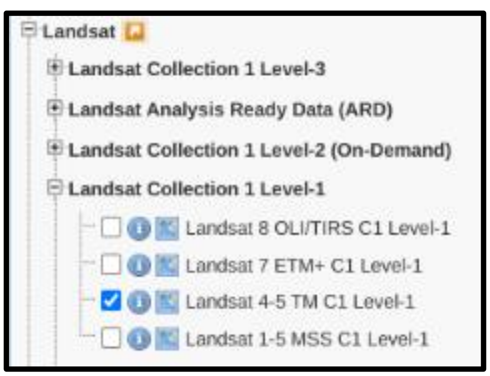
*Notice how the map travels to the location you clicked on.



When you scroll further down the "Search Criteria" tab, there is the option to select a date range. Using this feature is recommended since it only gathers information from a desired time period.

Step Two: Choose which data set you are using

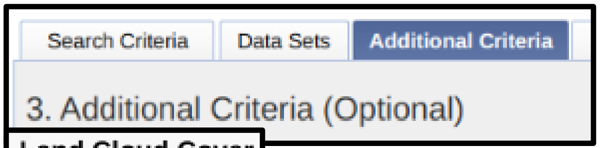
After you have completed all the instructions from Step One, scroll up and click the "Data Sets" tab.



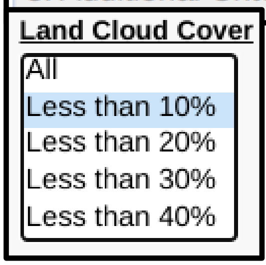
Once you open the tab, there are several different data sets to choose from. Select the small + sign next to the Landsat option. This should reveal several other options. Check off "Landsat 4-5 TM C1 Level-1".

* Make sure to choose a Landsat that has data from the date range you selected in the "Search Criteria" tab.

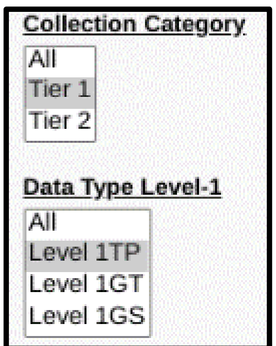
Step Three: Input any additional criteria



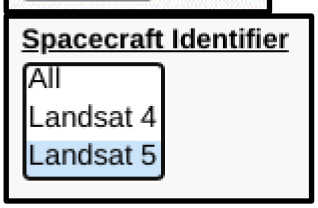
After you have completed all the instructions from Step Two, scroll up and click the "Additional Criteria" tab.



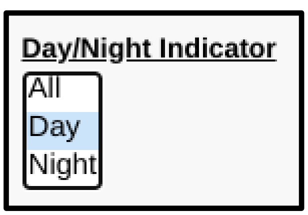
Scroll down to the "Land Cloud Cover" section and choose "Less than 10%." Images with less clouds are ideal so that more of the image can be seen.



Select "Tier 1" under the "Collection category." Then choose "Level 1TP" under "Data Type Level-1."



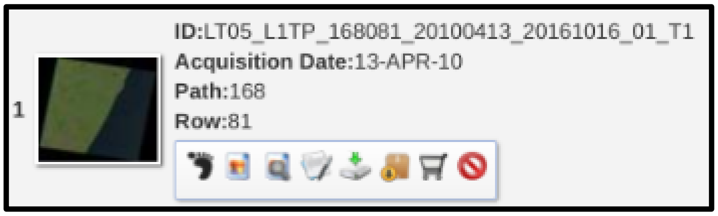
Proceed to the "Spacecraft Identifier" section and select "Landsat 5".



Choose the time of day you would like your images to be in. Select "Day."

Step Four: View Results

After you have completed all the instructions from Step Three, scroll up and click the "Results" tab.



Once the results tab has fully loaded, images satisfying all the selected criteria will appear.

* The icons under each image have different functions.

i.e. If you choose the second icon from the left, the image will be shown on the map.

i.e. If you select the icon with the green arrow, several options to download will appear. Select the last option (shown to the left).

Name: ______________________________ **Period:** _______ **Date:** ________

EarthExplorer Remote Sensing Imagery Analysis

Instructions: Use the EarthExplorer Manual, a computer and follow all steps to acquire remote sensing imagery from EarthExplorer (https://earthexplorer.usgs.gov/). Then, answer the questions below.

1. Describe how was your experience acquiring EarthExplorer Remote Sensing Imagery. Mention at least one struggle and one success during your experience.

2. Now you will choose New York City as a new location for the period of 2005-2010 during the day to acquire remote sensing imagery with less than 30% cloud coverage. Make sure to follow the instructions and specifications from the EarthExplorer Manual. Complete the characteristics below:

Name of location: ______________________ WRS Row: _________. Day/Night Indicator: _________

Acquisition date: __________ Land Cloud Cover: _________ Center Latitude: ________

Satellite: _________ WRS Path: _________ Scene Cloud Cover: ______ Center Longitude: _________

3. Describe the natural color image on the following quadrants:

Top left of imagery scene	Top right of imagery scene	Include imagery scene sample copy below:
Bottom left of imagery scene	Bottom right of imagery scene	

4. Analyze and compare the natural-color scene compared to the thermal preview scene.

5. Now you will choose a city or your choice from the list provided as a new location for the period of 1994-1999 with less than 70% cloud coverage during the day to acquire remote sensing imagery. Make sure to follow the instructions and specifications from the Manual. Complete characteristics below:

Name of location: ______________________ WRS Row: _________. Day/Night Indicator: _________

Acquisition date: __________ Land Cloud Cover: ________ Center Latitude: _________

Satellite: _________ WRS Path: _________ Scene Cloud Cover: ________ Center Longitude: _______

6. Describe the natural color and thermal image on the following quadrants:

Top left of imagery scene	Top right of imagery scene	Include imagery scene sample copy below:
Bottom left of imagery scene	Bottom right of imagery scene	

7. Explain why clouds are a concern when trying to access remote sensing imagery scenes? Think deeper. What could be another complication in your remote sensing scenes?

Rubric Category	Doesn't meet expectations	Satisfactory	Meets expectations	Exceeds expectations
Productivity	I don't follow the procedures, struggle to obtain Landsat imagery scenes, don't analyze the scenes and don't respond to all questions in an average way.	I can follow most of the procedures, obtain Landsat imagery scenes, analyze the scenes and respond to all questions in an average way.	I can follow all the procedures, successfully obtain Landsat imagery scenes, analyze the scenes and respond to all questions in a comprehensive way.	I can efficiently follow all the procedures, successfully obtain Landsat imagery scenes, analyze the scenes and respond to all questions in an exceptional way.
Understanding	I don't show a clear understanding of the scientific concepts behind remote sensing, satellite imagery and the uses of satellites for land surface research.	I show some understanding of the scientific concepts behind remote sensing, satellite imagery and the uses of satellites for land surface research.	I show a clear understanding of the scientific concepts behind remote sensing, satellite imagery and the uses of satellites for land surface research.	I show a clear and in-depth understanding of the scientific concepts behind remote sensing, satellite imagery and the uses of satellites for land surface research.

National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

Name: ________________________________ **Period:** _______ **Date:** ________

EarthExplorer Remote Sensing Imagery Analysis *ANSWER KEY*

Instructions: Use the EarthExplorer Manual, a computer and follow all steps to acquire remote sensing imagery from EarthExplorer (https://earthexplorer.usgs.gov/). Then, answer the questions below.

1. Describe how was your experience acquiring EarthExplorer Remote Sensing Imagery. Mention at least one struggle and one success during your experience.

This was a learning experience for me because I learned that we can see beyond our environment through satellites. I struggled the most with interpreting the data and the most successful thing was that I was able to see real images of the Earth.

2. Now you will choose New York City as a new location for the period of 2005-2010 during the day to acquire remote sensing imagery. Make sure to follow the instructions and specifications from the EarthExplorer Manual. Then complete the characteristics below:

Name of location: *New York*

Acquisition date: *2010 /11/ 09*

Satellite: *5* WRS Path: *013*

WRS Row: *0.32* Day/Night Indicator: *Day*

Land Cloud Cover: *10.00*

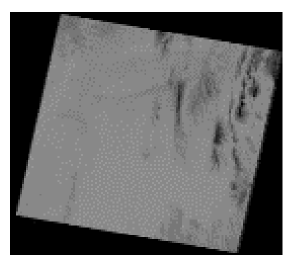
Scene Cloud Cover: *17.00*

3. Describe the natural color image on the following quadrants:

<table>
<tr><td>Top left of imagery scene

I can see that the green land and the blue ocean seem to be the same amount.</td><td>Top right of imagery scene

I can see more of the blue color that is the ocean. Also, white color is the clouds.</td><td rowspan="2">Include imagery scene sample copy below:

</td></tr>
<tr><td>Bottom left of imagery scene

Thermal detection images captured the land and the ocean show a white color.</td><td>Bottom right of imagery scene

The thermal Sensing Imagery captured the clouds showing a black color.</td></tr>
</table>

4. Analyze and compare the natural-color scene compared to the thermal preview scene.

The natural color scene shows the color of the ocean in a blue color and the green land shows that there is vegetation. On another hand, thermal detection shows black clouds because they absorb a small amount of solar energy and are cooler higher in the atmosphere.

5. Now you will choose a city or your choice from the list provided as a new location for the period of 1994-1999 with less than 70% cloud coverage during the day to acquire remote sensing imagery. Make sure to follow the instructions and specifications from the Manual. Complete characteristics below:

Name of location: *Barcelona, Spain*

Acquisition date: *10/19/1999*

Satellite: *5* WRS Path: *197*

WRS Row: *031* Day/Night Indicator: *Day*

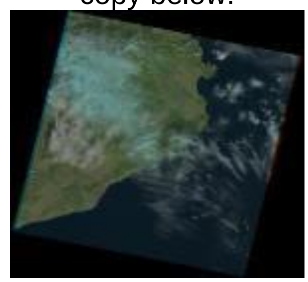
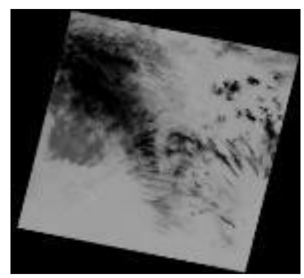
Land Cloud Cover: *58.00*

Scene Cloud Cover: *39.00*

6. Describe the natural color and thermal image on the following quadrants:

<table>
<tr><td>Top left of imagery scene

I can see a green and yellow area and in that area some white parts above and a little blue part below.</td><td>Top right of imagery scene

I can see a blue area and in all that area some white parts above.</td><td rowspan="2">Include imagery scene sample copy below:

</td></tr>
<tr><td>Bottom left of imagery scene

I can see a lot of black color at the top and a white area below, because the thermal detection images captured the more concentration of clouds in black showing that there was heat in that part since clouds being higher are cooler giving less IR.</td><td>Bottom right of imagery scene

I can see a lot of white color with some black parts because the thermal detection images captured the clouds in black showing different cool spots.</td></tr>
</table>

7. Explain why are clouds a concern when trying to access remote sensing imagery scenes? Think deeper. What could be another complication in your remote sensing scenes?

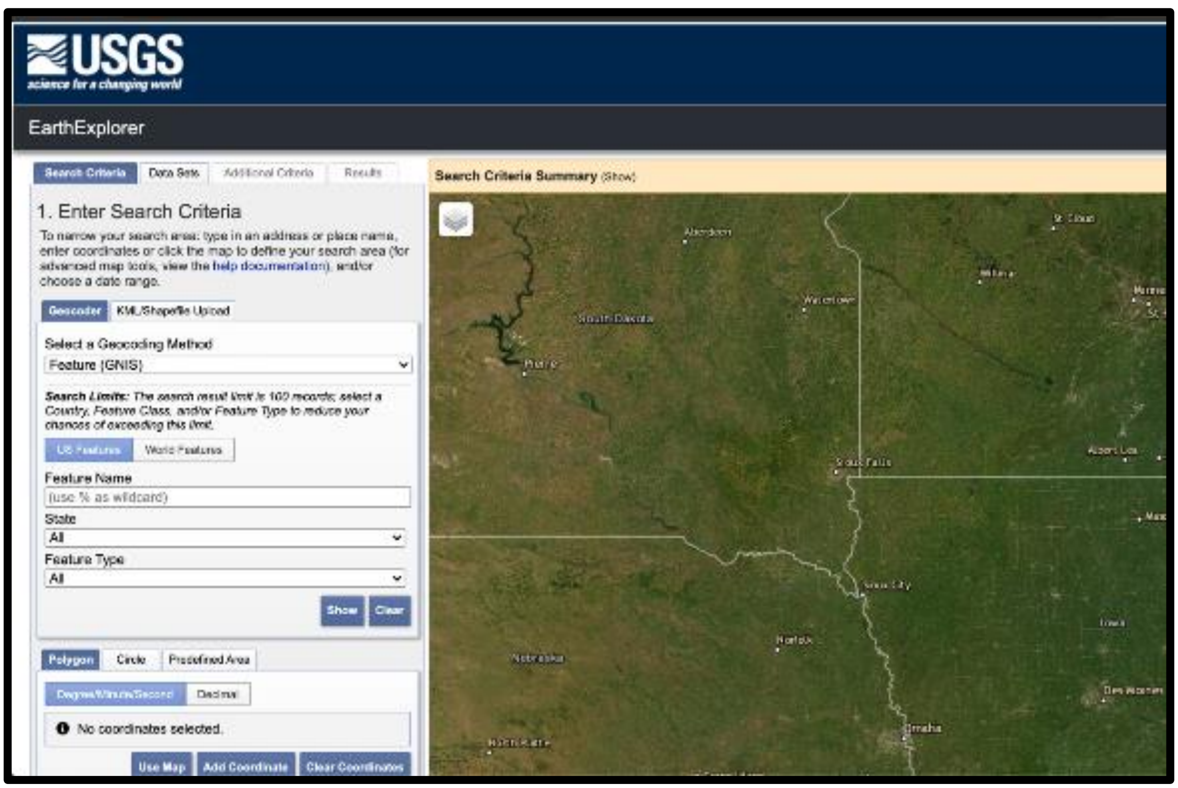
The clouds block the remote sensing view so the satellite does not provide a clear image because when you need to see the surface, the clouds block the image. Also, to analyze surface temperatures, a clarity of 10% or less cloudiness is required. A complication may be the concentration of snow, as it can also block our view of land surfaces due to the white color.

Rubric Category	Doesn't meet expectations	Satisfactory	Meets expectations	Exceeds expectations
Productivity	I don't follow the procedures, struggle to obtain Landsat imagery scenes, don't analyze the scenes and don't respond to all questions in an average way.	I can follow most of the procedures, obtain Landsat imagery scenes, analyze the scenes and respond to all questions in an average way.	I can follow all the procedures, successfully obtain Landsat imagery scenes, analyze the scenes and respond to all questions in a comprehensive way.	I can efficiently follow all the procedures, successfully obtain Landsat imagery scenes, analyze the scenes and respond to all questions in an exceptional way.
Understanding	I don't show a clear understanding of the scientific concepts behind remote sensing, satellite imagery and the uses of satellites for land surface research.	I show some understanding of the scientific concepts behind remote sensing, satellite imagery and the uses of satellites for land surface research.	I show a clear understanding of the scientific concepts behind remote sensing, satellite imagery and the uses of satellites for land surface research.	I show a clear and in-depth understanding of the scientific concepts behind remote sensing, satellite imagery and the uses of satellites for land surface research.

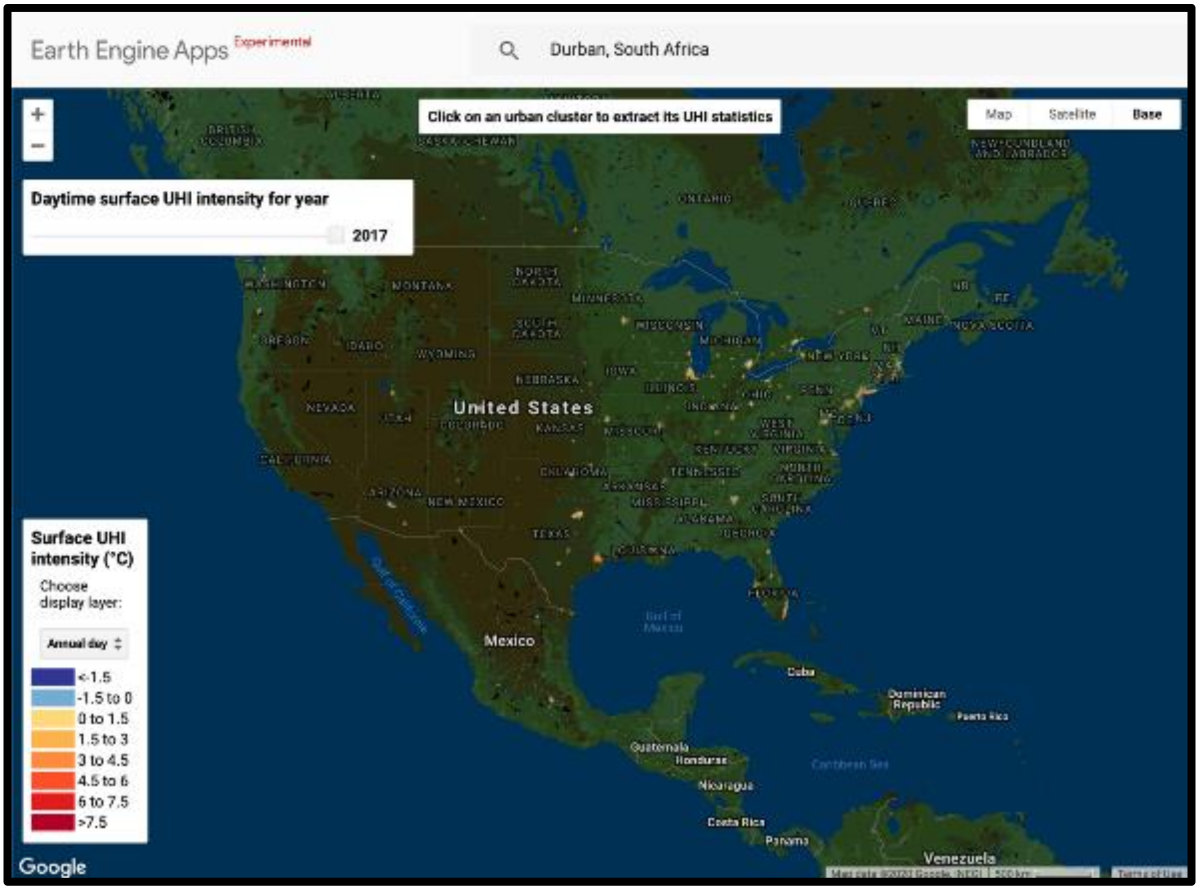
Websites used in this lesson:

NASA Urban Heat Islands: https://www.youtube.com/watch?v=InBO4vX82Fs

USGS EarthExplorer: https://earthexplorer.usgs.gov/

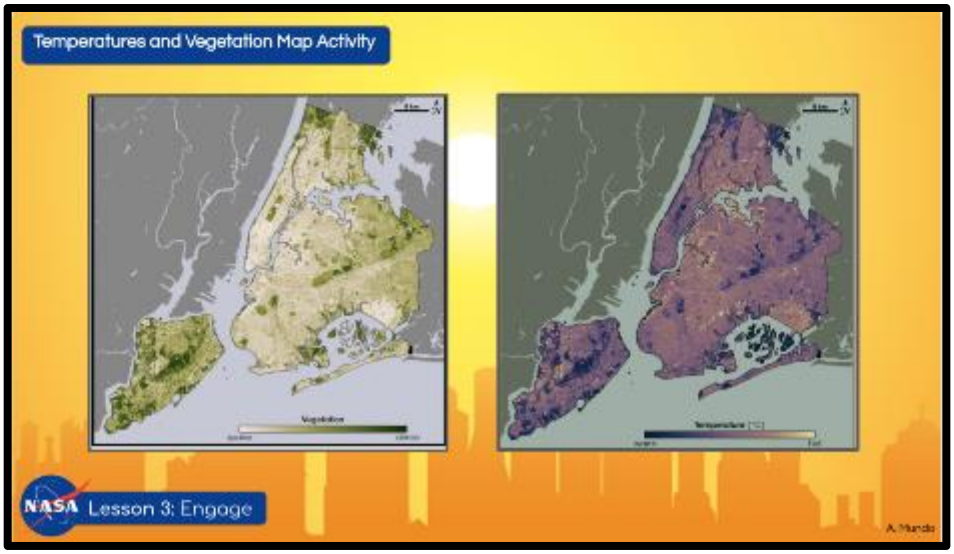


Google Earth Engine App: https://yceo.users.earthengine.app/view/uhimap



Lesson Presentation Slides:

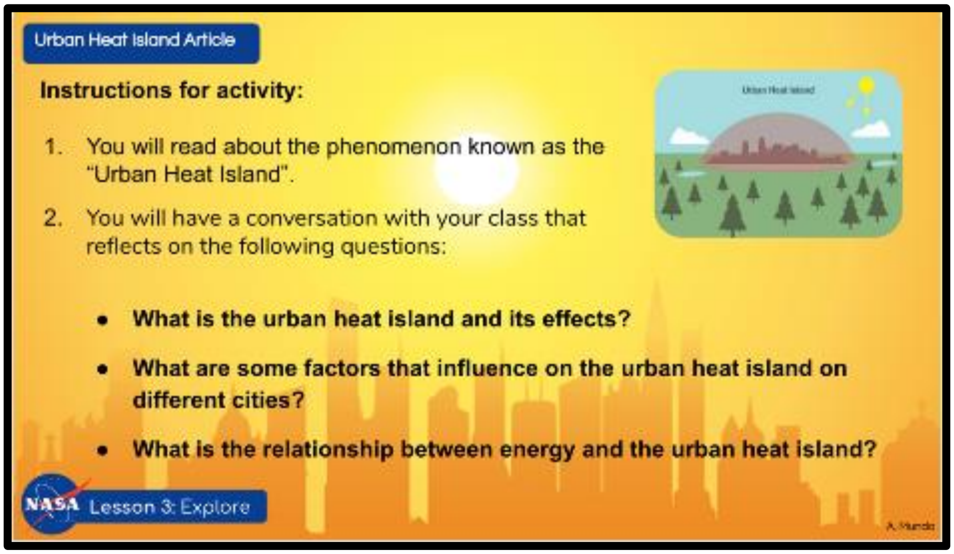
ENGAGE:

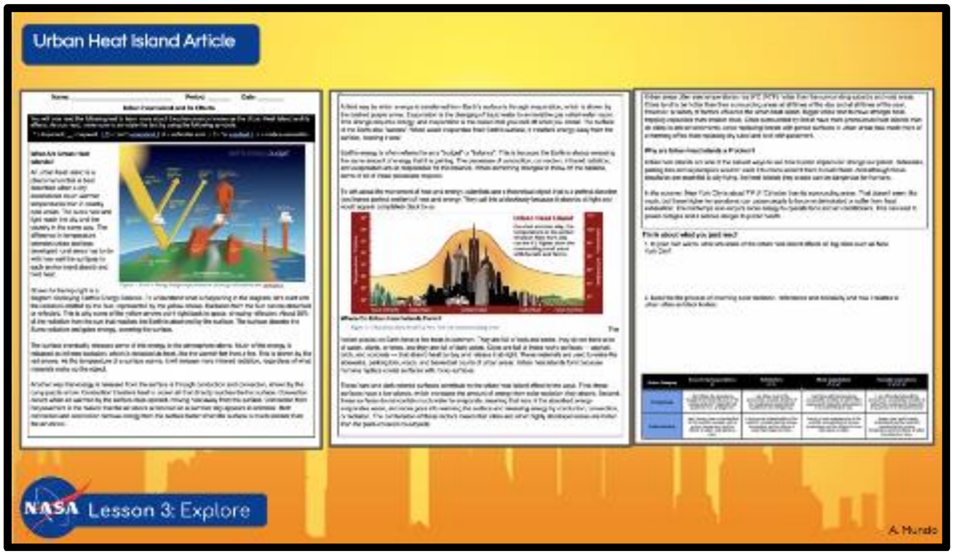

Temperatures and Vegetation Map Activity
Lesson 3: Engage


Temperatures and Vegetation Map Activity
Think deeper about
What do you see?
Where is this at?
What connections can you make?
Have you seen a map like this before?
Why is it important to have these maps?
How does it connect to the topic we're talking?
Lesson 3: Engage

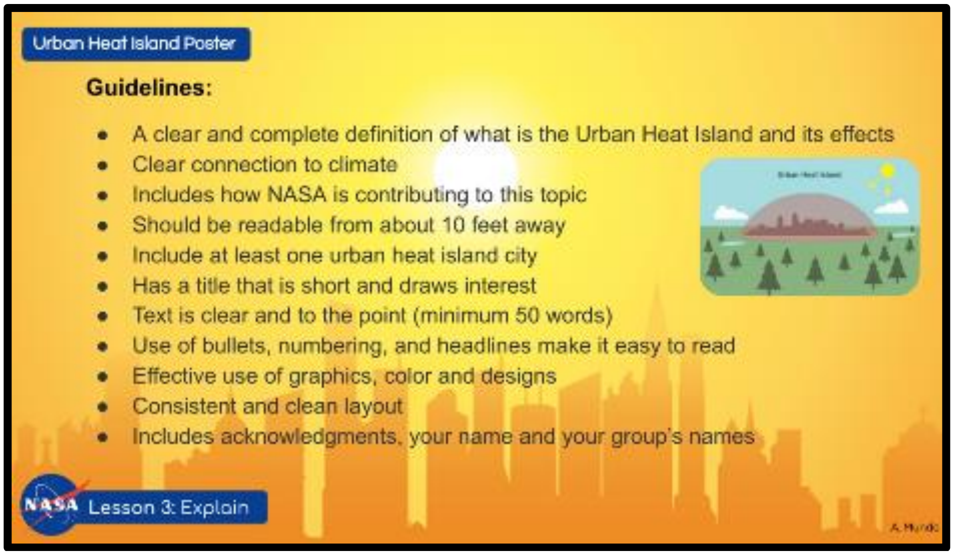

Temperatures and Vegetation Map Activity
NASA: Urban Heat Islands
Lesson 3: Engage

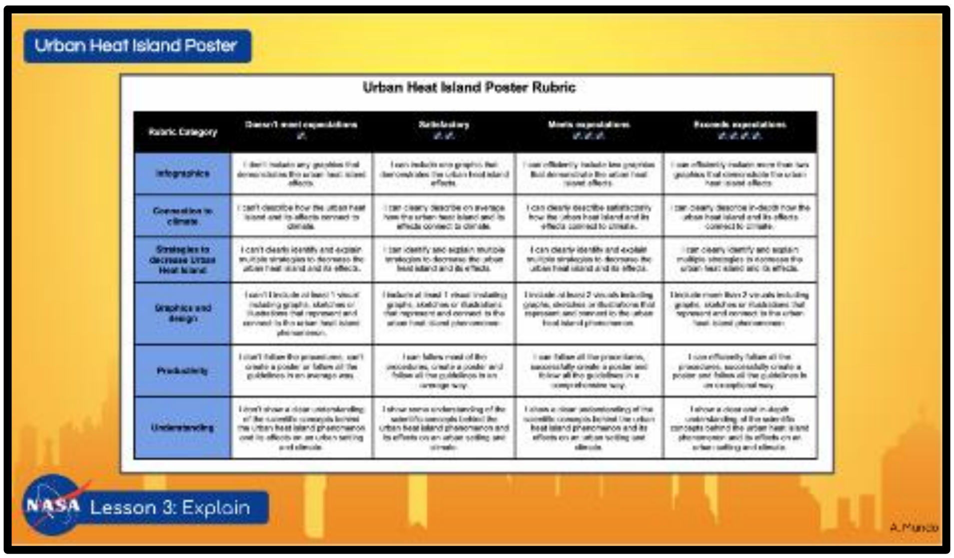
EXPLORE:



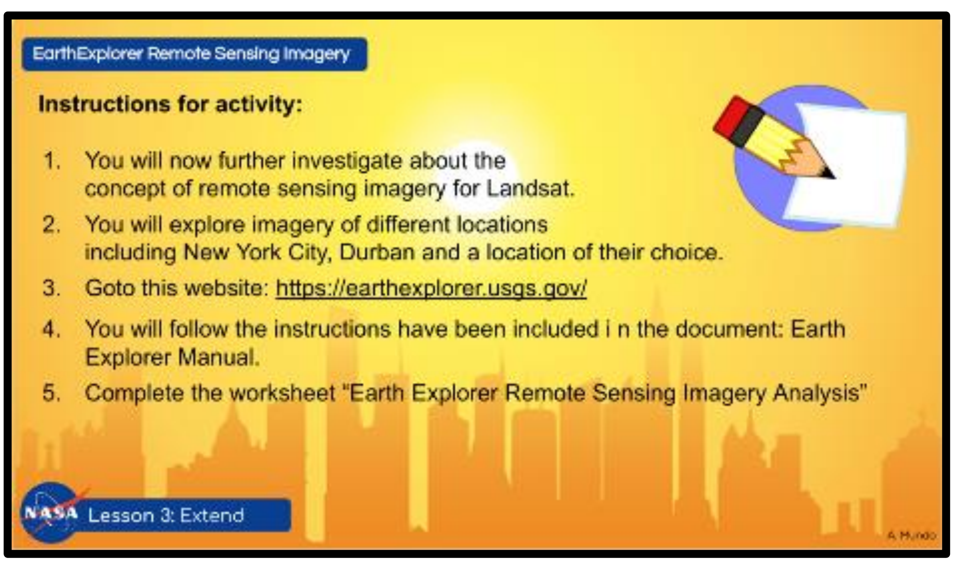


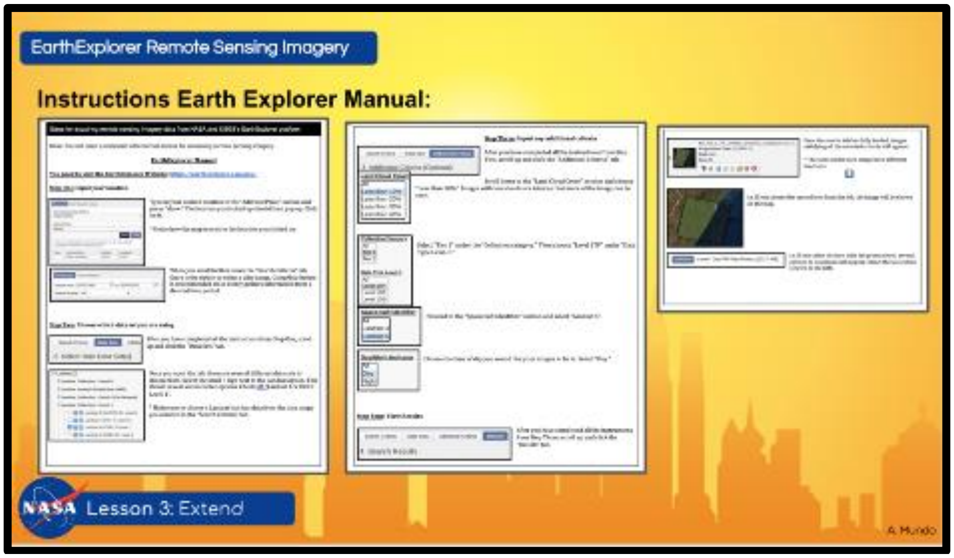
EXPLAIN:

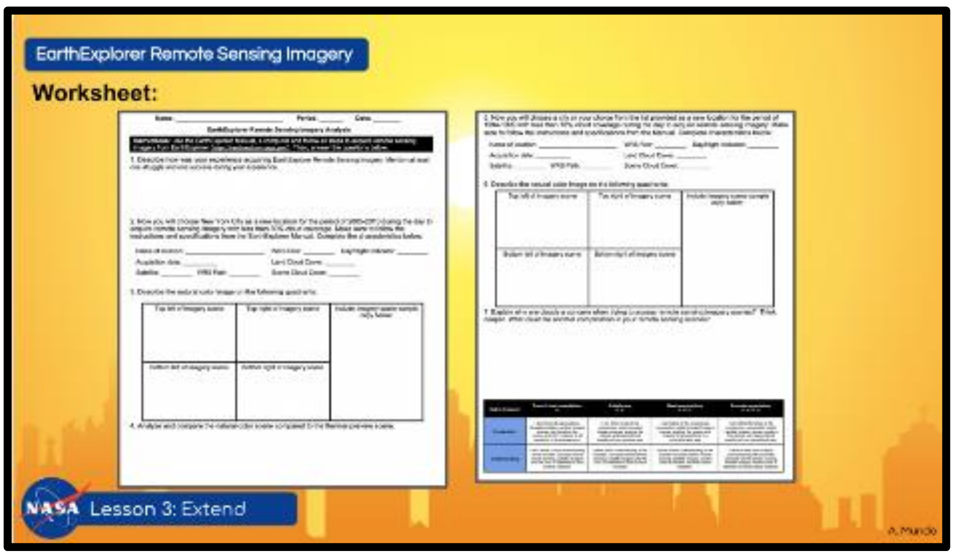

Urban Heat Island Poster
Guidelines:
A clear and complete definition of what is the Urban Heat Island and its effects
Clear connection to climate
Includes how NASA is contributing to this topic
Should be readable from about 10 feet away
Include at least one urban heat island city
Has a title that is short and draws interest
Text is clear and to the point (minimum 50 words)
Use of bullets, numbering, and headlines make it easy to read
Effective use of graphics, color and designs
Consistent and clean layout
Includes acknowledgments, your name and your group's names
NASA
Lesson 3: Explain
A. Mundo


Urban Heat Island Poster
Urban Heat Island Poster Rubric
Rubric Category
Infographics
Graphics and design
Understanding
NASA
Lesson 3: Explain
A. Mundo

EXTEND:

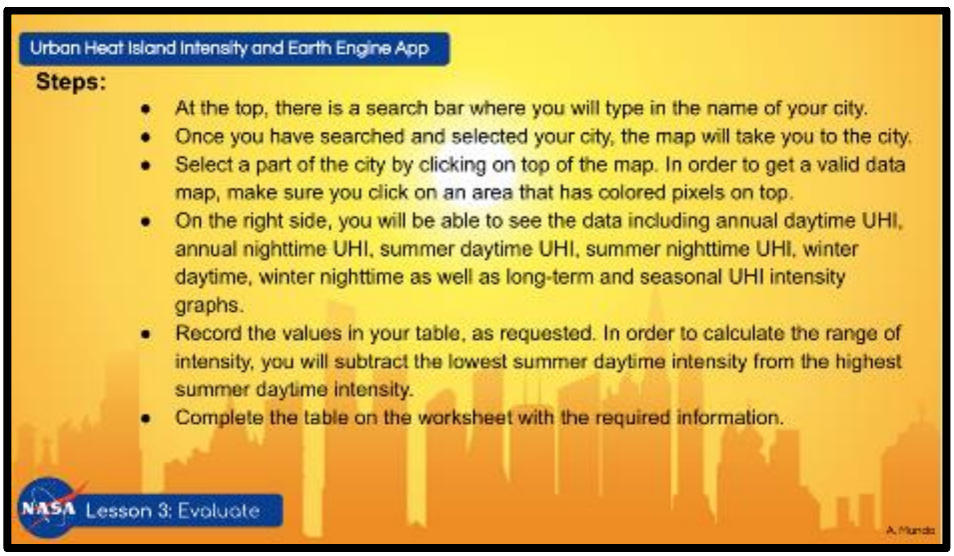

EarthExplorer Remote Sensing Imagery
Instructions for activity:
1. You will now further investigate about the concept of remote sensing imagery for Landsat.
2. You will explore imagery of different locations including New York City, Durban and a location of their choice.
3. Goto this website: https://earthexplorer.usgs.gov/
4. You will follow the instructions have been included i n the document: Earth Explorer Manual.
5. Complete the worksheet "Earth Explorer Remote Sensing Imagery Analysis"
NASA
Lesson 3: Extend
A. Mundo


EarthExplorer Remote Sensing Imagery
Instructions Earth Explorer Manual:
Lesson 3: Extend
A. Mundo


EarthExplorer Remote Sensing Imagery
Worksheet:
Lesson 3: Extend
A. Mundo

EVALUATE:


Urban Heat Island Intensity and Earth Engine App
Instructions for activity:
1. You will follow the steps that appear in the document called "Earth Engine App and Urban Heat Island Intensity".
2. Go to the website: https://yceo.users.earthengine.app/view/uhimap
3. Record your values in your table.
4. Complete the worksheet.
Lesson 3: Evaluate
A. Mundo



Differentiated instruction activities

This lesson includes instructional activities that promote differentiation in the following ways:

- Students learn new content in multiple ways including orally (through groups and class discussions), visually (through the use of videos and images), data analysis (through infographics and graphs) and reflection.
- Students use graphic organizers that help them process and organize their understanding of the new content.
- Lessons include graphic organizers with sentence starters that benefit English Language Learners and Special Education students to organize their ideas in better ways.
- Every lesson is adaptable to the personal learning plans of students.

11. Conclusion Assessment Quantification and linkage to next lesson:

This has been the third lesson of this climate unit plan which had a focus on the Urban Heat Island phenomenon and its effects. During this third lesson, students had the opportunity to make observations on remote sensing imagery from different cities, discuss and make connections about temperature and vegetation and reading about the Urban Heat Island phenomenon. In addition, they create a poster and explain what is the Urban Heat Island and its effects, investigate, access and download remote sensing imagery from EarthExplorer for New York City and a city of their choice. Furthermore, they analyze remote sensing imagery from EarthExplorer and reflect on the process and imagery characteristics, as well as calculate the land surface temperatures of different locations from the Earth Engine Apps specifications. The completion of all worksheets, tasks and activities with a high rubric grade demonstrates assessment quantification of student's learning. In the next lesson, students will learn more about the land surface temperatures as well as record, collect and upload their data.

National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

NASA Climate Change Research Initiative

Applied Research STEM Curriculum Portfolio

CCRI Unit Plan Template

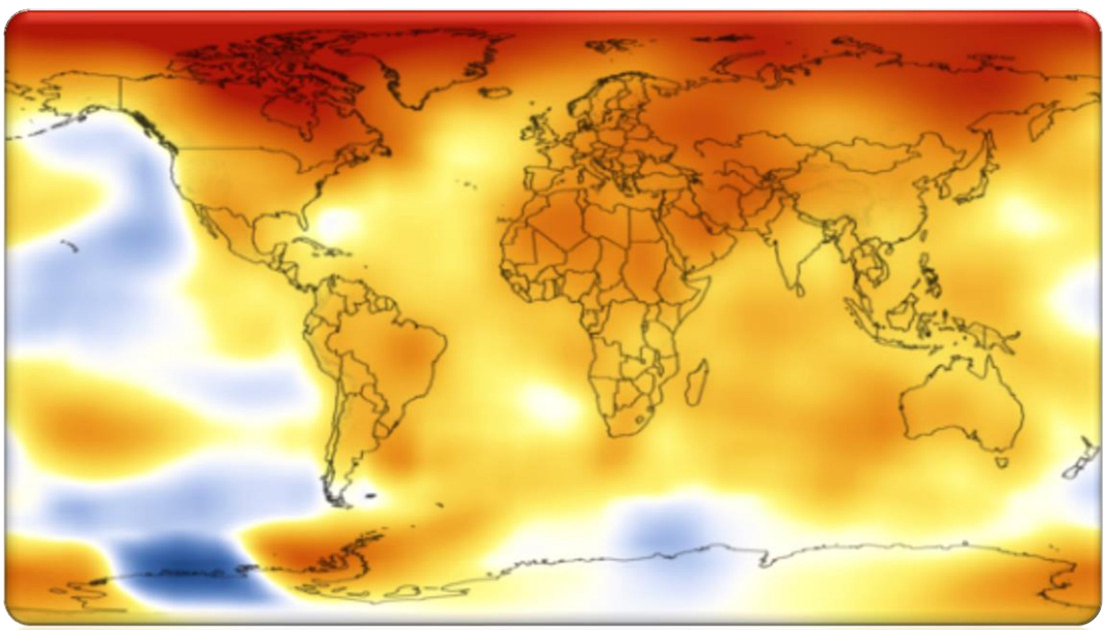
NASA Science Mission Directorate | Earth Sciences Division
NASA Goddard Institute for Space Studies
NASA Goddard Space Flight Center | Office of STEM Engagement

Unit Title: Land Surface Temperature in Urban Settings and the Heat Island Effect

Lesson 4 Title: Changing Land Surface Temperatures

NASA STEM Educator / Associate Researcher: Alejandro Mundo

NASA PI / Mentor: Dr. Christian Braneon



Lesson 4: Changing Land Surface Temperatures

1. Table of Contents for lesson

2. Summary and Goals of Lesson

This lesson is titled "Land Surface Temperatures Around Us" and it serves as an introduction to this unit plan which incorporates the 5E model template. It focuses on Urban Heat Island and its effects on cities such as changes in land surface temperatures.

The goals for this lesson include students to be able to:

- Predict what is the land surface temperature outside of school
- Discuss what factors influence land surface temperature changes
- Explore the land surface temperatures outside of school
- Use an infrared thermometer to record land surface temperatures
- Collect temperature data and upload it to the GLOBE platform
- Compare their land surface temperature results with other young scientists.
- Reflect on their results and the differences between their recordings.
- Analyze for any correlations between the land surface temperatures and the locations where they test temperatures
- Describe the process of recording temperatures locally outside of school (give steps) and explain how this relates to how scientists do this in the field.
- Review a scientific journal paper that focuses on the land surface temperatures and Urban Heat Island effects

The goals for this lesson will be met throughout the activities and assignments for each part of the lesson plan.

3. CCRI Lesson Plan Content Template

*Scroll to next to see this component.

NGSS Standards & NYS Standards:	Common Core Standard:	NASA Science:
HS-ESS3-1 Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems. **HS-PS4-6** Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. **New York State Earth Science Standards (NYSES):** **2.1a** Earth systems have internal and external sources of energy, which create heat. **2.2c** A location's climate is influenced by latitude, proximity to large bodies of water, ocean currents, prevailing winds, vegetative cover, elevation, and mountain ranges. **Phenomenon:** Flow of Energy and Matter **Crosscutting concepts:** • Systems and System Models • Stability & Change • Patterns Cause and Effect	**ELA-LITERACY.RL.11-12.1**: • Cite strong and thorough textual evidence to support analysis of what the text says explicitly as well as inferences drawn from the text, including determining where the text leaves matters uncertain. **CCSS.ELA-LITERACY.RST.11-12.9** • Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible. **CCSS.ELA-LITERACY.RST.11-12.4** • Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics. **MATH.CONTENT.HSN.Q.A.3** • Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.	—Earth Science

Content Area and Grade Level	Name of Project-Based Activity or Theme:	Estimated Time Frame to Complete:
Content Area: Earth Science **Grade Level:** 11 & 12 grades	Students will record land surface temperatures outside of school based on an infrared gun who they, analyze their recordings and uploading them to GLOBE portal.	This is the fourth lesson of 5 parts of this unit plan. It is estimated to take 5 days, if taught on periods of about 55 minutes a day.

Overall Investigation Question(s):	How can we use an instrument to explore the land surface temperatures outside of school and analyze them and relate to Urban Heat Island?
Overall Project Description/Activity:	Identify how land surface temperatures are different in several locations outside of school an analyze their meaning.

Materials Needed to Complete Project	Stakeholders:	Hyperlinks Used:	Multimedia/Technology:	Classroom Equipment:
• Provided worksheets • Infrared thermometers	–Students –Educator –Administrator	**GLOBE Data Entry Mobile App:** **Link:** https://www.globe.gov/globe-data/data-entry/data-entry-app **GLOBE Visualization System:** **Link:** https://climate.nasa.gov/interactives/climate-time-machine/	• Laptops with internet connection • Laptops with PowerPoint • Smartboard • Infrared thermometer	• Laptops • Printer • Smartboard

NASA System Engineering Behaviors	Category	Activities	Student Outcomes	Evaluation
Uses visuals to communicate complex interaction	Communications	Students will identify how the temperatures of several locations outside of school have different temperatures.	Work cooperatively with team members to record land surface temperatures with thermometer.	Urban Heat Island
Communicates effectively through personal interaction	Communications	Students will work together in groups to analyze a scientific journal about Heat Island Effects.	Complete the definition of Urban Heat Island and factor based on a scientific journal.	Urban Heat Island
Builds Team Cohesion	Leadership	Students will work in harmony and assign tasks and responsibilities among peers in order to work for a common goal.	Present about the Urban Heat Island scientific journal and present a part.	Climate
Appreciates/Recognizes Others	Leadership	Students value each of their members in the group for their contribution and support their ideas.	Provide feedback on their classmates' group presentations.	Climate
Has a comprehensive view	Attitudes & Attributes	Students will interpret how scientists do scientific research and how they report their findings based on a journal.	Discuss different parts of a scientific journal on Urban Heat Island effects.5	Urban Heat Island
Seeks information and uses the art of questioning	Attitudes & Attributes	Students will record their own temperature data from instrument and compare to their classmates to represent different surfaces and temperature connections.	Use the instrument to understand how different settings can absorb or reflect radiation.	Radiation
Validates facts, information and assumptions	Systems Thinking	Students will read about the effect of the Urban Heat Island effects.	Validates the evidence and puts it together in order to explain it.	Climate change evidence
Keeps the focus on mission requirements	Systems Thinking	Students will work on the assigned work and task in order to complete it by the given time.	Pay attention and follow procedures to complete the task.	
Learns from success and failures	Technical Acumen	Teacher will give feedback to students based on their performance at the activities and students will use and reflect on that feedback.	Reflects and uses feedback to do better.	
	Attachments?	**List Attached Documents:**		
List and attach all PowerPoint presentations and supportive documents for instructional activities	Yes	• Surface Temperature Recording • GLOBE Data Submission • Science Journal Article		
	Attachments?	**List Attached Rubrics:**		
List and attach all rubrics for activity and assessment evaluation	Yes	• Outside of School LST Local Recording Analysis Worksheet Rubric • Journal Paper Reading, Analysis and Interpretations Worksheet Rubric		

4. **Mission Alignment**
This lesson is part of this climate unit plan and aligns with NASA's Terra satellite mission. Terra explores the connections between Earth's atmosphere, land, snow and ice, ocean, and energy balance to understand Earth's climate and climate change and to map the impact of human activity and natural disasters on communities and ecosystems.

5. **Time to implement lesson**
This is the fourth lesson of 5 parts of this unit plan. It is estimated to take a whole week, if taught on periods of about 55 minutes a day.

6. **Materials required**
–Laptops –Infrared thermometers –Supplies
–Internet connection –Cell phones (students' mobile devices)
–Worksheets and supporting documents are provided at the end the lesson template.

7. **5 E lesson model template:**

What the Teacher does	What the Students do	Time
<u>**ENGAGE**</u> **Predicting Outside Land Surface Temperatures** • Tell students that in our previous lesson we analyzed satellite data from different locations but today we will predict and study our own area around our school! Mention that scientists compare results with other scientists in order to test observations and analyze them. • Create a discussion through a Write-Pair-Share where students will reflect on the following questions: *"What do you think will be the land surface temperature (LST)outside of our school? What about surrounding areas? Do you think that they will have different LST's?* Have students explain their ideas in their notebook (2 mins) and then have them share with each other (1 min). • Then facilitate a class discussion about students' answers and record their ideas on the board. Some further questions that can be implemented during the discussion include:	• Listen to introduction of activity. • Students are reflecting on their knowledge about land surface temperature (LST) and recording their ideas about the LST recordings outside school and factors that may affect it. • Students are sharing their ideas in a class discussion and building on each other's ideas about land surface temperatures.	35 m

○ What factors influence land surface temperature changes? ○ How much can land surface temperature vary during the day? ○ Which materials could contribute to warmer temperatures? ○ How does air temperature also connect with land surface temperatures?		
EXPLORE **Recording Land Surface Temperatures & GLOBE** • Tell students that they will be exploring the land surface temperatures (LST's) outside of school and compare their results with other young scientists (students) that have compiled their data like them by using NASA's sponsored program GLOBE. • Tell students that they will be collecting the LST's by using Infrared thermometers. • Model to students how to use an infrared thermometer and give the protocol to students. These are the instructions how to use a thermometer: ○ Hold the infrared thermometer in your hands. ○ Look for a Celsius/Fahrenheit (Cº/Fº) Button. ○ Flip the switch to the desired unit of measurement. Use ºF, if students in your location are more used to these. ○ Turn the temperature laser gun on with the power button. ○ Aim the laser on the temperature gun to the place where you want to measure a temperature. ○ Stand as closely as possible to the object for the most accurate temperature. ○ Pull the trigger to view the temperature reading on the digital display on the infrared thermometer. ○ Finally, take notes of the temperature obtained on the infrared thermometer.	• Listen to introduction of activity. • Learn how to use an Infrared thermometer and follow the protocol given in order to collect the LST's from 3 different locations around school. • Collect LST's using their infrared thermometers as they work together with their groups.	**50 mins**

• They will work in groups and choose 4 different locations around the school: one with obvious vegetation, one near the concrete roads/buildings/concrete, and one of their own liking. The teacher can choose to have more locations, depending on area. • Have students go outside of the school and give each group with an infrared thermometer. Remind students that if they have any questions, they can refer back to the protocol. • When students have recorded their surface temperatures, they should upload and enter their GLOBE data, as shown in the protocol, as teacher was trained in the protocol assigned in previous lesson.	• Work in groups to choose the locations around school to record their temperatures. • Go outside of school as a class and use thermometers to record surface temperature data. • Upload their data on GLOBE platform based on their characteristics and recordings.	
<u>EXPLAIN</u> **Land Surface Temperature GLOBE Data Entry** • Now that students have already recorded and collected the LST's in the locations of their choice, have students come back to the classroom. • Tell students that they will now make sense of their data that they have collected as well as the collections from the NASA GLOBE database. • By using laptops (although they can use their phones), students will access if their data connects to the observations from other young scientists like them. Students can also download the GLOBE App to access and upload data: https://www.globe.gov/globe-data/data-entry/data-entry-app • Visualizing the already submitted data: https://vis.globe.gov/GLOBE/ • If other sources have not uploaded similar data in local area, remind students that often a scientist can be the first in making certain observations for an area. We may be the first in the GLOBE community to do so. This	• Listen to introduction of activity. • Students will access the data and connect their collections to the GLOBE database by following the instructions on the GLOBE app. • Visualize the submitted data.	50 mins

uploaded process may take some time, as students will first have to discuss the precision of their own recordings.		

<u>EXTEND</u>
 	
Reflection and Analysis of GLOBE Data Entry
 	
• Give students a writing prompt that is based on students' Land Surface Temperature recordings. Have students reflect on their results and the differences between their recordings. Encourage them to recall their knowledge about remote sensing data. This will serve as a formative assessment. These are the prompts, which are also on the worksheet called "Outside of School LST Local Recording" that you will provide each student with a copy:
    ○ Describe what were the different locations *that you choose to record your temperatures and the land surface temperatures that you recorded.*
    ○ *Were there are any correlations between the land surface temperatures and the locations where you tested temperatures? Explain differences and similarities.*
    ○ *Describe the process of recording temperatures locally outside of school (give steps) and explain how this relates to how scientists do this in the field.*
    ○ Make an aerial-view sketch of the location and color the areas according to colors you choose to represent specific temperatures.
 	
• As students are reflecting on the analysis of their GLOBE data entry, circulate around the room to assist students. 50 minutes is recommended for this activity, but teacher may decide to extend it based on the students.
	• Listen to introduction of activity.
	
	• Record their ideas to answer the prompt given by the teacher.
	
	• Reflect on the process of acquiring land surface temperature data from infrared thermometer and uploading it to the GLOBE platform.
		50 mins

<u>EVALUATE</u> **Remotely Sensing Cooling Effects on Urban Heat Island Scientific Journal Article**		

• Tell students that they will now get to explore how scientists contribute and communicate their research projects through journals, such as journal paper called, "Remotely Sensing the Cooling Effects of City Scale Efforts to Reduce Urban Heat Island"
 	
• Provide a copy of the journal paper to every student and divide the class in different groups, where they will read the journal paper and make annotations with their groups. As students read the journal paper, they will also receive a graphic organizer that they will complete to keep track of their notes.
 	
• Then you will assign parts of the journal paper to all groups so that each group focuses on an assigned part of the paper and present their part in small 5-minute presentations. You can choose to assign the following paper divisions:
  ○ Introduction
  ○ Materials/Methods
  ○ Results
  ○ Discussion
  ○ Conclusion
 	
• The teacher may prefer to divide the groups in different subsections of the paper, if preferred.
 	
• As students are listening to their classmates present their assigned parts, they will record their notes on the graphic organizer.
	• Listen to introduction of activity.
	
	• Read and annotate the journal paper with their groups.
	
	• Present about their assigned part from the Journal paper and as one group presents, the other students record their observations.
		60 mins

8. **Standards**

Next Generation of Science Standards (NGSS):

HS-ESS2-2. Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.

HS-PS4-6 Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

DCI ESS2.A Earth Materials and Systems

CC Energy and matter: Energy drives the cycling of matter within and between systems. (HS-ESS2-3)

Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible. (HS-ESS2-1)

New York State Earth Science Standards (NYSES):

NYSES 2.1a Earth systems have internal and external sources of energy, both of which create heat.

NYSES 2.2c A location's climate is influenced by latitude, proximity to large bodies of water, ocean currents, prevailing winds, vegetative cover, elevation, and mountain ranges.

Common Core Standards:

MATH.CONTENT.HSN.Q.A.3
Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.

ELA-LITERACY.W.9-10.9
Draw evidence from literary or informational texts to support analysis, reflection, and research.

a. **NASA System Engineering Behavior Model utilized in lesson**

- **Leadership**
  - Builds Team Cohesion
  - Appreciates/Recognizes Others
- **Communication**
  - Listens Effectively and Translates Information
  - Communicates Effectively Through Personal Interaction
- **Attitudes and attributes**
  - Has a Comprehensive View
- **Problem Solving & Systems Thinking**
  - Assimilates, Analyzes, and Synthesizes Data
  - Validates Facts, Information and Assumptions
  - Has the Ability to Find Connections and Patterns Across the System

9. **Supporting Documents:**

*Scroll down to see elements

Atmosphere Investigation — Surface Temperature Report

School name: ____

Study site: ____

Names of observers: ______________________________________

Date: __________________ **Time:** _____________________

Sample 1
Describe the surface in details. Is it wet or dry? Describe below:

Describe the vegetation in this area, include the vegetation type, density, trees, grass, etc.

Sample 2
Describe the surface in details. Is it wet or dry? Describe below:

Describe the vegetation in this area, include the vegetation type, density, trees, grass, etc.

Sample 3
Describe the surface in details. Is it wet or dry? Describe below:

Describe the vegetation in this area, include the vegetation type, density, trees, grass, etc.

Sample 4
Describe the surface in details. Is it wet or dry? Describe below:

Describe the vegetation in this area, include the vegetation type, density, trees, grass, etc.

Sky Conditions

Atmosphere Investigation: Surface Temperature Data Sheet - Page 2

* Required Field

Study Site: ____________________ Date: _______________ Time (UT): ____________

1. What is in Your Sky?

Total Cloud/Contrail Cover:

- ○ Sky is Obscured →
  - ○ Fog ○ Heavy Rain ○ Heavy Snow ○ Blowing Snow
  - ○ Sand ○ Spray ○ Smoke ○ Dust
  - ○ Haze ○ Volcanic Ash
  - Go to box 6
- ○ None (Go to box 2)
- ○ Few(<10%)
- ○ Isolated (10-25%)
- ○ Scattered (25-50%)
- ○ Broken (50-90%)
- ○ Overcast (90-100%)

*If you can observe sky color or visibility, complete box 2

2. Sky Color and Visibility

Color (Look Up):	○ Cannot Observe	○ Deep Blue	○ Blue	○ Light Blue	○ Pale Blue	○ Milky
Visibility (Look Across):	○ Cannot Observe	○ Unusually Clear	○ Clear	○ Somewhat Hazy	○ Very Hazy	○ Extremely Hazy

3. High Level Clouds

○ No High Level Clouds Observed (Go to box 4)

Cloud Type:

- ○ Contrails (number of): → # short-lived / # persistent / # persistent spreading
- ○ Cirrus
- ○ Cirrocumulus
- ○ Cirrostratus

Cloud Cover:

- ○ Few (<10%)
- ○ Isolated (10%-25%)
- ○ Scattered (25%-50%)
- ○ Broken (50%-90%)
- ○ Overcast (>90%)

Visual Opacity:

- ○ Opaque
- ○ Translucent
- ○ Transparent

4. Mid Level Clouds

○ No Mid Level Clouds Observed (Go to box 5)

Cloud Type:

- ○ Altostratus ○ Altocumulus

Cloud Cover:

- ○ Few (<10%)
- ○ Isolated (10%-25%)
- ○ Scattered (25%-50%)
- ○ Broken (50%-90%)
- ○ Overcast (>90%)

Visual Opacity:

- ○ Opaque
- ○ Translucent
- ○ Transparent

5. Low Level Clouds

○ No Low Level Clouds Observed (Go to box 6)

Cloud Type:

- ○ Fog ○ Stratus
- ○ Nimbostratus ○ Cumulus
- ○ Cumulonimbus ○ Stratocumulus

Cloud Cover:

- ○ Few (<10%)
- ○ Isolated (10%-25%)
- ○ Scattered (25%-50%)
- ○ Broken (50%-90%)
- ○ Overcast (>90%)

Visual Opacity:

- ○ Opaque
- ○ Translucent
- ○ Transparent

6. Surface Conditions

Mandatory:

	Yes	No		Yes	No
Snow/Ice	○	○	Dry Ground	○	○
Standing Water	○	○	Leaves on Trees	○	○
Muddy	○	○	Raining/Snowing	○	○

Optional:
You may submit any or all

Temperature: ___°C
Barometric Pressure: ___mb
Relative Humidity: ___%

Surface Temperature Protocol

Field Guide

Task

Measure surface temperature.

What You Need

- ❑ *Surface Temperature Data Sheet*
- ❑ Hand-held Infrared Thermometer (IRT)
- ❑ Thermal Glove (use when the air temperature at the study site varies more than 5 degrees Celsius from the air temperature of where the IRT has been stored.)
- ❑ Ruler or Meter Stick, (if snow cover is present)
- ❑ Pencil or pen
- ❑ GLOBE Cloud Chart
- ❑ Accurate watch

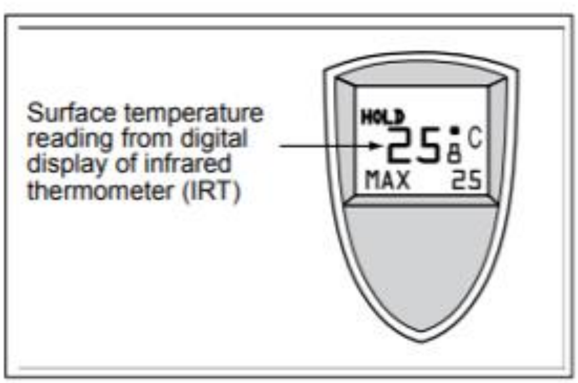
In The Field

1. When necessary, either wrap the IRT in a Thermal Glove before you go to your study site or place the IRT outdoors for at least 30 minutes prior to data collection. For more details, refer to the *Thermal Glove -or- Place IRT Outdoors For At Least 60 Minutes* section of this protocol.
2. Complete the top section of your *Surface Temperature Data Sheet* (fill out the *Supplemental Site Definition Data* section if you are taking Surface Temperature Measurements at a particular site for the first time, or if one of the values in that section has changed).
3. Take cloud observations following *GLOBE Cloud Protocols*.
4. If there is no snow on the ground anywhere in your Site, then check either "Wet" or "Dry" for the Site's Overall Surface Condition field on your *Surface Temperature Data Sheet*.
5. Check the box that corresponds to the method used to prevent the IRT from experiencing thermal shock.
6. Pick **4** Observation Spots that are in open areas within your site and are at least 5 meters apart. The Spots should also be away from trees and buildings that create a shadow on the land and in locations that have not been recently disturbed by people or animal traffic. (Note: It is best that you take readings at the 9 individual Observation Spots within seconds of each other.)
7. Go to one of the nine Observation Spots and stand so that you do not cast a shadow on the Spot.
8. Record the Current Time and its corresponding Universal Time (UT) on your *Surface Temperature Data Sheet*.
9. Hold the infrared thermometer (IRT) (wrapped in a Thermal Glove when necessary) with your arm extended straight out and point the instrument straight down at the ground.

10. Hold the IRT (wrapped in a Thermal Glove when necessary) as still as possible. Press and release the recording button. [You MUST release the recording button for the instrument to register and hold your spot's surface temperature.]
11. Read and record the surface temperature from the digital display screen located on the top of the IRT. (Note: Surface Temperature is recorded in Celsius to the nearest tenth degree, ie. 25.8)
12. Measure and record the snow depth in millimeters at the Observation Spot.
13. Repeat steps 7-12 at each of the remaining three Observation Spots.
14. Record any other information that explains the environmental conditions of the day or site in the Comments field.

a. b.

The above pictures show correct use of IRT, a) without a Thermal Glove and b) with Thermal Glove



National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

Name: ________________________________ **Period:** _______ **Date:** ________

Outside of School LST Local Recording Analysis

Instructions: Record land surface temperatures outside of school and enter data on GLOBE platform. Then answer and reflect on the following questions.

1. Make an aerial-view sketch of the location and color the areas according to colors you choose to represent specific land-surface temperatures.

Aerial-View Sketch of the research area	Temperature and colors
Date: ______________ Time: ______________	**Temp.** **Color** ______ o __ = ________ ______ o __ = ________ ______ o __ = ________ ______ o __ = ________

2. Describe what were the different locations that you chose to record your temperatures and the land surface temperatures that you recorded.

3. Were there are any correlations between the land surface temperatures and the locations where you tested temperatures? Explain differences and similarities.

4. Describe the process of recording temperatures locally outside of school (give steps) and explain how this relates to how scientists do this in the field.

Rubric Category	Doesn't meet expectations	Satisfactory	Meets expectations	Exceeds expectations
Productivity	I don't follow the procedures, struggle to sketch the research location and don't respond to all questions in an average way.	I can follow most of the procedures, sketch the research location and respond to all questions in an average way.	I can follow all the procedures, successfully sketch the research location and respond to all questions in a comprehensive way.	I can efficiently follow all the procedures, successfully sketch the research location and respond to all questions in an exceptional way.
Understanding	I don't show a clear understanding of the scientific concepts behind land surface temperature and the effects of Urban Heat Island on cities.	I show some understanding of the scientific concepts behind land surface temperature and the effects of Urban Heat Island on cities.	I show a clear understanding of the scientific concepts behind land surface temperature and the effects of Urban Heat Island on cities.	I show a clear and in-depth understanding of the scientific concepts behind land surface temperature and the effects of Urban Heat Island on cities.

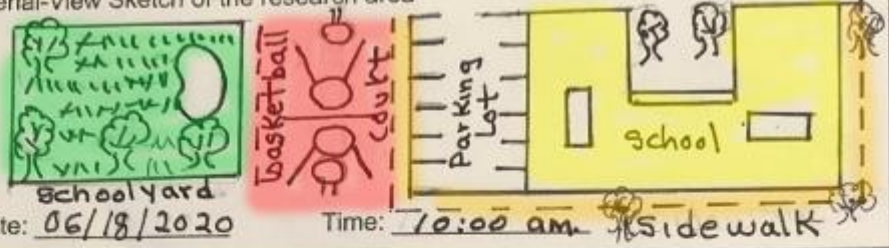
Name: ______________________ Period: ______ Date: ______

Outside of School LST Local Recording Analysis *ANSWER KEY*

Instructions: Record land surface temperatures outside of school and enter data on GLOBE platform. Then answer and reflect on the following questions.

1. Make an aerial-view sketch of the location and color the areas according to colors you choose to represent specific land-surface temperatures.

Aerial-View Sketch of the research area



Date: 06/18/2020 Time: 10:00 am.

Temperature and colors

Temp.	Color
75 °F	= Green
90 °F	= Red
78 °F	= Yellow
81 °F	= Orange

2. Describe what were the different locations that you choose to record your temperatures and the land surface temperatures that you recorded.

I chose 4 different locations: school yard, side walks, basketball court and near school building. The temperatures that I recorded at 10:00 a.m to:

School yard	75°F	Green
Basketball court	90°F	Red
Sidewalks	81°F	Orange
School building	78°F	Yellow.

3. Were there are any correlations between the land surface temperatures and the locations where you tested temperatures? Explain differences and similarities.

Yes, asphalt (basket ball court) was hotter and had a higher surface temperature of 90°F. On the other hand, the school yard had a lower surface temperature of 75°F. The two places were in the same area but the diference is that the asphalt didn't have trees, grass and plants so it was hotter. But the school yard has a surface with trees, grass and plants. The surface temperature was the lowest. Both surfaces have the same measure in the same area but the diference is the temperature.

4. Describe the process of recording temperatures locally outside of school (give steps) and explain how this relates to how scientists do this in the field.

First, I chose the research area.
Next, I chose the strategies (like the location) outside of school.
then I used instruments like the thermometer gun and I recorded the data, and uploaded it on the GLOBE platform to share with other scientists and school community.
Lastly, I made a temperature color-coded map and analized and interpreted the data.
All of these are practices that scientists do while performing research in the field.

NASA Goddard Institute for Space Studies | Climate Change Research Initiative (CCRI) | A. Mundo 2020
Matthew Pearce | Education Program Specialist | GSFC Office of STEM Engagement

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Name: ______________________________ **Period:** _______ **Date:** ________

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Remotely sensing the cooling effects of city scale efforts to reduce urban heat island

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ABSTRACT

While recent years have seen many analyses of techniques to reduce urban heat island, nearly all of these studies have either been evaluations of real small scale applications or attempts to model the effects of large scale applications. This study is an attempt to analyze a real large scale application by observing recent vegetated and reflective surfaces in LANDSAT images of Chicago, a city which has deployed a variety of heat island combative methods over the last 15 years. Results show that Chicago's new reflective surfaces since 1995 produced a noticeable impact on the citywide albedo, raising it by about 0.016, while citywide NDVI increase is around 0.007. This finding along with counts of pixels with increased albedo and NDVI suggest that the reflective strategies influenced a larger area of the city than the vegetative methods. Additionally, plots between albedo increase and corresponding LANDSAT temperature change over the test period have linear regressions with steeper slopes (−15.7) and stronger linear correlations (−0.33) than plots between NDVI increase and temperature change (−8.9 slope, −0.17 correlation). This indicates that the albedo increases produced greater LANDSAT cooling than the NDVI increases. Observation of aerial images confirmed that typical instances of efforts to increase albedo, such as reflective roofs, produced stronger LANDSAT cooling than common instances of NDVI efforts, such as green roofs, street trees and green spaces. Accordingly, the reflective strategies were likely much more effective at cooling Chicago's LANDSAT heat island and may signify a generally more effective strategy for similar cities.

1. Introduction

Since the first observations of the urban heat island (UHI) effect, in which urban areas can be a few degrees warmer than surrounding rural areas, there has been a growing agreement that strategies to cool cities must be developed and tested. The present urbanization projections that estimate 6.3 billion people living in cities by 2050 have intensified the need to make urban environments more comfortable and livable [27]. At the same time, recent concerns about energy consumption have placed emphasis on minimizing the energy used to achieve thermal comfort, urging people to rely on passive ventilation from their UHI-altered surroundings [22]. Moreover, with global warming projections threatening to further increase urban temperatures world-wide, urban cooling techniques may prove even more important in the coming decades [22].

Faced with these issues, many scientists are developing a number of possible urban cooling strategies [14,28] and two have gained acceptance to the point that they are being implemented in a number of cities. These implemented strategies include one that seeks to increase urban reflectivity [6] and another that seeks to increase urban vegetation [10]. Both of these accepted methods focus on mitigating one of the primary causes of UHI outlined by [18] – the fact that urban materials, when compared to rural materials, tend to have properties conducive to higher temperatures. These properties include lower moisture contents, lower thermal roughness lengths, and lower surface albedos. By increasing the reflectiveness of urban surfaces, the former strategy helps remove solar radiation that would otherwise be converted into heat. In the latter strategy, increased vegetation provides enhanced evapotranspiration, which converts absorbed solar radiation into latent heat instead of sensible heat [12]. Additionally, increasing vegetation increases land surface roughness, which

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promotes the transfer of heat to the air and the convection of heat away from the ground [4]. Typical urban strategies belonging to the former category include the installation of reflective roofs or pavement [23] while strategies belonging to the latter category include the introduction of vegetation by means of green roofs, street/yard trees, and green spaces [10].

Numerous studies have revealed that both the reflective and vegetative strategies have the potential to significantly cool urban environments. However, these studies have either been on a small scale, observing individual instances of cooling method application [7,8,23,25]; or they have been attempts to model what would happen if such methods were adopted on a city scale or larger [1,2,6,24]. This study is one of the first to present data regarding the actual implementation of urban cooling strategies on a city scale. Up until this point, the cooling efforts of most cities appear to be too small to have noticeable impacts on this scale and their effects are likely indistinguishable amid other alterations such as land use change with development. However, after almost two decades of minimal development while implementing UHI-combative strategies in both the vegetated and reflective categories (outlined in Appendix A), the city of Chicago has established itself as an optimal testing ground for the comparison of such efforts.

This study's analysis of Chicago's cooling efforts is particularly helpful for informing the debate over the comparative effectiveness of the reflective and vegetated methods. To date, this debate has been informed only by the aforementioned means of analysis and this has had limitations in terms of the complex issues cities face as they seek to reduce their temperature. For example, while the replacement of vegetation with impermeable surfaces is a major cause of UHI and one should probably favor vegetated surfaces over impermeable ones when drafting cooling strategies [16]; some studies have revealed that this may not always be the best route to follow. One multi-year study in Hyōgo, Japan found that highly reflective impermeable white roofs were slightly cooler than grassy green ones, suggesting that these roofs could compete with vegetative methods [25]. Supporting these findings are a number of studies verifying that vegetation must be dense and include shrubs/trees in order to produce the large cooling effects needed to affect changes on a city scale [5,8,19]. When viewed in relation to vegetation-based strategies, this may arouse economic concerns since dense vegetation often has high planting and maintenance costs in urban areas. Some have suggested that the additional ecosystem services offered by a vegetative strategy, such minimized storm water runoff and air purification, might be enough to make it a worthwhile investment [17,20]. However, it is difficult to quantify the value of such benefits and understand how they will impact the effectiveness of strategies as they are implemented over an entire city.

It is because of complications such as these that information on the actual implementation of cooling strategies over cities is particularly helpful. Issues such as maintenance costs and ecological services are difficult to factor into computer models and observations of small-scale applications often have unique situations that are different than that of an entire city. Accordingly, this study will observe a real-world example in an attempt to address some of the limitations in these previous studies. Specifically, this study will observe the citywide increases in Chicago's vegetation and albedo over the last 15 years and compare each of their effects on remotely-sensed surface temperature.

2. Material and methods

Data collection began with the selection of LANDSAT 5 images to represent Chicago at present and prior to the implementation of cooling strategies (around 1995). Only the area within the political borders of the city was considered for analysis since it was within these limits that the most intense and organized efforts took place. An attempt was made to find images without cloud cover, with comparable anniversary dates, and with similar atmospheric conditions in order to minimize error in the comparison of the images' vegetation, albedo and surface temperatures. Ultimately, 8 individual images were selected and these were arranged to produce 5 pairs of past/present images. Table 1 displays data regarding the atmospheric conditions of the images and illustrates that the disparities between each of the pairs are not great enough to compromise the integrity of the analysis. In the course of the study, the only disparity that seems to have produced an anomalous result was the difference in previous day's and month's precipitation in Image pair 5. However, the pair represents an interesting finding that may have relevance for long-term cooling strategies factoring in precipitation increases from global warming and, thus, it was kept in the study. It is important to note that,

Table 1
The atmospheric conditions over Chicago when each of this study's LANDSAT images was taken. "Ground" refers to values that are an average between those recorded at O'Hare International Airport and Midway Airport in the hour the satellite passed overhead. "Balloon" refers to an average of values recorded at a pressure/height of 925 hpa by weather balloon soundings in nearby Lincoln, IL and Davenport, IL. Since soundings occur every 12 h, the values were interpolated to the time that the satellite passed over.

Date	Average LANDSAT surface temp. (°C)	Ground air temp (°C)	Ground Dewpt. (°C)	Balloon air temp (°C)	Balloon Dewpt. (°C)	Ground wind speed (km h-1)	Prev. day's rain (cm)	Prev. month's rain (cm)	Percent of city in cloud/shadow
Image Pair 1									
May 30 1995	29.8	22.9	13.1	15.1	4.5	6	0.0	8.9	0.0
June 5 2009	30.9	20.6	6.4	14.7	3.0	14	0.0	14.2	0.0
Difference	**+1.1**	**−2.3**	**−6.7**	**−0.4**	**−1.5**	**+8**	**0.0**	**+5.3**	**0.0**
Image Pair 2									
July 3 1996	31.3	22.9	14.0	16.5	10.5	21	0.0	11.4	1.5
July 2 2007	30.2	21.5	8.8	17.9	6.8	15	0.4	6.4	0.0
Difference	**−1.1**	**−1.4**	**−5.2**	**+1.4**	**−3.7**	**−7**	**+0.4**	**−5.0**	**−1.5**
Image Pair 3									
June 15 1995	32.4	27.5	13.8	18.1	9.9	10	0.3	8.1	0.0
June 16 2007	35.0	30.5	15.3	24.0	11.1	14	0.0	5.5	0.0
Difference	**+2.6**	**+3.0**	**+1.5**	**+5.9**	**+1.2**	**+4**	**−0.3**	**−2.6**	**0.0**
Image Pair 4									
July 1 1995	29.8	20.3	8.2	12.3	5.5	17	0.0	6.6	2.4
July 2 2007	30.2	21.5	8.8	17.9	6.8	15	0.4	6.4	0.0
Difference	**+0.4**	**+1.2**	**+0.6**	**+5.6**	**+1.3**	**−3**	**+0.4**	**−0.2**	**−2.4**
Image Pair 5									
June 15 1995	32.4	27.5	13.8	18.1	9.9	10	0.3	8.1	0.0
June 24 2010	32.0	23.7	15.9	18.4	12.2	16	3.1	18.6	4.0
Difference	**−0.4**	**−3.8**	**+2.1**	**+0.3**	**+2.3**	**+6**	**+2.8**	**+10.5**	**+4.0**

because all the images of the study are from LANDSAT 5, all images of Chicago were taken at the same time of day (10:29 AM) and have comparable sun angles for images with similar anniversary dates.

After the LANDSAT images were selected, their digital numbers were converted to radiance or reflectance using information in the header files and a series of algorithms in the software ENVI. Next, pixels outside the Chicago political border were masked using a vector file obtained from the city government. Additionally, the three images that possessed cloud cover in their scenes (see Table 1) had their cloud and cloud shadow pixels manually masked.

In order to further minimize the errors caused by differences in atmospheric conditions, an atmospheric correction was performed on all five pairs. This began with the designation of 29 pixels throughout the city that represent objects of very stable reflectance. While 29 pixels is a small number of pixels in relation to the size of Chicago, observation of aerial images revealed great uncertainty with the stability of many surfaces in the city over the 15-year period. For example, streets and playing courts were often repaved or became weathered, light roofs accumulated dust, bare soil and vegetated surfaces changed in vegetation content, and shallow water bodies changed in algae levels. Most pixels in Chicago included a portion of these land cover types and were subsequently unsuitable for this correction strategy. Accordingly, only the few surfaces that were identified in aerial imagery as having undergone the smallest change were used. These mostly included deep water bodies, large dark warehouse roofs, and sections of concrete pavement at airports. A linear regression of the individual band reflectance values of the selected 29 pixels was derived between the past and present images of each pair. The equation of this regression was then applied to one of the images in each pair in order to correct it to the other. If one image in a pair was thought to possess a generally clearer atmospheric condition than the other (i.e. lower dew point in Table 1), it was used as the base image and the other was corrected to it. Otherwise the past image was corrected to the present one as a default.

Admittedly, this form of atmospheric correction may compromise this study's ability to accurately derive values pertaining to individual scenes, such as the city's absolute albedo in a given image. However, this method was found to be optimal for deriving the changes between image pairs – such as the change in citywide albedo over the test period – and, accordingly, it was found to give results with a higher degree of consistency than some physics-based correction techniques that were investigated.

This correction method was also applied to the radiance of the LANDSAT thermal bands since it was assumed that objects that did not undergo major surface changes during the test period should also have stable average surface temperatures. Like the reflectance, this means that the surface temperature values in this study are not precise indications of the actual surface temperatures of individual LANDSAT scenes. Rather, they are meant to capture the average temperature change from surface modifications during the test period.

Normalized difference vegetation index (NDVI) was calculated for all images using the corrected reflectance of LANDSAT bands 3 and 4 and a threshold NDVI of 0.35 was applied to all images to distinguish vegetated surfaces from non-vegetated ones. It is worth noting that this NDVI threshold value is fairly high for most studies and, as a result, a number of sparse lawns that did not have an NDVI as high as 0.35 were not classified as vegetated surfaces. However, this 0.35 value is justifiable by the fact that pixels with an NDVI below it did not exhibit a strong correlation between NDVI and temperature while those above it did. This trend is visible in Fig. 1 as well as a number of other studies that observe urban NDVI [13,26]. The high threshold is also justifiable in that, above 0.35, NDVI is agreed to have a strong correlation to photosynthetic

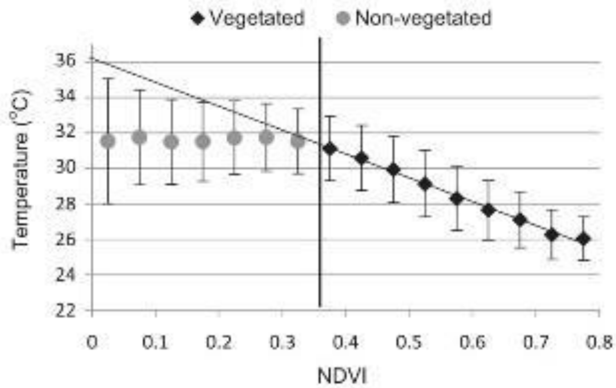

Fig. 1. The origin of the 0.35 NDVI threshold as illustrated by the relationship between NDVI and temperature in the image from May 30th 1995. Each data point represents a bin-averaged value with error bars indicating one standard deviation. The best fit line for values above 0.35 has a negative slope indicating cooling as NDVI increases while values below 0.35 are best fit by a flat line with no correlation. This trend of temperature decrease above a 0.35 NDVI is observable in all 8 Chicago scenes of this study.

activity and plant evapotranspiration [11]. Accordingly, NDVI can be used as a measure of quantity of vegetation within a pixel and not just a measure of how likely that a given pixel is vegetated.

Once the threshold was set, images of Chicago's NDVI in vegetated pixels (above the 0.35 threshold) were generated for each of the dates along with images of multi-band reflectance for non-vegetated pixels (below the 0.35 threshold). Images of multi-band reflectance then had their water pixels masked out after a supervised classification of such areas in each LANDSAT scene. Next, the multi-band reflectance images were converted into broadband albedo images using the formula developed by [15] for a band-weighted average albedo.

Temperature was calculated by using the inverse of the Planck function. An emissivity value of 0.954 was used in this function that was derived by averaging the values of all pixels within the Chicago political border of a July 2006 ASTER emissivity product. The images of NDVI and albedo were then laid over their corresponding temperature images and the relationships between the variables were assessed. Afterward, the pixel values of all 1995 images were subtracted from those of the corresponding present images to yield data sets for the change in albedo, NDVI, and temperature between 1995 and the present. The albedo change and NDVI change images were laid over their corresponding temperature change images and the relationships between them were assessed.

When evaluating the relationships between NDVI, albedo and the corresponding temperature, analysis was done on a pixel-by-pixel basis. For example, let a_p and b_p represent the albedo change and temperature change respectively at pixel p of an image pair. A negative correlation between a and b across the city would provide confirmation of the effectiveness of the albedo strategy since temperature decreases as albedo increases.

After this analysis, an attempt was made at verifying the causes of albedo and NDVI changes observed in the LANDSAT images using high resolution aerial photography from an April 1998 National Aerial Photography Program (NAPP) flyover and a June 2010 aerial flyover by the USDA Farm Service Agency. Aerial images were laid over images depicting change in LANDSAT data and specific areas of NDVI, albedo, and temperature change were identified. This last step verified that many of the instances with decreased temperature in the LANDSAT images were the result of efforts to reduce urban temperatures such as the installation of new reflective roofs, the zoning of new parks, and the planting of new street/yard trees.

3. Results

3.1. *Correlations of NDVI and albedo to temperature within single scenes of Chicago*

Before the selected LANDSAT data can be used to draw conclusions regarding the effectiveness of cooling strategies, it is first necessary to determine whether satellite-observed NDVI and albedo actually correspond to lower LANDSAT temperatures in individual scenes of Chicago. As Fig. 2 illustrates, both parameters exhibit inverse correlations to temperature and generate negatively sloped linear regressions in plots against temperature. This, along with Table 2, which displays the correlations and slopes of the 8 plots used to make Fig. 2, establishes that LANDSAT temperature in Chicago consistently decreases as NDVI and albedo increase.

Though NDVI and albedo share this trend, Chicago's vegetated NDVI has a much stronger relationship to lower temperature than its non-vegetated albedo. For example, NDVI above the 0.35 threshold consistently produces strong correlations around −0.67 while non-vegetated, non-water albedo consistently produces far weaker correlations around −0.15.In accordance with this, the linear regressions for NDVI/temperature plots consistently have steep slopes around −16.2 while those for albedo/temperature plots have shallow slopes around −6.9. Such a comparison of slopes is meaningful because both graphs in Fig. 2 portray similar ranges of both NDVI and albedo, which conveniently marks the approximate maximum and minimum of both parameters in the scenes of Chicago. Multiplying these similar ranges by the regression slopes grants a sense of the typical maximum cooling provided by each parameter within Chicago, translating to a maximum NDVI cooling around −6.5 °C and a maximum albedo cooling around −3.1 °C.

These sharp differences between NDVI and albedo seem consistent with the observations of previous studies that have used remote sensing to compare similar parameters to temperature within cities. For example, a study of 24 cities by Small [21] used a vegetation index to observe the strong inverse correlation between surface temperature and vegetation fraction that this study notes above through NDVI. Additionally Small [21], found the relationship between surface temperature and thermal rock substrate, which is related to non-vegetated albedo, to typically be much weaker and explained this through competing effects of albedo, illumination and soil moisture. Factors such as soil moisture, which darkens and cools surfaces, may also explain the weaker relationship between non-vegetated albedo and temperature observed here. Regardless of explanation, the consistency of these findings with studies of multiple cities suggests that these trends are common and are likely relevant to many other situations.

Table 2
The linear correlations and slopes of linear regressions for plots of NDVI and albedo against temperature in single scenes of Chicago.

Date	NDVI to temperature		Albedo to temperature	
	Regression slope	Correlation	Regression slope	Correlation
May 30th 1995	−13.2	−0.64	−5.1	−0.10
June 5th 2009	−16.6	−0.67	−11.4	−0.21
July 3rd 1996	−16.1	−0.69	−4.1	−0.12
July 2nd 2007	−16.7	−0.67	−11.2	−0.14
June 15th 1995	−16.9	−0.66	−4.2	−0.14
June 16th 2007	−18.9	−0.69	−7.4	−0.17
July 1st 1995	−17.0	−0.71	−6.6	−0.21
June 24th 2010	−14.2	−0.63	−5.0	−0.09
Average	**−16.2**	**−0.67**	**−6.9**	**−0.15**

3.2. *Correlations of NDVI and albedo change to temperature change between paired images*

In spite of the above trend emphasizing the cooling impact of vegetation over albedo, it appears that Chicago's increases in albedo during the test period were more effective at lowering LANDSAT surface temperatures than its increases in vegetation. Fig. 3 displays this by plotting the average albedo and NDVI increases of the 5 images pairs against the corresponding temperature changes over the test period. Table 3 displays the correlations and slopes of the individual plots used to make Fig. 3 and shows that the trends are consistent across the 5 images pairs. As both the figure and table illustrate, increases in non-vegetated non-water albedo had strong correlations to temperature decrease around −0.33 while increases in vegetated NDVI had weaker ones around −0.17. Similarly, the slopes of regressions for albedo increase/temperature change plots are steep around −15.7 while those for NDVI increase/temperature change plots are shallow around −8.9. Multiplied by the ranges of NDVI and albedo increase, this translates to a typical maximum albedo cooling of −6.3 °C and a typical maximum NDVI cooling of-3.6 °C.

Though Table 3 displays an acceptable degree of consistency between the correlations and regression slopes of the 5 image pairs, many of the disparities between them have reasonable explanations that strengthen the certainty of their accuracy. For example, the fact that Image pairs 1 and 5 have stronger correlations and steeper slopes for albedo increase than pairs 2, 3 and 4 makes sense in light of the fact that 1 and 5 use images from 2009 to 2010 to signify the present while the others use images from 2007. In 2008, Chicago's reflective roof zoning codes were intensified to require a higher minimum albedo for new roofs and this likely

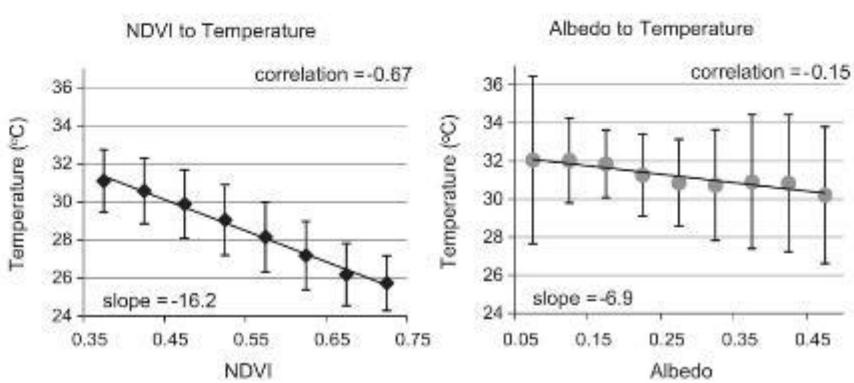

Fig. 2. Plots of NDVI and albedo against LANDSAT temperature depicting the average values and trends across all 8 images observed in the study. Each data point represents a bin-averaged value with error bars indicating one standard deviation.

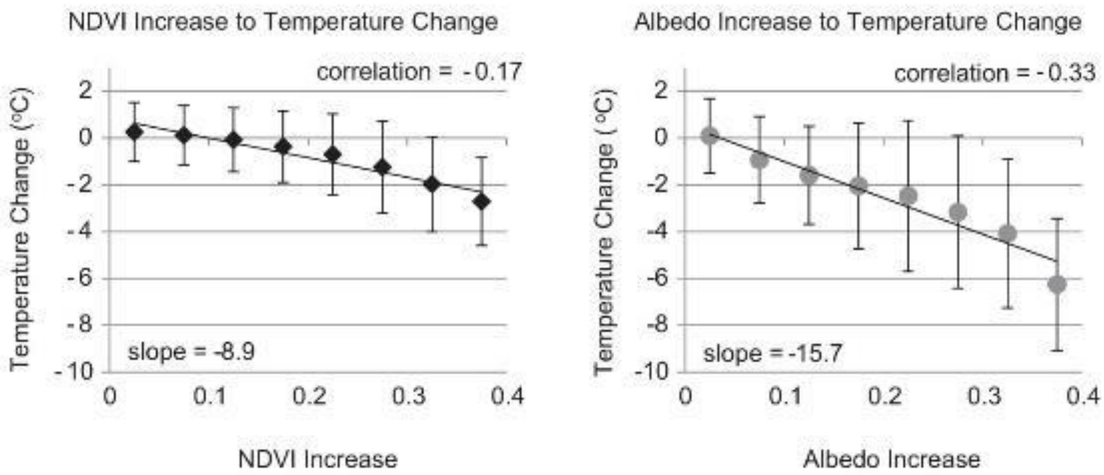

Fig. 3. Plots of NDVI and albedo increase against LANDSAT temperature change between 1995 and the present. Data points and regression curves depict the average values and trends across all 5 LANDSAT past/present pairs observed in the study. Each data point represents a bin-averaged value with error bars indicating one standard deviation.

strengthened the cooling effect of albedo increases in pairs using images after this policy change. Yet another disparity with a reasonable explanation is the unusually strong correlation (−0.32) and steep slope (−15.1) of image pair 5's NDVI increase to temperature change. This anomaly is clarified in Table 1, which reveals that Image pair 5 has an unusually large disparity between the two images' previous rainfalls. Before the day that the image characterizing the present was taken in this pair, there was a substantial precipitation event of 3.1 cm that was not reciprocated in the past image. Also, the month before the present image's capture had a record-breaking quantity of rainfall around 18.6 cm while the past only received 8.1 cm. The additional rainfall in the present image must have intensified the cooling effects of the vegetation increases between the two dates by accelerating plant growth, productivity and evapotranspiration in a way that the minor precipitation disparities of the other pairs did not. Interestingly enough, this increased precipitation does not seem to have strengthened the correlation of the present image's overall NDVI to temperature within that one scene (−0.63) as this value is less than the average of all 8 scenes (−0.67). However, such precipitation has clearly had an effect on the NDVI increases between the dates and reveals that the cooling effects of Chicago's new vegetation are highly dependent upon rain. This finding has interesting consequences for cooling strategies that anticipate increases in precipitation from global warming since, in a scenario with increasing rain such as this, the cooling effects of new vegetation appear nearly equivalent to those of new reflective surfaces. However, for the purposes of understanding the optimal methods in the absence of changing precipitation conditions, the aforementioned trends stressing albedo cooling over NDVI cooling are valid and accurate.

Table 3
The linear correlations and slopes of linear regressions for plots of NDVI and albedo increase against temperature change over the test period.

Image pair	NDVI increase to temperature change		Albedo increase to temperature change	
	Regression slope	Correlation	Regression slope	Correlation
Pair 1	7.0	0.09	21.1	0.36
Pair 2	−5.9	−0.14	−10.1	−0.31
Pair 3	−9.8	−0.11	−17.2	−0.31
Pair 4	−6.8	−0.18	−11.8	−0.34
Pair 5	−15.1	−0.32	−18.5	−0.34
Average	**−8.9**	**−0.17**	**−15.7**	**−0.33**

3.3. Changes in area of vegetated and reflective surfaces between paired images

In addition to evaluating relationships between NDVI/albedo increases and temperature change, it is also useful to understand how much of the city's area was affected by such changes. One means of informing such an understanding is to consider the average quantities of LANDSAT pixels that increased in albedo and NDVI between the 5 image pairs. This reveals that there were approximately twice as many non-vegetated pixels that increased in albedo during the test period (300 579) as there were pixels that increased in NDVI to or above the 0.35 vegetation threshold (162 243). While informative, these quantities are not necessarily an indication that efforts to increase albedo influenced a larger area of the city since many of these pixels could be very close to a zero change between the two images and just happened to fall on the side of increase. One possible means of distinguishing the pixels that were effective efforts from the arbitrary increases is to eliminate the pixels that increased in albedo or NDVI by a value smaller than 0.01. This reveals an average of 142 367 pixels for NDVI and 216 581 pixels for albedo. Yet another means of distinguishing the cooling efforts is to only count pixels that increased in albedo/NDVI and also decreased in LANDSAT temperature and this method shows an average of 69 281 pixels for NDVI and 154 615pixels for albedo.

Perhaps the most informative way to understand the area cooled by each of the strategies is to multiply the area of pixels that increased in NDVI/albedo and decreased in temperature by the average cooling that was noted in these pixels. This would yield a general "area cooling index" for each method with the units of km^{2}°C. Following this process, NDVI increases exhibited an average area cooling index of 74.8 km^{2}°C while albedo increases had a much larger 214.6 km^{2}°C. An abstract way of understanding these values is to think of the cooling that occurred in Chicago as a region that had a uniform drop in temperature of 1 °C. In this sense, the area cooling index is the size of this region in km^2 that resulted from each of the methods.

3.4. Changes in citywide NDVI and albedo

With the exact area of the city that increased in albedo or NDVI still in question, it is worthwhile to inform this issue with observations of the citywide changes in these parameters over the test period. Table 4 displays such information and reveals a subtle increase in Chicago's average citywide NDVI around +0.009, which is mirrored by a small increase in vegetated surface area around +11.7 km^2. Although such an average increasing trend seems like a reasonable result of efforts to increase vegetation over the test period, this increase is inconsistent across the 5 image pairs and such a discrepancy must be explained in order for this inference to be acceptable. Notably, image pair 1 exhibits an almost nonexistent increase in citywide NDVI (+0.001) and a total decrease in Chicago's vegetated area (−5.8 km^2) that is contradictory to the overall increasing trend. The primary cause of this lack of consistency is likely the differences in precipitation before the images were taken, which can raise or lower the NDVI of surfaces by influencing plant productivity and photosynthesis. Such an explanation is supported by the general relationship between the pairs' previous-week precipitation difference and the citywide NDVI change, both of which are noted in Table 4. In this sense, the decreasing vegetated area of pair 1 is the result of a large decrease in the previous week's precipitation between the two dates. All image pairs support the trend of greater vegetation increase with an increase in previous-week rain except for Image Pair 4, which has the largest decrease in rainfall but also the greatest increase in NDVI of all the pairs. The reason for this anomaly is probably the 2.4% cloud cover in the past image of the pair (see Table 1), which sits directly above one of the largest areas of vegetation clearing that occurred during the test period. After this cleared area was masked in both the present and past images as part of the procedure, the citywide NDVI increase was recorded to be much greater than what actually happened over the whole city and, accordingly, this pair is not suitable for documenting the city's overall NDVI change. However, all other observations of pair 4 in this study should be valid as this section is the only one where vegetation decreases between dates play a role. Discounting this pair, the average NDVI change of the entire city is +0.007 and the average change in vegetated surfaces is +9.4 km^2. Since these 4 remaining pairs encompass a diverse enough number of precipitation scenarios, their average values of vegetation change are hopefully a good reflection of the terrestrial alterations that occurred during the test period and do not heavily reflect the changing rain conditions. Some reassurance of this can be found in the average change of previous week's rain among the 4 pairs (+0.62 cm), which is close to zero.

Contrary to the subtle effects of vegetation increases that are difficult to distinguish amid rain and cloud cover, Chicago's new reflective surfaces had a clear impact on the albedo of the city. All 5 pairs exhibit an increase in Chicago's citywide albedo that averages out to 0.016 and translates to 0.022 when one narrows down the domain to just the city's non-vegetated and non-water pixels. The area covered by pixels with albedo above 0.2 also increased by an average of 51.9 km^2, which is noteworthy because 0.2 is approximately the minimum albedo of a reflective roof. Though these findings exhibit a more certain trend than the NDVI increases, there is still a degree of inconsistency between the pairs in Table 4 that should be addressed. An important factor that likely accounts for the much higher albedo increase in pairs 1 and 5 is the aforementioned intensification of reflective roof zoning codes in 2008, which raised the albedo of the present images of these pairs (taken in 2009 and 2010) above that of the other pairs (taken in 2007). In this sense, the aforementioned average albedo increases are an indication of the change as of approximately 2008 and albedo seems to have continued to increase after this time. Yet another factor that likely contributes to the inconsistency is the effect that varying precipitation between the images has on soil albedo. As is the case with NDVI, the diversity of precipitation scenarios between the image pairs should be enough to counteract this error in the averages noted here.

The average albedo increase of 0.016 can also help give a sense of the change in the city's heat absorption that occurred over test period. For example, a citywide albedo increase of 0.016 means that an additional 3.9 W/m^2 are reflected away from the surface of Chicago during the months of June, July and August. This translates to an average reflection of 2.4 GW over the entire city during this time. To put this estimate in more tangible terms, this is the equivalent cooling power of approximately 65 000 large window air conditioning units operating non-stop at full capacity throughout these months or more than one extra air conditioning

Table 4
Parameters describing the citywide changes in Chicago's NDVI and albedo between past/present image pairs. "Vegetated" and "Non-vegetated" refer to pixels above and below the 0.35 NDVI threshold respectively. All values come from LANDSAT data except for the previous week's rainfall, which was calculated using airport records.

Date	Whole city NDVI	Veg. area (km^2)	Veg. % of city	Whole city albedo	Non-veg. albedo	Area w/Albedo >0.2 (km^2)	Prev. week's rainfall (cm)
Image Pair 1							
May 30th 1995	0.295	222.3	36.6	0.152	0.153	21.0	5.1
June 5th 2009	0.296	216.5	35.6	0.173	0.180	84.4	2.3
Change	**+0.001**	**−5.8**	**−1.0**	**+0.021**	**+0.027**	**+63.4**	**−2.8**
Image Pair 2							
July 3rd 1996	0.270	177.5	29.7	0.159	0.160	29.1	0.0
July 2nd 2007	0.278	190.7	31.9	0.168	0.173	61.4	0.5
Change	**+0.008**	**+13.2**	**+2.2**	**+0.009**	**+0.013**	**+32.3**	**+0.5**
Image Pair 3							
June 15th 1995	0.277	185.5	30.5	0.156	0.156	23.9	0.5
June 16th 2007	0.284	196.0	32.3	0.172	0.178	73.0	0.0
Change	**+0.007**	**+10.5**	**+1.8**	**+0.016**	**+0.022**	**+49.1**	**−0.5**
Image Pair 4							
July 1st 1995	0.263	166.4	28.0	0.156	0.157	24.9	4.3
July 2nd 2007	0.277	187.4	31.6	0.168	0.174	65.0	0.5
Change	**+0.014**	**+21.0**	**+3.6**	**+0.012**	**+0.017**	**+40.1**	**−3.8**
Image Pair 5							
June 15th 1995	0.276	177.8	30.5	0.156	0.157	23.5	0.5
June 24th 2010	0.289	197.6	33.9	0.181	0.187	98.4	5.8
Change	**+0.013**	**+19.8**	**+3.4**	**+0.025**	**+0.030**	**+74.9**	**+5.3**
Average							
1995	0.276	185.9	31.1	0.156	0.157	24.5	2.1
Present	0.285	197.6	33.0	0.172	0.178	76.4	1.8
Change	**+0.009**	**+11.7**	**+1.9**	**+0.016**	**+0.022**	**+51.9**	**−0.3**

for every two households. Of course, it is important to keep in mind that this cooling is diffused whereas air conditioners act on specific rooms but this quantity nevertheless suggests that reflective efforts produced a large enough effect to impact microclimates, especially in some neighborhoods where albedo increases were found to be as much as four times that of the city average.

3.5. *Changes on building to neighborhood scales*

In an attempt to verify that the NDVI and albedo changes observed in the previous sections were the result of at least partially-intentional urban cooling efforts, high resolution aerial images taken in 1998 and 2010 were analyzed in relation the LANDSAT data. To accomplish this, LANDSAT-derived images were generated in which areas of increased and decreased NDVI, albedo and temperature could be easily located (Fig. 4). Areas of apparent albedo and NDVI increase were observed in relation to the aerial images and specific instances that represent the effects of certain methods were selected for display in Fig. 5. For this figure, an attempt was made at finding instances that best characterized the citywide impacts of each of four different types of cooling efforts employed by Chicago in the test period: reflective roofs, green roofs, street trees, and green spaces (i.e. parks, grassy schoolyards, and nature preserves).

LANDSAT temperature changes resulting from new reflective roofs were some of the largest of those observed in the study. Certain multi-block neighborhoods, such as the Western Ukrainian Village depicted at the top of Fig. 5, were found to have cooled by as much as 3.4 °C with albedo increases around 0.07. Some large warehouse roofs that became reflective, such as the one on the Industrial Storage Warehouse Corporation on W Ohio Street (second row of Fig. 5), cooled by as much as 5.0 °C with albedo increases around 0.16. It is worth noting that a large fraction of the areas of albedo increase in Fig. 5(the green areas) were found to be the result of reflective roofs. From simple visual observations, more than 75% of the "green areas" in Fig. 5 can be attributed to new reflective roofs and most of the remaining changes appear to be the result of new bare soil or the weathering of asphalt. Accordingly, this effort had a definite cooling impact that was widespread and likely affected the LANDSAT heat island of the city.

Green roofs were admittedly difficult to evaluate using this method since many of the new instances that were larger than a 30 m pixel were installed over new skyscrapers in the downtown region where bare soil had existed previously. In spite of this, there are a few striking trends in the LANDSAT images that reveal the effectiveness of this strategy. Most importantly, out of 21 new green roofs larger than a 30 m pixel that were identified in the downtown area, not a single one succeeded in producing a LANDSAT pixel with an NDVI greater than 0.35 in any of the images of this study. As noted in Fig. 1 and other studies [13,26]; the surpassing of this threshold is necessary for a vegetated surface to produce noticeable cooling effects and suggests that the green roofs were ineffective at lowering LANDSAT temperature over the test period. The third row of Fig. 5 supports this inference with observations of one of the few large green roofs that arose over an existing building in the test period: the new green roof atop City Hall. As the figure illustrates, the new vegetation over this 120 m × 60 m surface fails to produce any 30 m-pixels that pass the 0.35 threshold and instead shows up as an albedo increase of 0.02 in the LANDSAT images. In accordance with this, an insignificant average LANDSAT temperature change of 0.1 °C occurs over the roof.

The failure of the green roofs in this manner is surprising and, as other instances of cooling efforts will reveal, grass at ground level easily passes the vegetation threshold and produces noticeable LANDSAT cooling. Accordingly, there appears to be a consistent difficulty in getting vegetation to be dense enough in the layer of soil on building roofs such that there are noticeable effects on the LANDSAT scale. It can thus be concluded that this type of effort had an insignificant effect on Chicago's LANDSAT heat island and this is especially true when one considers that all of the city's new green roofs account for at most 7 million square feet of additional vegetation, which is approximately one thousandth of the city's total area.

Unlike new green roofs, certain multi-block neighborhoods with new street trees exhibited strong indications of cooling. The fourth row of Fig. 5 is a good example of this trend and depicts a neighborhood where increases in NDVI were primarily the result of new trees: the blocks bounded by Garfield Boulevard, Ashland Avenue, 51st Street, and the rail yards of the New City Community Area. Here, areas of NDVI increase from new trees in the NDVI-change image seem to be mirrored by areas of temperature decrease in

Fig. 4. Images used to identify areas of NDVI, albedo and temperature change for comparison with aerial images. Albedo and NDVI change images depict LANDSAT data of each parameter from 1995 set to a red channel and from 2009 set to a green channel. Thus, an area appears greener if it increased in the given parameter over the test period and redder if it decreased. Yellow, brown and black signify minimal change. The temperature change image is a color coded subtraction of 1995 temperature from present day temperature. The darkest blue denotes a decrease in temperature by 3 °C while the darkest red is an increase in temperature by 3 °C. Original LANDSAT images for this figure are taken from image pair 1. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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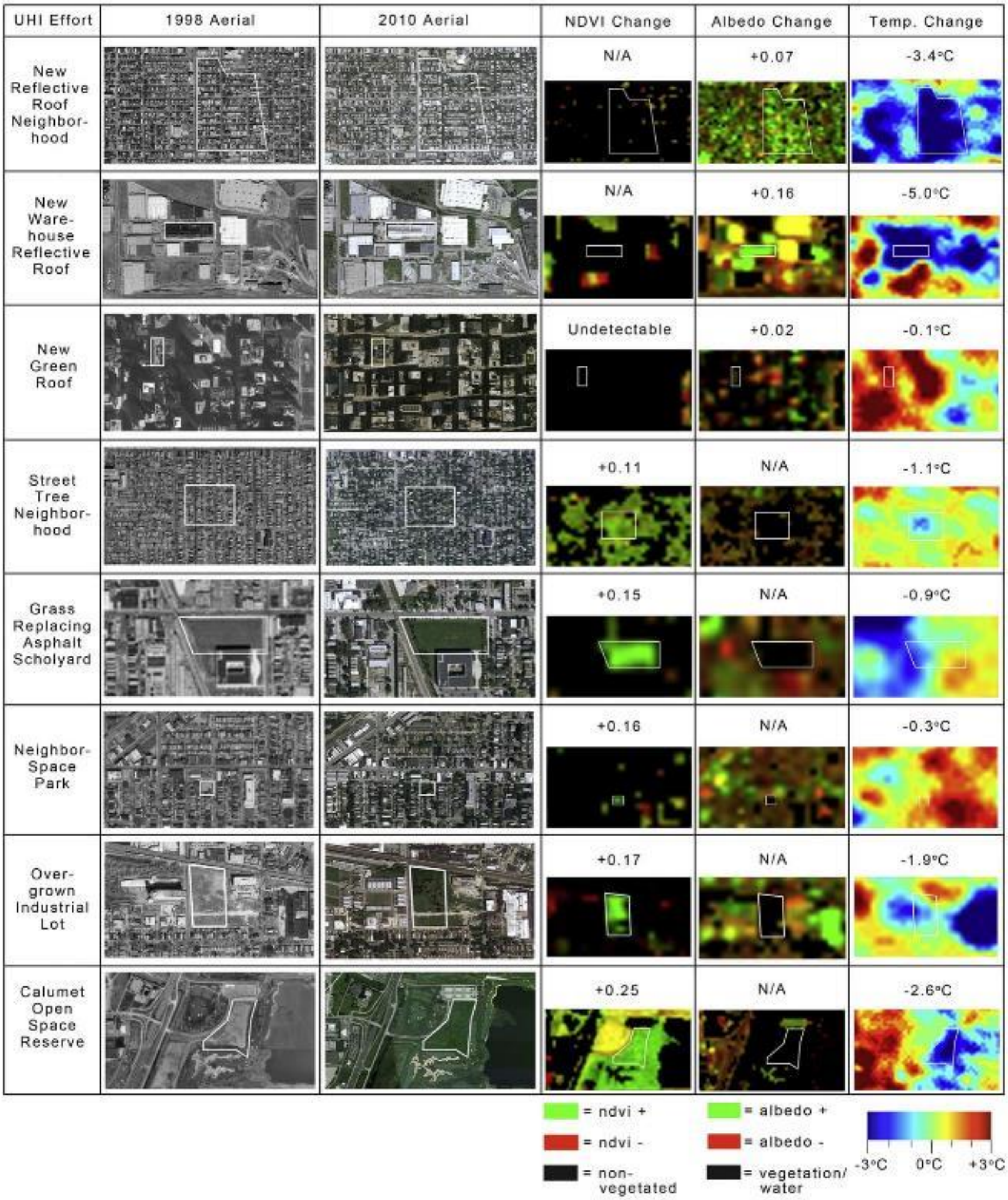

Fig. 5. Specific examples of UHI efforts during the test period. The two left columns contain high resolution aerial images while the three right columns show enlarged and resampled versions of the LANDSAT images in Fig. 5. Quantities above the images in the three right hand columns represent the change in the area bounded by the white lines averaged across all 5 image pairs. Note: NDVI change values only account for the portion of the change above the 0.35 threshold.

the LANDSAT thermal image. Also, when zoomed in to specific blocks of particularly intensive tree planting (bounded by the white box), cooling trends around −1.1 °C are apparent amid NDVI increases of 0.11. In light of this and the fact that Chicago increased its tree count by at least 15% during the test period, it seems likely that the trees had a cooling effect on Chicago's LANDSAT UHI. This effect was larger than that of green roofs but does not appear to be as influential as the reflective roof zoning.

New green spaces produced the most varied results of all the cooling techniques observed because they encompass a large range of sub-methods including the replacement of asphalt schoolyards with grass, the zoning of new community parks, and the establishment of new nature preserves. The conversion of schoolyards from blacktop to grass produced noticeable results in LANDSAT imagery, which appear comparable in cooling and NDVI change to blocks of intense street-tree planting. For instance, the conversion of the playing field at Ames Middle School (fifth row of Fig. 5) cooled the area by approximately 0.9 °C while increasing NDVI by 0.15. Considering that Chicago converted over 100 of such schoolyards in the test period, it seems likely that this strategy had a modest cooling effect.

Many of the areas that were identified as the city's newly-zoned parks were sub-block-sized sites such as the McKinley Library Park in the sixth row of Fig. 5. As the figure suggests, these strategies were large enough to produce noticeable changes in single 30 m-pixels of the NDVI change images but had relatively insignificant effects on the thermal images, which were captured using LANDSAT 5's 120 m-pixel thermal thematic mapper. Consequently, the park in Fig. 5 exhibited a large NDVI increase of 0.15 but a temperature change of only −0.3 °C. Although this study's method of evaluation is not ideal for determining the effects of such small parks, it seems safe to conclude that these parks had a minor citywide cooling impact. This is especially true when one considers that there were over 100 similar new green spaces that arose during the test period which, when taken together, would amount to a large area exhibiting noticeable LANDSAT cooling.

A collection of new vegetated areas that proved much more noticeable than these identified parks was a number of slightly larger industrial lots that became abandoned and overgrown in the test period. If action were to be taken to allow these newly vegetated areas to be left intact, then this strategy could certainly be considered an effective method for cooling and reducing urban temperatures. A good example of one such site is a lot next to an abandoned warehouse with the address 1856 N Leclaire Ave. (eighth row of Fig. 5). As the figure illustrates, the NDVI of the lot increased by 0.17, triggering a substantial drop in temperature around 1.9 °C. An exact count of these sites was difficult to assemble but they seem least as common as converted schoolyards and they had more intense cooling effects than these schoolyards.

The largest cooling from vegetation was a previously industrial site around the recently established Calumet Open Space Reserve (last row of Fig. 5). With this site seemingly left to return to levels of native vegetation, the area cooled by 2.6 °C with an overall NDVI increase of 0.25. Although there is only one of these reserve-scale areas that arose in the test period, this instance establishes a compelling argument for large parks/reserves as the vegetation-based strategy that is the most effective at cooling.

4. Discussion

Before the findings of this study can inform planning decisions and urban cooling strategy, it is first necessary to consider a few limitations of the data set. Perhaps most importantly, this study relies almost entirely on data from LANDSAT 5, which has several limitations in terms of the accuracy of albedo, NDVI and temperature values that are derived from it.

Firstly, the albedo values that were generated in this study do not take into account the hemispherical reflectance of surfaces in the manner that some of today's sensors can and, accordingly, albedo values only indicate the changes at specific sensor and sun angles for each image or pair. MODIS bi-directional albedo products, which are much better at describing this hemispherical albedo, give generally lower values for the citywide albedo of Chicago that are around 0.13 (the LANDSAT values of this study are around 0.17). Also, the citywide MODIS albedo increase between 2002 and the 2010 is around 0.006, which suggests that the average citywide increase in LANDSAT albedo between 1995 and the present (0.016) may be slightly lower when one considers hemispherical effects. This inaccuracy is not enough to undermine the general trends that the LANDSAT albedo demonstrates, such as its correlation to temperature or the fact that it noticeably increased over the city during the test period. However, it does throw into question the exact albedo values of the study and the information that is derived from them.

Another limitation of the older LANDSAT 5 data in this study is that it is difficult to obtain several atmospheric profiles to correct for the effect that the atmosphere has on the thermal radiance reaching the sensor. More explicitly, the formulas for temperature calculation in this study do not account for the radiation that is inevitably lost through the small amounts of humidity and aerosols in a clear-sky atmosphere and so the actual surface temperature values are slightly higher than those listed here. The atmospheric correction performed in this study accounts only for the atmospheric differences between image pairs based on the matching of stable surfaces and does not account for the amount of radiation lost to a clear-sky atmosphere. Thus, if a complete physics-based atmospheric correction with on-site balloon sounding data were applied to the LANDSAT images, it would likely shift all calculated temperature values up by a few degrees depending on the humidity and aerosols in the atmosphere [3]. Based on observations of the present day images of the study, for which there was sufficient sounding data, temperature values were shifted up by an average of 6 °C although this varied by one or two degrees depending upon the image.

A third major limitation is that only one emissivity value of 0.954 was used to derive surface temperature values for the entire city. In order to understand the error that this might generate, an ASTER emissivity product of Chicago in July 2006 was analyzed, which revealed a tendency for emissivity to slightly increase as NDVI increased and decrease as albedo increased. This resulted in a temperature error of as much as ±1 °C for the highest albedo and NDVI pixels respectively (Fig. 6). The regression curves derived from the ASTER product in Fig. 6 can be used to correct some of the trends observed in the LANDSAT images, such as those displayed in Fig. 2. With this correction, the average correlation between NDVI and temperature in single scenes is slightly more negative around −0.71 (originally −0.67) and the correlation between albedo and temperature is slightly less negative around −0.10 (originally −0.15). Applying these same regressions to the NDVI and albedo change plots of Fig. 3 may generate misleading results because the changes in NDVI and albedo over the last 15 years are different than these absolute parameters across the city. However, it is at least good to know that this study's primary conclusions still hold in the application of these regressions. For example, albedo increases still have a stronger correlation to temperature decrease (−0.29) than NDVI increases (−0.23). Additionally, albedo increases still have stepper slopes in plots against temperature change (−12.8) than NDVI increases do (−10.2). Furthermore, the “area cooling index” that was described in Section 3.4 is still greater for albedo (227.2km^{2o}C) than it is for NDVI (75.5km^{2o}C).

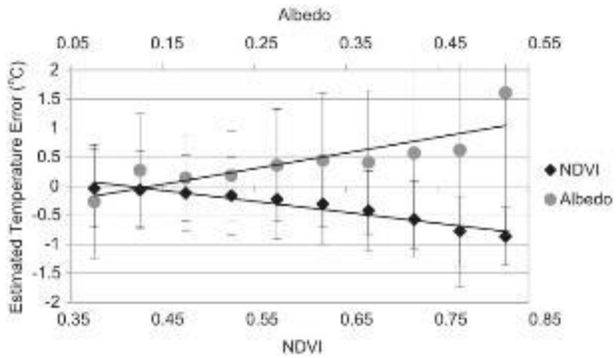

Fig. 6. NDVI and albedo plotted against estimated temperature error resulting from differing emissivity in a 2006 ASTER image of Chicago. Estimated temperature error was derived using the Planck function with emissivities taken from the ASTER image in the LANDSAT TM thermal wavelength and temperature from the average LANDSAT surface temperature across the 8 images in this study (304.4 K).

In addition to the limitations of the LANDSAT 5 sensor, there are also general limitations in using any form of remotely-sensed data to draw conclusions about the effects of surface changes on humans. Notably, satellite data tends to over sample typically uninhabited places such as rooftops, treetops and roads while under sampling the places people usually occupy such as sidewalks, the spaces beneath trees and rooms beneath roofs. Consequently, there is a great deal of uncertainty when attempting to evaluate how exactly these remotely-sensed temperature changes will affect the inhabitants of Chicago.

In spite of this ambiguity, this study can provide relatively reliable conclusions regarding the impact of these methods on nighttime air temperature. This is because surfaces that retain more heat during the day will release more heat at night, warming the inhabited areas around the typically uninhabited rooftops, treetops, and roads. Arguably, this process is one of many that generate the clearer citywide heat island observed at night, as the heat held by particular urban surfaces with high thermal retention capacities disperses. Thus, the general air temperature of Chicago's neighborhoods at night is correlated to the heat that specific surfaces retain during the day. The heat stored by these surfaces is often correlated to their daytime temperature unless one is considering the effects of water bodies or street canyons, which store a lot of heat but do not register very high daytime LANDSAT temperatures. Considering that street canyons and water bodies remained mostly stable during the test period, changes in LANDSAT temperature likely resulted from surface property modifications such as albedo and vegetation cover changes. Consequently, the daytime LANDSAT surface temperature changes observed in this study are likely related to similar changes in Chicago's nighttime air temperature and it is through this lens that the effect of these surface modifications on humans can be evaluated.

In light of this, the findings of this study are much more practical when they are applied to the night-time UHI and its effects. This may add more meaning to the findings since most heat-related deaths occur at night [9] and nighttime is arguably the period of the day when thermal comfort is most needed in order to induce sleep. A greater emphasis on nighttime effects also means that inhabitant behavior patterns are more predictable since most citizens will be sleeping in their residences at this time. This underscores the efforts that are often closest to these residences such as reflective roofs, green roofs and sometimes street/yard trees, while deemphasizing those efforts that are often further away, such as green spaces.

5. Conclusion

Taken together, the results present a compelling argument for reflective cooling strategies over the vegetative. The impact of Chicago's reflective increases in the test period surpassed those of vegetation in terms of the number of pixels that they cooled, the clarity of their effect on the whole city, and the strength of their correlation to lower temperatures. Aerial image analysis confirmed that reflective roofs were responsible for a large fraction of albedo increases in the test period and closer observations showed these roofs were responsible for some of the greatest cooling trends of all observed methods.

Accordingly, cities similar to Chicago in climate, population and economic situation that wish to reduce their temperatures should consider making reflective efforts a critical point of their strategies. Specifically, reflective roofs have proven themselves effective and this is likely because they provided the greatest amount of cooling for the smallest amount of money invested. Vegetation that is dense enough to provide desired cooling seems to have high installation and maintenance costs that prevent it from having the same widespread cooling effects of reflective roofs. Also, the fact that new vegetation often replaces moist soil, an already cool surface, means its impact is diminished in relation to reflective roofs, which are typically installed over dark impermeable surfaces.

In spite of these findings in favor of reflective roofs, this does not mean that vegetation-based strategies should be disregarded. It is important to remember that NDVI in single scenes of Chicago exhibited the highest linear correlation to lower temperature out of any in this study and this hints at an enormous potential for cooling if vegetation can be installed to a great enough density. Perhaps a cooling strategy is not subject to economic concerns would place a high priority on the planting of vegetation to reach an ideal minimization of its UHI. This notion of the ideal vegetated city is also supported by the additional benefits that vegetation brings over reflective surfaces, such as reduced storm water runoff and a number of other ecosystem services.

In summary, while a vegetated strategy may be effective over the span of several decades in cities with plentiful funding for cooling efforts, Chicago's reflective strategies were much more effective at cooling the city over the last 15 years and likely denote a more effective strategy over such a time period for today's temperature metropolises.

Role of the funding source

This study was supported by Yale University. The sponsor had no role in the design of the study; in the collection, analysis or interpretation of data; in the writing of the report; or in the decision to submit the paper for publication.

Acknowledgments

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Appendix. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.buildenv.2011.08.004.

References

[1] Akbari H, Konopacki S. Calculating energy-saving potentials of heat-island reduction strategies. Energ Pol 2005;33:721–56.

Name: ______________________________ **Period:** _______ **Date:** ________

Journal Paper Reading, Analysis and Interpretations

Instructions: Read the introduction and abstract of the journal article. Then work with your group to take notes on the part of the journal paper you have been assigned. Then be ready to present and record notes.

1. After you have read the abstract and introduction of this journal paper, in your own words explain what is the purpose of the journal paper.

2. Now you will take notes on the article section that you have been assigned.

Name of the journal part that I was assigned: ________________________________

My notes based on the journal paper part I was assigned:

3. What question(s) do you still have about the assigned journal part that you just read?

4. Now you will take notes on the other groups' presentations about their assigned parts. Record your annotations and your notes in the space below.

Name of the journal part that another group was assigned: ________________________________

My notes based on another group's presentation of their assigned journal paper part:

Name of the journal part that another group was assigned: ________________________________

My notes based on another group's presentation of their assigned journal paper part:

Name of the journal part that another group was assigned: ________________________________

My notes based on another group's presentation of their assigned journal paper part:

Name of the journal part that another group was assigned: ________________________________

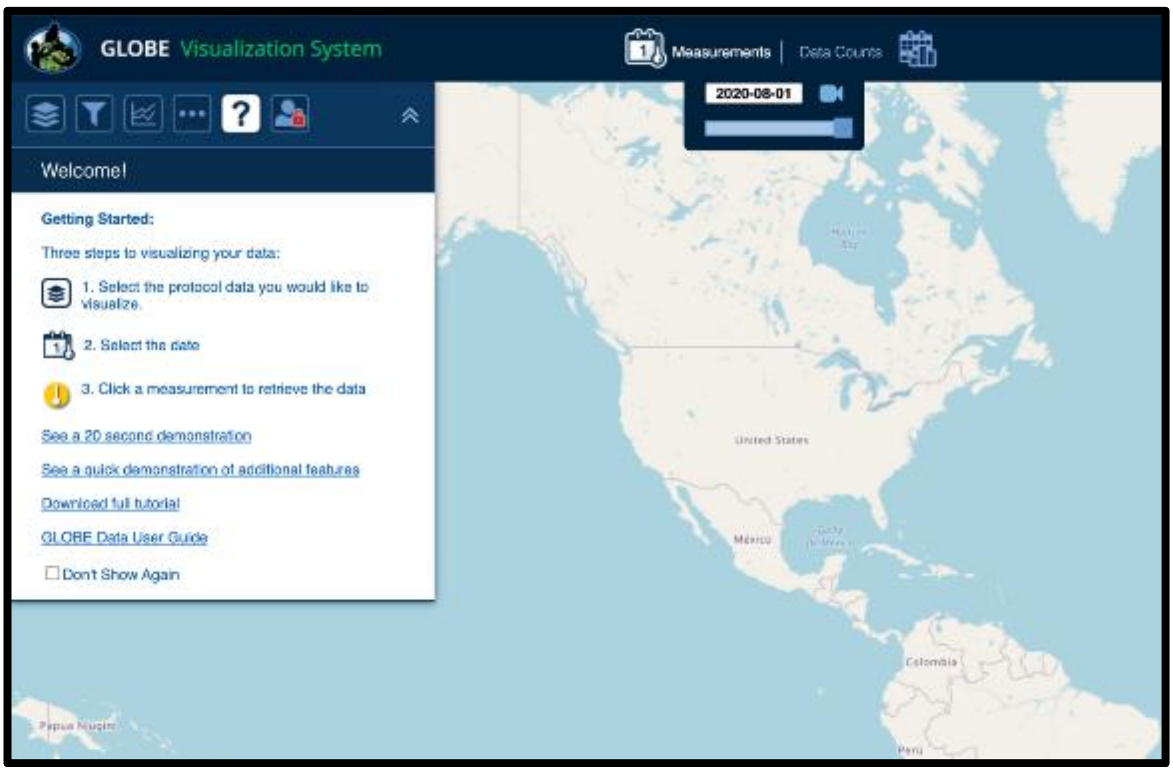
My notes based on another group's presentation of their assigned journal paper part:

Rubric Category	Doesn't meet expectations 🛰	Satisfactory 🛰 🛰	Meets expectations 🛰 🛰 🛰	Exceeds expectations 🛰 🛰 🛰 🛰
Productivity	I don't follow the procedures, struggle to read and interpret the abstract, introduction and my assigned part and don't take notes for journal parts in an average way.	I can follow most of the procedures, read and interpret the abstract, introduction and my assigned part and take notes for all journal parts in an average way.	I can follow all the procedures, successfully read and interpret the abstract, introduction and my assigned part and take notes for all journal parts in a comprehensive way.	I can efficiently follow all the procedures, successfully read and interpret the abstract, introduction and my assigned part and take notes for all parts in an exceptional way.
Understanding	I don't show a clear understanding of the scientific concepts behind remote sensing and the Urban Heat Island on cities.	I show some understanding of the scientific concepts behind remote sensing and the Urban Heat Island.	I show a clear understanding of the scientific concepts behind remote sensing and the Urban Heat Island on cities.	I show a clear and in-depth understanding of the scientific concepts behind remote sensing and the Urban Heat Island on cities.

10. Supporting Documents:

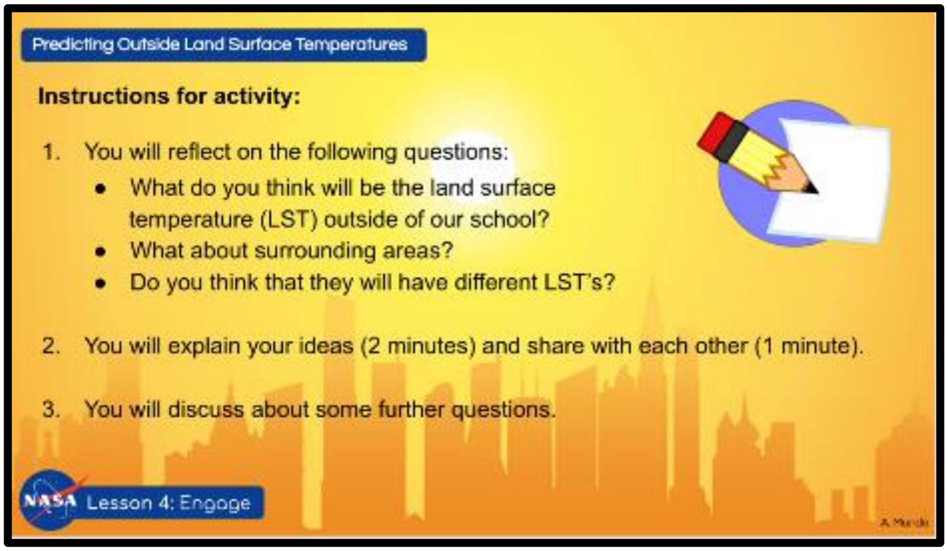
GLOBE Data Entry Mobile App: https://www.globe.gov/globe-data/data-entry/data-entry-app

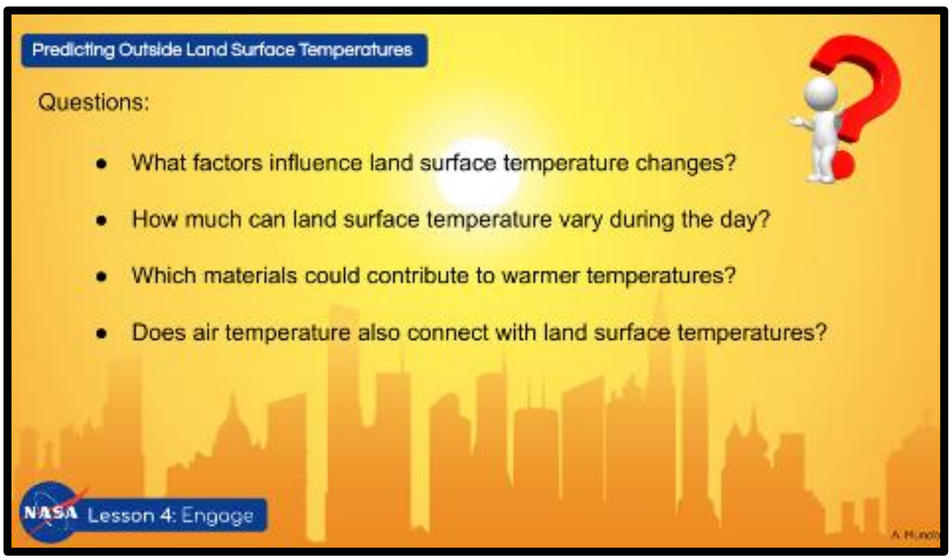
GLOBE Visualization System: https://climate.nasa.gov/interactives/climate-time-machine/



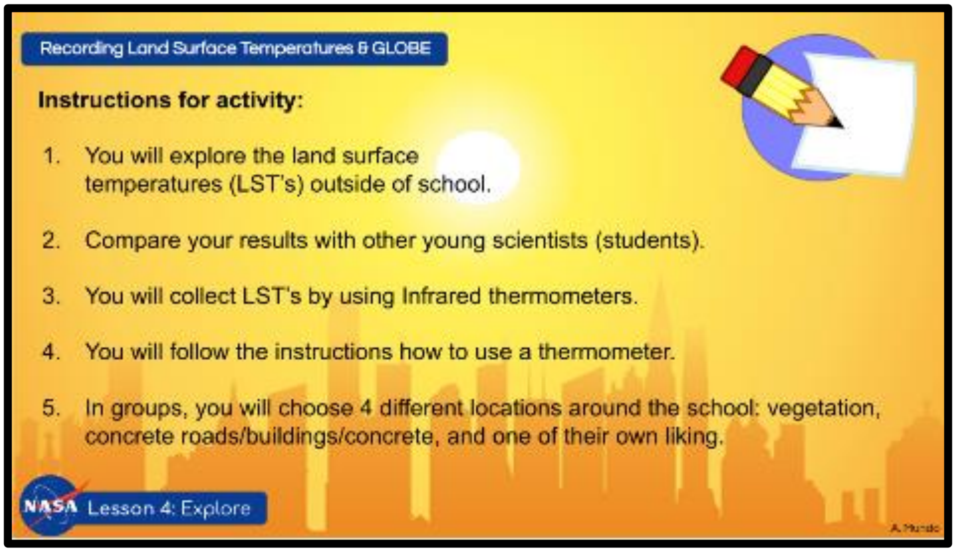
Lesson Presentation Slides:

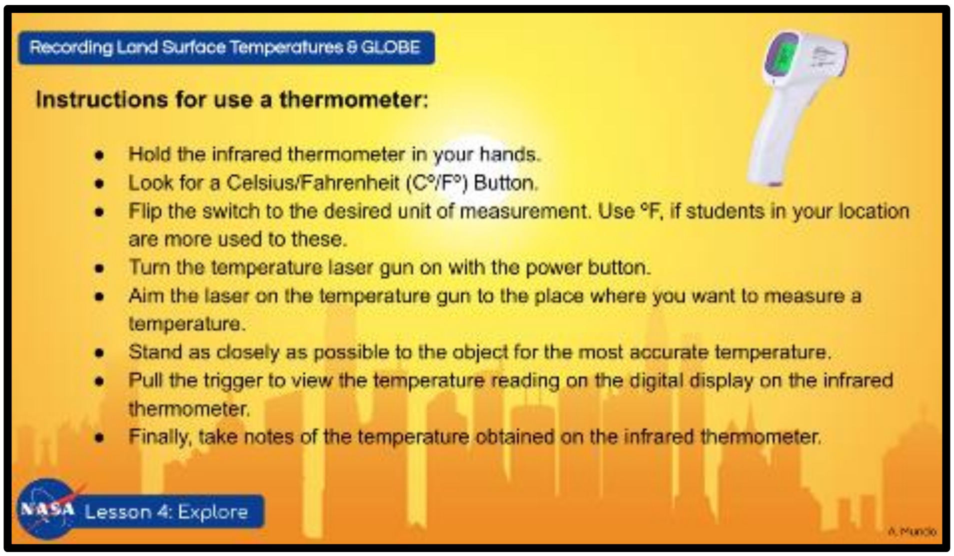
ENGAGE:

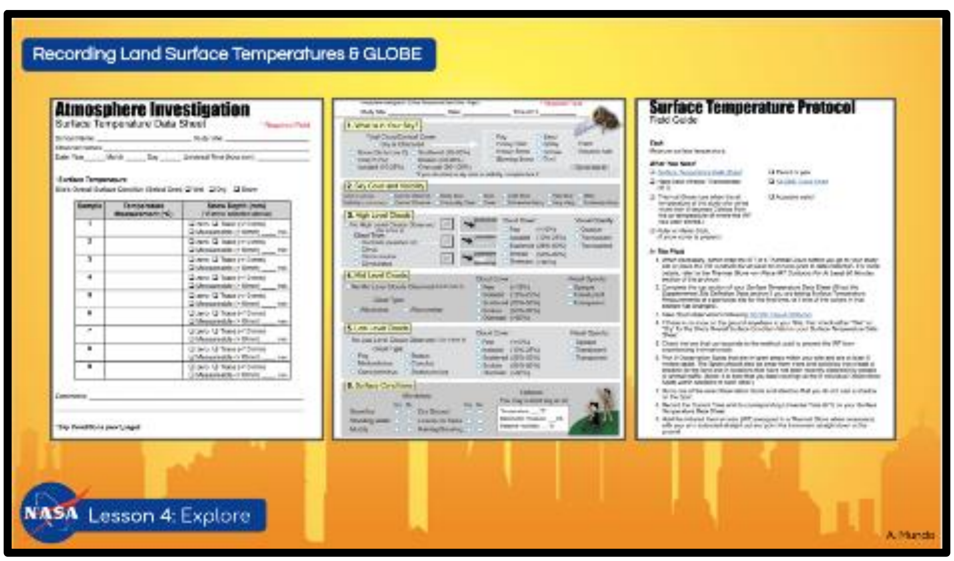




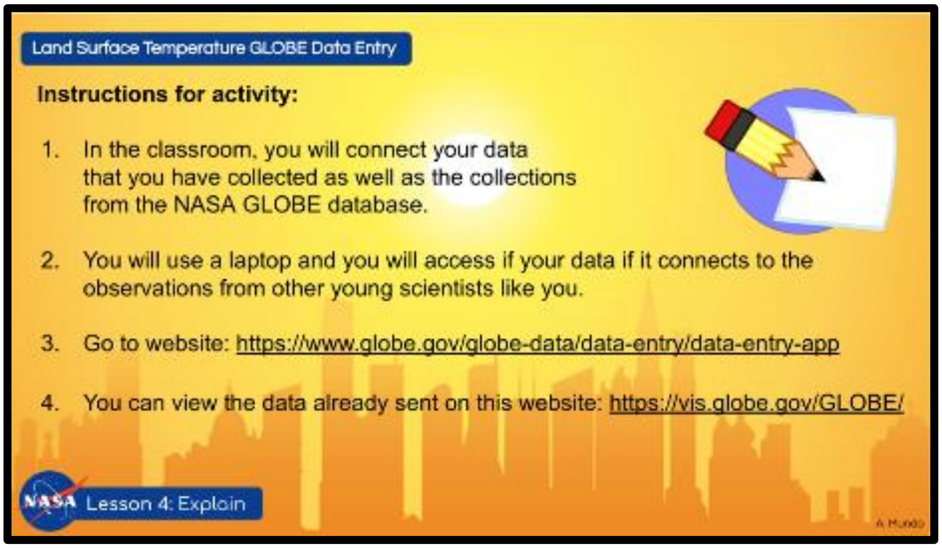
EXPLORE:


Recording Land Surface Temperatures & GLOBE
Instructions for activity:
1. You will explore the land surface temperatures (LST's) outside of school.
2. Compare your results with other young scientists (students).
3. You will collect LST's by using Infrared thermometers.
4. You will follow the instructions how to use a thermometer.
5. In groups, you will choose 4 different locations around the school: vegetation, concrete roads/buildings/concrete, and one of their own liking.
Lesson 4: Explore
A. Mundo

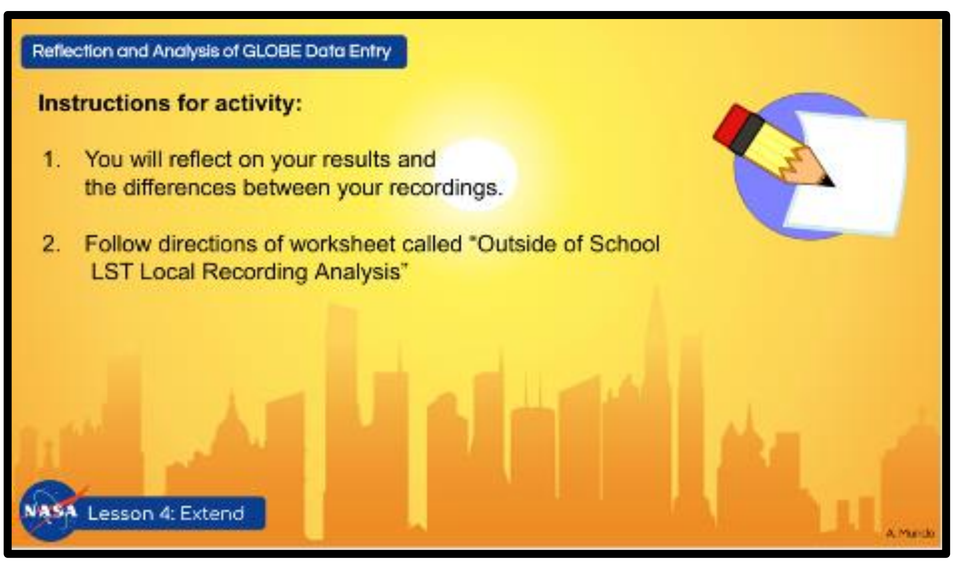

Recording Land Surface Temperatures & GLOBE
Instructions for use a thermometer:
• Hold the infrared thermometer in your hands.
• Look for a Celsius/Fahrenheit (C°/F°) Button.
• Flip the switch to the desired unit of measurement. Use °F, if students in your location are more used to these.
• Turn the temperature laser gun on with the power button.
• Aim the laser on the temperature gun to the place where you want to measure a temperature.
• Stand as closely as possible to the object for the most accurate temperature.
• Pull the trigger to view the temperature reading on the digital display on the infrared thermometer.
• Finally, take notes of the temperature obtained on the infrared thermometer.
Lesson 4: Explore
A. Mundo

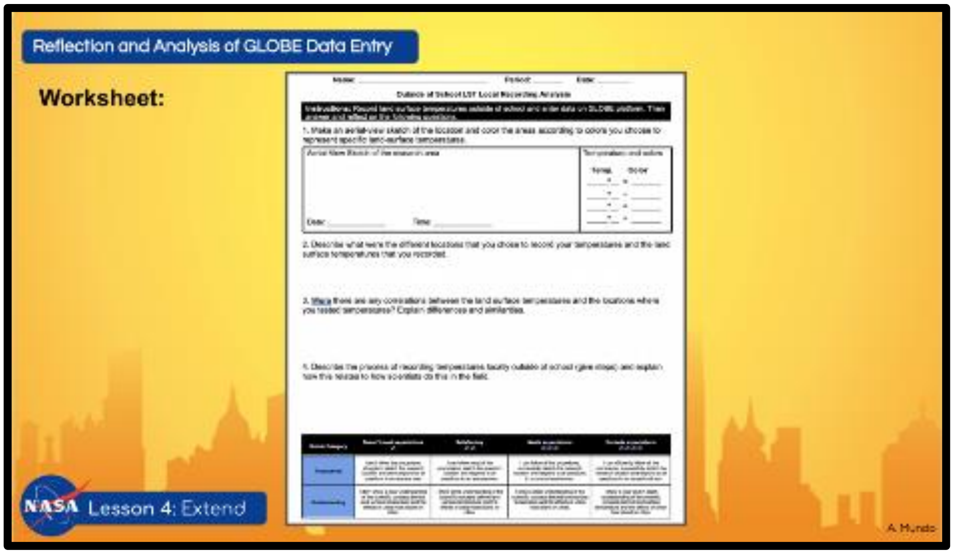

Recording Land Surface Temperatures & GLOBE
Atmosphere Investigation
Surface Temperature Data Sheet
Surface Temperature Protocol
Field Guide
Lesson 4: Explore
A. Mundo

EXPLAIN:

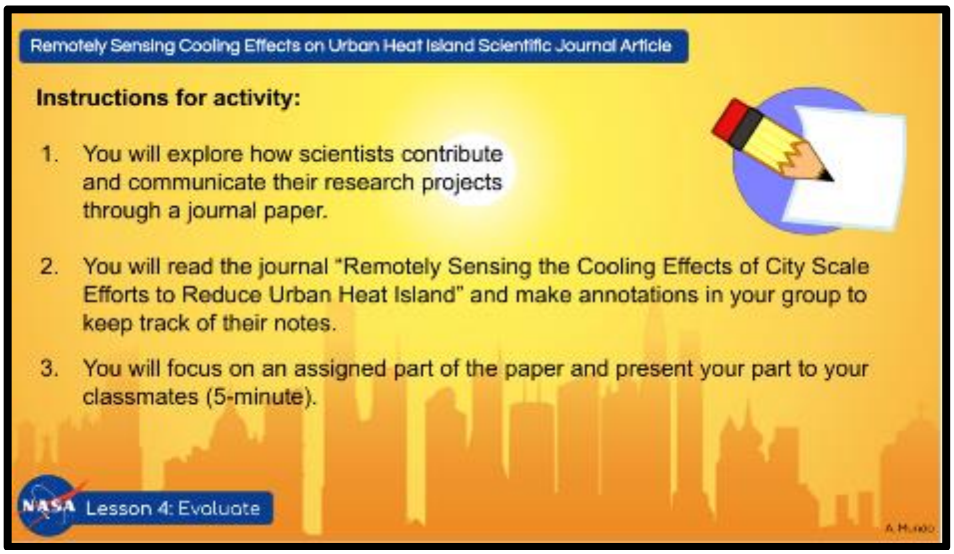


EXTEND:

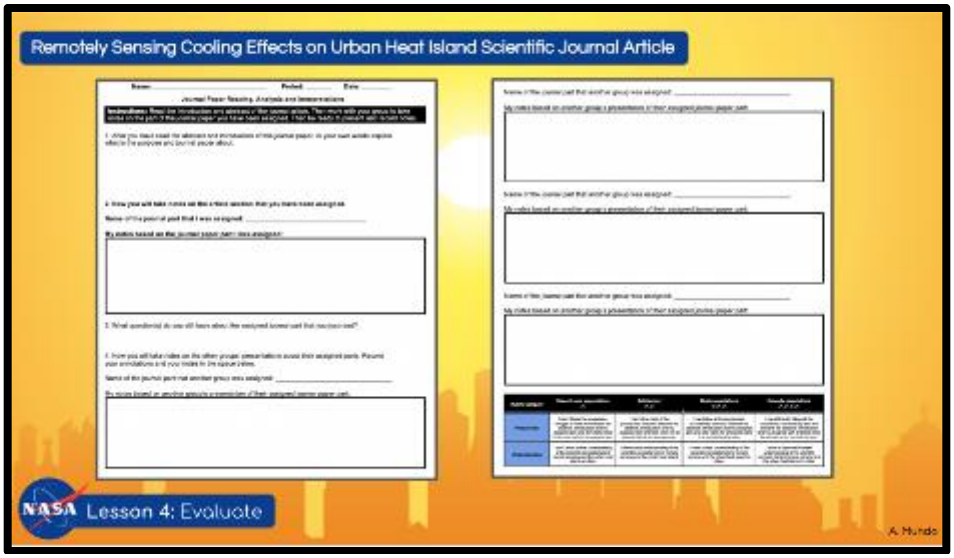



Reflection and Analysis of GLOBE Data Entry
Worksheet:
Lesson 4: Extend
A. Mundo

EVALUATE:


Remotely Sensing Cooling Effects on Urban Heat Island Scientific Journal Article
Instructions for activity:
1. You will explore how scientists contribute and communicate their research projects through a journal paper.
2. You will read the journal "Remotely Sensing the Cooling Effects of City Scale Efforts to Reduce Urban Heat Island" and make annotations in your group to keep track of their notes.
3. You will focus on an assigned part of the paper and present your part to your classmates (5-minute).
Lesson 4: Evaluate
A. Mundo


Remotely Sensing Cooling Effects on Urban Heat Island Scientific Journal Article
Journal Paper:
Lesson 4: Evaluate
A. Mundo



Differentiated instruction activities

This lesson includes instructional activities that promote differentiation in the following ways:

- Students learn new content in multiple ways including orally (through groups and class discussions), visually (through the use of videos and images), data analysis (through infographics and graphs) and reflection.
- Students use graphic organizers that help them process and organize their understanding of the new content.
- Lessons include graphic organizers with sentence starters that benefit English Language Learners and Special Education students to organize their ideas in better ways.
- Every lesson is adaptable to the personal learning plans of students.

11. Conclusion and linkage to next lesson:

This has been the fourth lesson of this climate unit plan which had a focus on land surface temperatures and its variations. During this fourth lesson, students had the opportunity to predict what was the land surface temperature outside of school, discuss what factors influence land surface temperature changes, explore the land surface temperatures outside of school, and use an infrared thermometer to record land surface temperatures. In addition, students collect temperature data and upload it to the GLOBE platform comparing their land surface temperature results with other young scientists. Furthermore, students analyze for any correlations between the land surface temperatures and the locations where they tested temperatures, describe the process of recording temperatures locally outside of school (give steps) and explain how this relates to how scientists do this in the field, review a scientific journal paper that focuses on the land surface temperatures and Urban Heat Island effects. The completion of all worksheets, tasks and activities with a high rubric grade demonstrates assessment quantification of student's learning. In the next lesson, students will focus on a capstone project that will serve as a culminating task where students will demonstrate their understandings and knowledge from this unit plan.

National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

NASA Climate Change Research Initiative
Applied Research STEM Curriculum Portfolio

CCRI Unit Plan Template

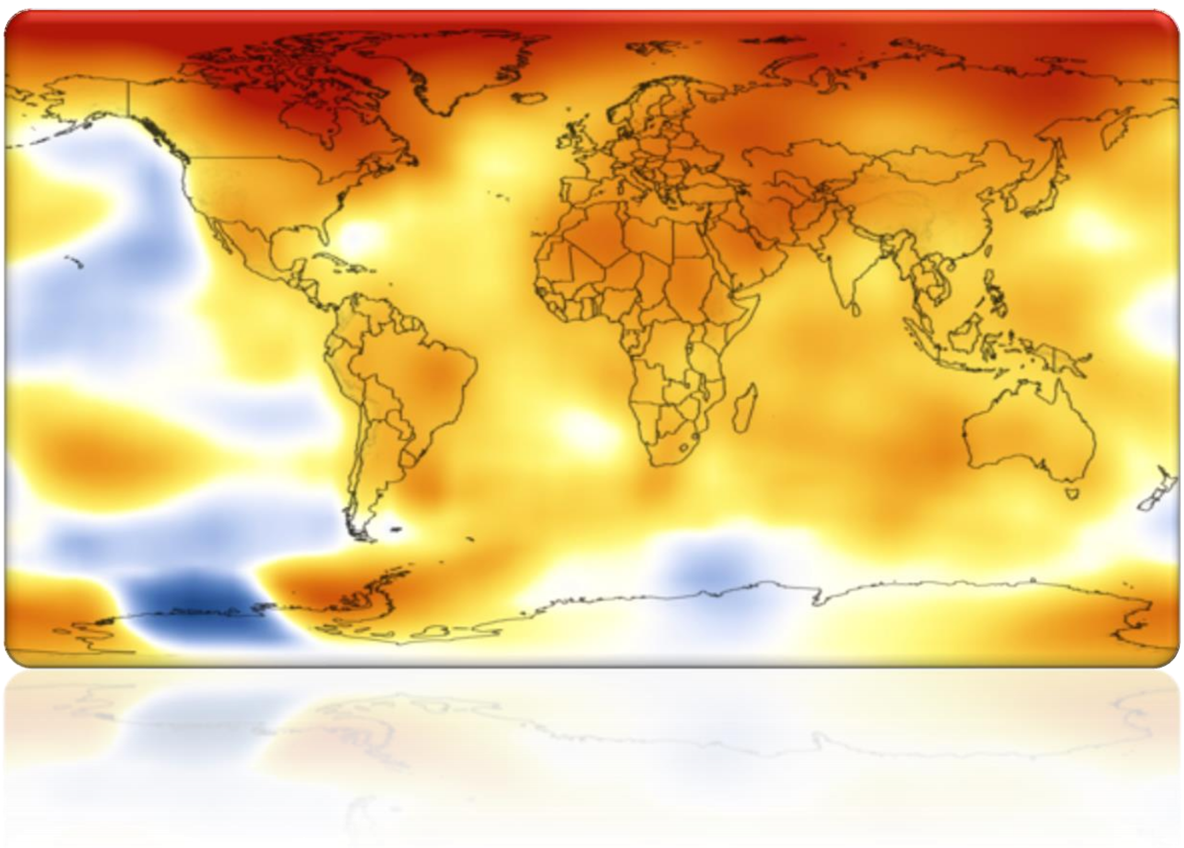
NASA Science Mission Directorate | Earth Sciences Division
NASA Goddard Institute for Space Studies
NASA Goddard Space Flight Center | Office of STEM Engagement

Unit Title: Land Surface Temperature in Urban Settings and the Heat Island Effect

Capstone Project Title: Urban Heat Island Physical City Model

NASA STEM Educator / Associate Researcher: Alejandro A. Mundo

NASA PI / Mentor: Dr. Christian Braneon



I. **Capstone Project:** Urban Heat Island Physical City Model

Table of Contents for lesson

2. Summary and Goals of Lesson Summary and Goals of Lesson

This capstone project is titled “Urban Heat Island Physical City Model” and it serves as the culminating task of this climate unit which incorporates the 5E model template. It focuses on having students create a physical model of a city where they incorporate their knowledge of the Urban Heat Island, land surface temperature data and mitigation strategies.

The goals for this lesson include students to be able to:

- Read about the type of roofs used for mitigation aspects in urban settings.
- Determine the ways in which green roofs benefit cities more than white roofs.
- Create a physical model of a city that is based on knowledge and understanding of the Urban Heat Island effects and remote sensing.
- Write a paper of the physical city model to explain city development and mitigation factors.
- Use research tools like EarthExplorer and Google Earth Engine App to gather data about the chosen city.
- Create a science poster about their group’s capstone project.
- Present their science poster in a classroom symposium and participate in the science classroom community poster session.

The goals for this lesson will be met throughout the activities and assignments for each part of the lesson plan.

3. CCRI Lesson Plan Content Template

*Scroll down to see element

NGSS Standards & NYS Standards:	Common Core Standard:	NASA Science:
HS-ESS3-1 Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity. **HS-PS4-6** Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. **New York State Earth Science Standards (NYSES):** **2.1a** Earth systems have internal and external sources of energy, which create heat. **2.2c** A location's climate is influenced by latitude, proximity to large bodies of water, ocean currents, prevailing winds, vegetative cover, elevation, and mountain ranges. **Phenomenon:** Flow of Energy and Matter **Crosscutting concepts:** • Systems and System Models • Stability & Change • Patterns Cause and Effect	**ELA-LITERACY.RL.11-12.1**: • Cite strong and thorough textual evidence to support analysis of what the text says explicitly as well as inferences drawn from the text, including determining where the text leaves matters uncertain. **CCSS.ELA-LITERACY.RST.11-12.9** • Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible. **CCSS.ELA-LITERACY.RST.11-12.4** • Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics. **MATH.CONTENT.HSN.Q.A.3** • Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.	—Earth Science

Content Area and Grade Level	Name of Project-Based Activity or Theme:	Estimated Time Frame to Complete:
Content Area: Earth Science **Grade Level:** 11 & 12 grades	Students will create a physical model of an Urban Heat Island, connect it to a city of their choice, and create mitigation strategies	This is the first lesson of 5 parts of this unit plan. It is estimated to take 5 days, if taught on periods of about 55 minutes a day.

Overall Investigation Question(s):	How can we use a climate simulation graph, images of change and other evidence to analyze, explain and present how climate has changed over time?
Overall Project Description/Activity:	Identify how climate has been altered before and after an event in different parts of the world by observing and analyzing different satellite images.

Materials Needed to Complete Project	Stakeholders:	Hyperlinks Used:	Multimedia/Technology:	Classroom Equipment:
• Markers • Blank poster paper • Provided worksheets	–Students –Educator –Administrator	**GLOBE Visualization System:** **Link:** https://climate.nasa.gov/interactives/climate-time-machine/ **Earth Now** **Link:** https://climate.nasa.gov/interactives/climate-time-machine/ **Earth Explorer** **Link:** https://climate.nasa.gov/evidence/ **Google Earth Engine App** **Link:** https://climate.nasa.gov/images-of-change	• Laptops with internet connection • Laptops with PowerPoint • Smartboard	• Laptops • Printer • Smartboard

NASA System Engineering Behaviors	Category	Activities	Student Outcomes	Evaluation
Uses visuals to communicate complex interaction	Communications	Students will identify how climate has been altered before and after an event in different parts of the world by observing and analyzing different satellite images.	Work cooperatively with team members to discuss satellite images over time.	Climate change evidence
Communicates effectively through personal interaction	Communications	Students will work together in groups in order to define and discuss what is climate change.	Complete the definition of climate and climate change successfully with group members	Climate change
Builds Team Cohesion	Leadership	Students will work in harmony and assign tasks and responsibilities among peer in order to work for a common goal.	Present about the image of change and work on a climate definition.	Climate
Appreciates/Recognizes Others	Leadership	Students value each of their members in the group for their contribution and support their ideas.	Provide feedback on their classmates' posters that supports the community.	
Has a comprehensive view	Attitudes & Attributes	Students will interpret satellite images in order to see how they have changed over time and explain their views according to the before and after factors.	Discuss different views and opinions about the satellite images and their importance.	Climate
Seeks information and uses the art of questioning	Attitudes & Attributes	Students will use different types of resources (evidence) in order to analyze climate change evidence and explain why it's meaningful.	Use the provided resources to explain how climate has been affected by humans and other factors.	Climate change evidence
Validates facts, information and assumptions	Systems Thinking	Students will find climate change evidence and explain its significance.	Validate the evidence and put it together in order to explain it.	Climate change evidence
Keeps the focus on mission requirements	Systems Thinking	Students will work on the assigned work and task in order to complete it by the given time.	Pay attention and follow procedures to complete the task.	
Learns from success and failures	Technical Acumen	Teacher will give feedback to students based on their performance in the activities and students will use and reflect on that feedback.	Reflects and uses feedback to do better.	

	Attachments?	List Attached Documents:
List and attach all PowerPoint presentations and supportive documents for instructional activities	Yes	• Know and Wonder About Climate Change Worksheet • Time Machine Climate Simulation Worksheet • Scientific Explanation on Climate Change Worksheet • Images of Change Worksheet
	Attachments?	**List Attached Rubrics:**
List and attach all rubrics for activity and assessment evaluation	Yes	• Know and Wonder About Climate Change Worksheet Rubric • Time Machine Climate Simulation Worksheet Rubric • Scientific Explanation on Climate Change Worksheet Rubric • Images of Change Worksheet Rubric • Images of Change Poster Rubric For Students

4. Mission Alignment

This lesson is part of this climate unit plan and aligns with NASA's Landsat satellite mission, whose groundbreaking series of repetitive imaging of Earth's land at a spatial resolution show human interaction with the environment.

5. Time to implement lesson

This is the last lesson of 5 parts of this unit plan. It is estimated to take approximately two weeks, if taught on periods of about 55 minutes a day, although it depends on how much students are used to doing research in the classroom.

6. Materials required.

–Computers
–Worksheets and supporting documents which are provided at the end the lesson template.
–Poster Printer
–Office supplies

7. 5 E lesson model template:

What the Teacher does	What the Students do	Time

<u>ENGAGE</u>
 	
White vs. Greens Activity
 	
• Tell students that they will now learn about the use of white vs. green roofs in city buildings, like New York.
 	
• Remind students that when it comes to roofs in city buildings, there is a better option to help cities lower the surface temperatures and Urban Heat Island.
 	
• Give the article "Whites Versus Greens" to students. The teacher may choose to have students read on their own, in groups or as a class. Then facilitate a conversation that reflects on the following questions:
    ○ Determine the ways in which green roofs benefit cities more than white roofs.
    ○ Generate a new title for the article and explain your new title.
    ○ What is your opinion of green roofs? Would you be interested in building one?
	• Listen to the introduction of the activity.
	
	• Read and annotate the article.
	
	• Engage in group/class discussion where everyone gets to express their opinions based on what they have learned about green roofs.
		45 mins

○ How successful would it be if the government had guidelines and regulations for buildings? • Teacher may add further questions that relate to the article and promote critical thinking.		
EXPLORE **Urban Heat Island City Physical Model** • Tell students that they will now have the opportunity to explore ways to create a physical model of a real city at a smaller scale. The idea is for this to be an individual project, as it will demonstrate the skills and understanding of students in regards to climate and the Urban Heat Island effect. • Allow students to join in groups of 3 (or desired number) for this research group. Give instructions to the students for the capstone project: • You have to create a physical model of a major city on Earth, which reflects your knowledge and understanding of the Urban Heat Island Effect and remote sensing. Your model should have the following aspects: ○ Should have buildings ○ Should reflect the use of Urban Heat Island mitigation strategies, like green spaces, green roofs, etc. ○ Be 3-dimmensional ○ Should represent a real city environment, that includes buildings, houses, parks, etc. ○ You can use office supplies like cardboard, construction paper, color paper, colors, scissors, glue, markers, etc. ○ This model should be your own work and all materials put in the model should be built by you. ○ Once your physical model is finished, you have to take a picture from the top of the model, which represents the remote sensing method. This picture should indicate the areas of heat trap,	• Listen to the introduction of the activity. • Work on the capstone physical model of their urban city by using supplies and involving the Urban Heat Island mitigation strategies, like green spaces, green roofs, etc. • Work on their physical model following all the guidelines. • Follow safety procedures when building their city physical model.	150 mins

where red represents heat and blue represents vegetation. Include a before version (where heat would be trapped) and the after version (where heat is not trapped anymore) ◦ Remind students about safety. As you build your model, you might use supplies that can be sharp, like scissors or paper. Be careful as you are building your physical model so that you don't hurt yourself. If you need assistance, ask an adult for assistance. ◦ Remind students that this is a group project and it's very important to work together as a community of young scientists.	• Students work together with their groups to construct their physical city model.	
EXPLAIN **Urban Heat Island City Model Paper Report** • Tell students that they will now get to share more about their physical models by writing a complete paper of what they represent. In their explanation, students will be asked to explain the following: ◦ What is the regional location of the city? ◦ What is the population of your city? ◦ How has the population changed over time? ◦ Describe the internal migration within the city. ◦ What is the industry and production within the city based on? ◦ What is the climate of the city? ◦ What is the temperature variation during the year? ◦ How are the Urban Heat Island effects visible in this city? Provide examples. ◦ What type of partnerships and agreements are there within the government and private sectors of your city? ◦ What type of mitigations have been implemented recently in your city? ◦ How have the mitigation factors affected the city development over time?	• Listen to the introduction of the activity. • Construct a physical model of a city that resembles the Urban Heat Island effect.	120 mins

◦ Students are expected to use the research tools we have used in the last two lessons in order to gather data from different locations such as: ▪ EarthExplorer ▪ Google Earth Engine • Remind students that they should follow the guidelines for the paper and answer all these questions in a narrative version.		
<u>EXTEND</u> **Urban Heat Island Model Poster** • Tell students that they will now extend their capstone project paper by creating a digital science poster, where they will include the aspects of their city model Tell students that the guidelines for their poster include: • A title • Author names and affiliations (their group roles in the project) • An introduction • Methods (use of research tools) • Results • Conclusions • Acknowledgements sections • A sample of a research poster is included in the additional documents. • The digital poster can be created with the program Microsoft Office Power Point. When completed, allow these posters to be printed on a poster printer. • Remind students that every member of the group should be involved in the development of the poster.	• Listen to the introduction of the activity. • Create a poster from their capstone project by following the guidelines provided. • Work together with their groups, where the work is divided and every member works on a different part of the research poster.	5 hours
<u>EVALUATE</u> **Urban Heat Island City Model Symposium** • Tell students that they will now work on evaluating their peers' posters by having a small classroom science symposium.		

• Plan this science classroom poster session so that groups can share with their classmates about their capstone projects as Urban Heat Island physical city models and their research. • In order for everyone to be involved, it's recommended that half of the classroom groups present with their posters around the classroom while the other students become their audience, then they will switch so that whoever was presenting, now is the audience. • Encourage students to ask questions to their class groups about projects. As students are presenting their posters, circulate around the room and facilitate questions with the groups. • It's recommended that you invite other teachers, staff and/or parents to this session, as it will present students' capstone projects. • Tell students that scientists also involve in presenting their research through posters and it's a good way for them to know about new research that others are doing in science. • This capstone project serves as a conclusion of this climate unit with a focus on the Urban Heat Island Effect and land surface temperatures in urban settings.	• Listen to the introduction of the activity. • Present their capstone projects in the classroom as a symposium activity, where their classmates provide feedback and ask questions as well.	90 m

8. <u>Next Generation of Science Standards (NGSS)</u>:

HS-ESS2-4	Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.
HS-ESS2-2.	Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.
DCI ESS2.A	Earth Materials and Systems
ESS2.D:	Weather and Climate
CC	Energy and matter: Energy drives the cycling of matter within and between systems. (HS-ESS2-3) Stability and Change

New York State Earth Science Standards (NYSES):

NYSES 2.1a Earth systems have internal and external sources of energy, both of which create heat.

NYSES 2.2c A location's climate is influenced by latitude, proximity to large bodies of water, ocean currents, prevailing winds, vegetative cover, elevation, and mountain ranges.

Common Core Standards:

MATH.CONTENT.HSN.Q.A.3
Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.

ELA-LITERACY.W.9-10.9
Draw evidence from literary or informational texts to support analysis, reflection, and research.

1. NASA System Engineering Behavior Model utilized in lesson

- **Leadership**
  - Builds Team Cohesion
  - Appreciates/Recognizes Others
- **Communication**
  - Listens Effectively and Translates Information
  - Communicates Effectively Through Personal Interaction
- **Problem Solving & Systems Thinking**
  - Assimilates, Analyzes, and Synthesizes Data
  - Validates Facts, Information and Assumptions
  - Has the Ability to Find Connections and Patterns Across the System

2. Supporting Documents:

*Scroll down to see component

Name: ______________________________ **Period:** _______ **Date:** ________

White vs. Greens Article

You will now read the following text to learn more about white and green roofs, its benefits and its effects on urban environments. As you read, make sure to annotate the text by using the following symbols:

***** = important | __ = keyword | **?** = I don't understand | ⬭ = unfamiliar word | **!** = I'm surprised | ∞ = made a connection

Anyone who has ever planned to spend hours outside on a hot, sunny day has probably heard the advice to wear light colors. Pale colors reflect much of the Sun's light, keeping their wearers cool. The same is true for buildings. Gaffin and his colleagues presented the results of their 2002 New York City heat wave study at a science meeting in January 2006, and at that time, he considered white roofs the winning strategy. By April 2006, however, he had changed his mind.

The study in New York confirmed that white roofs—generally made with the use of a thin, light coating—absorb much less of the Sun's energy than asphalt roofs, and they are fairly inexpensive and easy to install. But even though white surfaces may be cooler than dark surfaces, they still trap heat. "Just go around your neighborhood. I think you'll find that lighter urban surfaces are still pretty hot in the summer, compared to plants," Gaffin says. What's worse, "in urban settings, white roofs get dirty quickly," reducing their ability to reflect sunlight. Even when they're kept clean, white roofs cause problems, he explains. In reflecting the sunlight, they may just bounce much of it off nearby buildings, heating up the immediate area. "You haven't really gotten the light out of the city," he says. And in the wintertime, light roofs may cool buildings unnecessarily, increasing heating demands.

Light-colored roofs held another drawback for Gaffin. As he researched mitigation options for the Urban Heat Island, he became aware of another issue that causes some cities as much hardship: stormwater runoff. "The purpose of asphalt is to create an impervious surface," he explains, to keep out water. Unfortunately, the water that can't be absorbed by roofs and roads has to go somewhere else.

To deal with runoff from heavy rains, cities have storm sewers, but many cities use the same systems to handle both the overflow from rainstorms and the water flushed out of toilets. Heavy rains can overwhelm these systems (called combined sewer overflows), pushing raw sewage into waterways. "It's the major source of pathogens in the New York Harbor. It's a major problem in Europe. This is one of the impediments to ever reclaiming the recreational and other values of our urban water systems," he says. He has coined a term for this problem, as a parallel to the Urban Heat Island. He calls it "the urban runoff island." Light-colored roofs might absorb less of the Sun's energy than dark roofs, he says, but they do nothing to mitigate runoff.

"I'm no fan of white roofs anymore," Gaffin concludes. "I started this line of research thinking they should be promoted. I finished this research thinking they are a secondary option."

Figure 1: Green roof can range in complexity from a shallow layer of soil and plants to gardens with trees and shrubs.

Gaffin would rather promote a solution that addresses both urban heat and urban runoff. If cities don't have much room for lots of additional trees, and if light-colored roofs only partially reduce urban heat and in no way reduce runoff, just one option remains: vegetation-covered roofs.

While Gaffin and his colleagues undertook the 2002 New York City study, experiments were already underway at Pennsylvania State University to assess the cooling capabilities of roofs covered with vegetation. In 2003, Gaffin worked with Penn State researchers to compare the temperatures of roofs planted with Sedum spurium to standard dark roofs.

Figure 2: Sedum spurium is a drought-adapted plant often used for low-maintenance green roofs.

"Sedum is a desert-adapted plant with shallow root systems. The plants can tolerate long periods of drought. They're lush green, beautiful to look at, quite pleasant to touch," he says. In the arid American Southwest, this cactus-family succulent is a popular landscaping choice for those looking to minimize water use in lawns.

During their rooftop garden project, Gaffin and the Penn State team found that the peak temperatures on the roofs planted with Sedum were 30 degrees Celsius (54 degrees Fahrenheit) lower than the temperatures on standard roofs. They also found that the low-maintenance Sedum plants thrived without any supplemental watering.

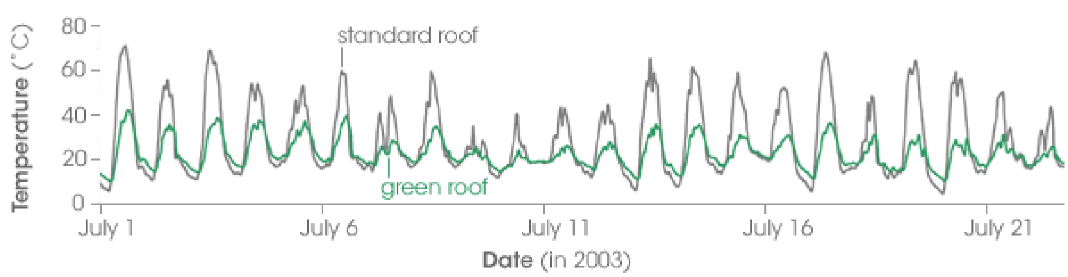
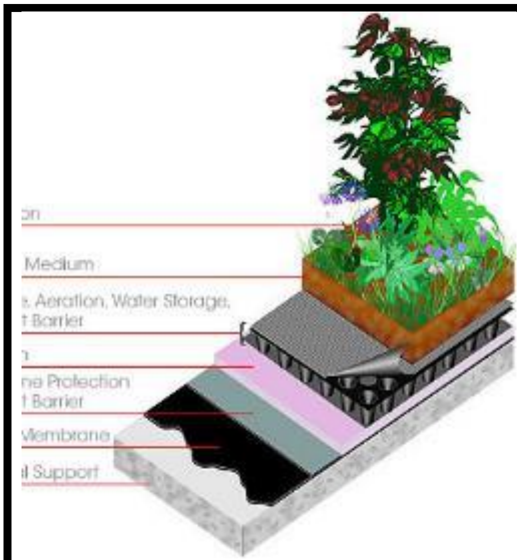


Figure 3: In a 2003 study, Gaffin and his collaborators measured the temperatures on both green and dark roofs. Both kinds of roofs warmed during the day and cooled overnight. While dark roofs cooled slightly more overnight, however, they warmed up much more during the day than their green counterparts

Despite Gaffin's confidence in green roofs, he knows their implementation could be complicated. "A lot of people think green roofs are going to cause problems, that they're going to leak or fall apart," he says, "but it's just the opposite. They actually leak less. There are [green] roofs in Europe that last 30, 40, 50 years, or more." Longevity, however, comes at a price. "We spend a lot of time on the economics of green roofs. They're expensive, and we're trying to see how to bring the costs down. Part of the problem is that we don't have a mature industry here in the United States. It's still a somewhat specialized construction procedure."

Vegetation-covered roofs typically include the following layers: a waterproof membrane at the bottom, a layer of drainage materials, a root-repellant and filter layer, a lightweight soil-like growing medium, and finally the plants. Compared to standard roofs, green roofs do have more mass, but thin systems of only 3 to 4 inches (7.5 to 10 centimeters) are sufficient. When they are saturated with rainwater, they may create a load of 1,197 pascals (about 25 pounds per square foot), which is often feasible for many city buildings. By



evaporating moisture, the plants release heat without raising local temperatures. Likewise, the plants and soil soak up rainfall like a sponge instead of letting it roll right off the surface.

If green roofs do provide a sound solution to urban heat and runoff islands, they may need to be implemented differently in different places. The experiments in Pennsylvania showed that Sedum could thrive without irrigation, but Pennsylvania is more humid and rainy than other parts of the world. Places like sub-Saharan Africa and northwestern China are vulnerable to severe, prolonged droughts. Even gardeners in the American Southwest run into difficulties.

So in the driest climates, the ideal green roof might require an irrigation system, and overcoming the expense of implementing green roofs may slow their adoption. But as temperatures rise, the green roofs' potential to cool cities remains attractive.

Recent heat wave tolls show the gravity of warming temperatures. The Chicago heat wave of 1995 claimed more than 700 lives. The record-warm European summer of 2003 claimed between 22,000 and 45,000 lives. "Can we air condition our way out of these heat waves? Not always," Gaffin says. "So how can we cool these cities down? There aren't many strategies we can choose. But green roofing looks like a great way to alleviate these problems."

Analysis Question

1. Are green roofs more efficient than black roofs? Describe its pros and cons on both types. Then explain your reasoning and provide evidence from the research cited in this article.

*Use the back of this paper for additional space, if needed.

Rubric Category	Doesn't meet expectations	Satisfactory	Meets expectations	Exceeds expectations
Productivity	I don't follow the procedures, struggle to annotate all parts of the reading and don't respond to all questions in an average way.	I can follow most of the procedures, annotate all parts of the reading and respond to all questions in an average way.	I can follow all the procedures, successfully annotate all parts of the reading and respond to all questions in a comprehensive way.	I can efficiently follow all the procedures, successfully annotate all parts of the reading and respond to all questions in an exceptional way.
Understanding	I don't show a clear understanding of the scientific concepts behind energy, green roofs and the effects of Urban Heat Island on cities.	I show some understanding of the scientific concepts behind energy, green roofs and the effects of Urban Heat Island on cities.	I show a clear understanding of the scientific concepts behind energy, green roofs and the effects of Urban Heat Island on cities.	I show a clear and in-depth understanding of the scientific concepts behind energy, green roofs and the effects of Urban Heat Island on cities.

National Aeronautics and Space Administration
Goddard Institute for Space Studies
New York, N.Y.

Name: ______________________________ **Period:** _______ **Date:** ________

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National Aeronautics and Space Administration
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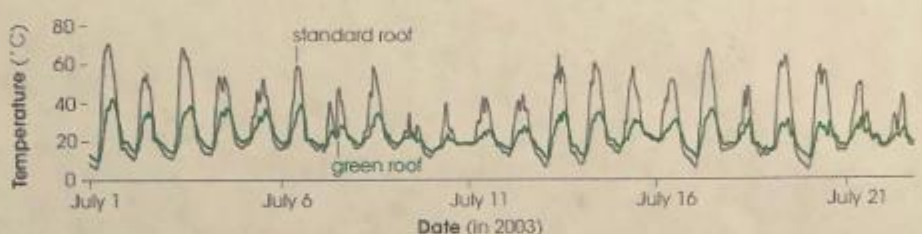

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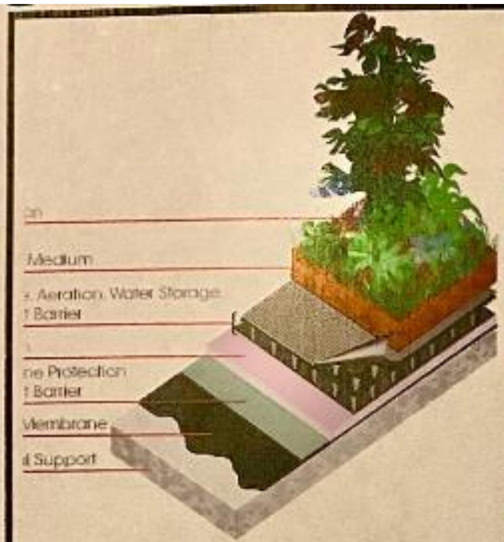

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Analysis Question

1. Are green roofs more efficient than black roofs? Describe its pros and cons on both types. Then explain your reasoning and provide evidence from the research cited in this article.

Yes, the green roofs are more efficient than black roofs because they help temperatures drop.

Pros		Cons	
Black roofs	Green roofs	Black roofs	Green roofs
- Warmer overnight	- Lower urban heat - Absorbs less sun's energy	- Absorbs most of sun's energy	- Could be complicated - they're going to lea[k] - Fall apart - Expensive

-We can use green roofs to lower the Urban heat on the cities and look for more strategies to cover the roofs with plants that absorb the heat but not needed to much water. It's very important to lower the temperatures in the big cities or places with droughts because a lot of people die every year due to an increase of temperatures, lack of vegetation in cities and poor urban planning.

Class Discussion Prompts after Reading of White vs. Green Roofs Article

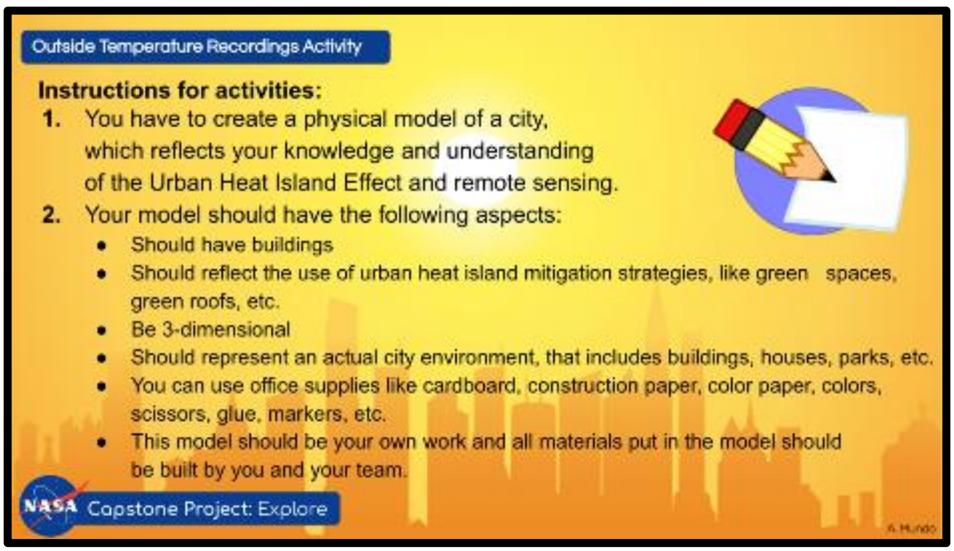
- Determine the ways in which green roofs benefit cities more than white roofs.
- Generate a new title for the article and explain your new title and why you would name it like that.
- What is your opinion of green roofs? Would you be interested in building one? Why?
- How successful would it be if the government had guidelines and regulations for buildings and houses in regards to the Urban Heat Island effect?
- If you had the opportunity to create a school movement so that our school had a green roof, how would it look like? What factors would you consider when putting a plan for creating a green roof?

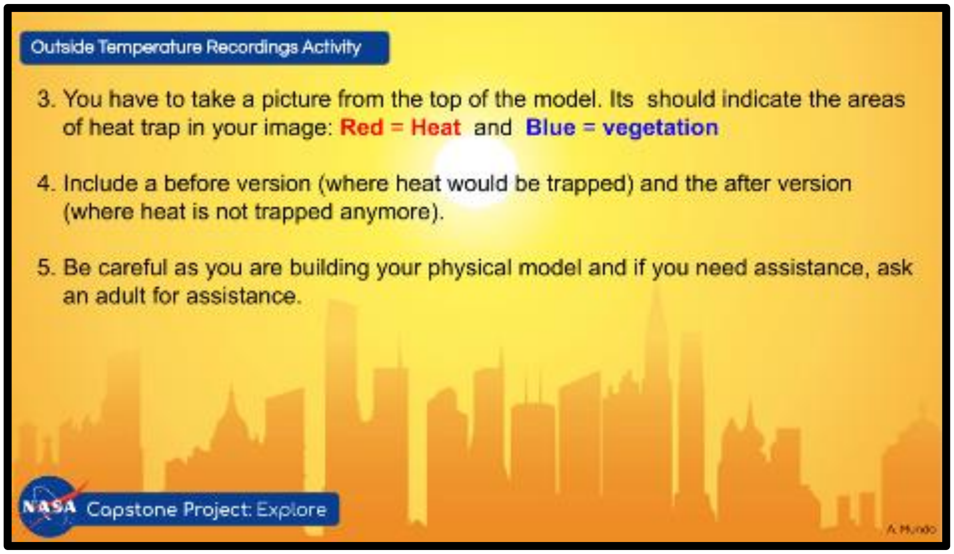
Sample capstone project physical model:

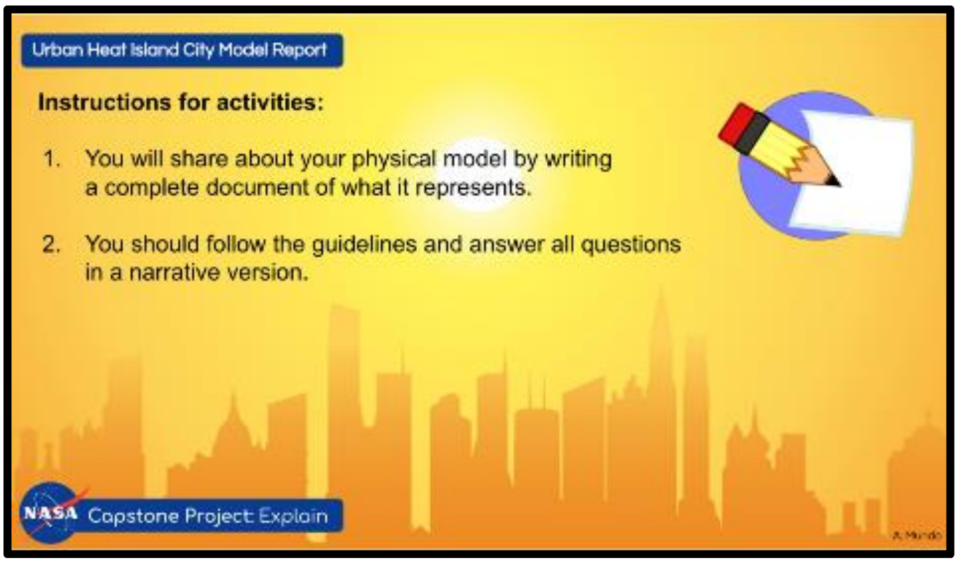
Capstone Project Presentation and Paper Rubric

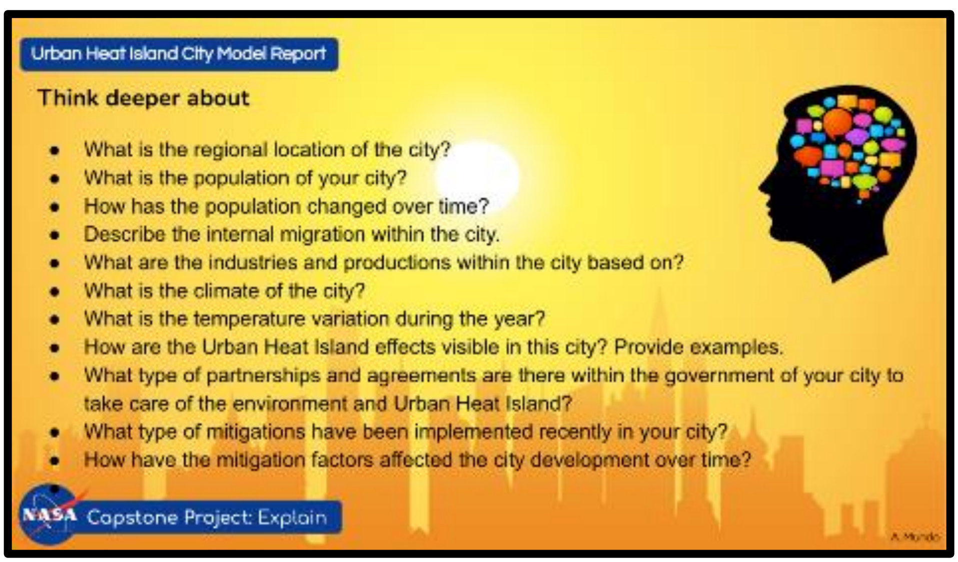
Rubric Category	Doesn't meet expectations	Satisfactory	Meets expectations	Exceeds expectations
Presentation and paper	The grammar, mechanics, and spelling mistakes are so prevalent it is nearly impossible to understand the paper. (0 points) There is no cover page whatsoever. (0 points) The paper is missing 3 or more sections (1-2 points)	The grammar, mechanics, and spelling issues make the report hard to read. (1 point) The cover is unattractive and very basic (1 points) The paper is missing 2 sections. (3 points)	The grammar, mechanics, and spelling are adequate, and only 1-2 errors exist (2 points) The cover somewhat attractive and grabs the readers' attention. Missing some aspect. (1 points) The paper is missing 1 section. (4 points)	The grammar, mechanics, and spelling are essentially perfect, and need no corrections. (3 points) The cover is attractive and grabs the readers' attention (2 points) The paper contains all necessary sections. (5 points)
Purpose	The student poses no question whatsoever, or has a free flowing, but unfocused introduction. (3-4 points)	The student asks a question which is either untestable, or not ultimately what they test. (5-6 points)	The student asks a rather basic testable question. Their question matches what is actually tested. (8 points)	The student asks a relevant, testable question, which matches up to what is actually tested. (10 points)
Background Research	Background research makes little to no sense, and maybe missing formatting. (4-5 points)	Background research is mostly coherent, but has no formatting (6-7 points)	Background research is mostly coherent, but has no formatting (8-9 points)	Background research is coherent, properly formatted (using #'s) and adds to presentation. (10 points)
Data collection	Data is not reported, does not make sense, or is unclear. (3 points) Some sections are missing. Very limited information is given, hard to understand how the data proves anything, no mention of source of error. (5-9 points)	Data was only collected one time. It was summarized in a clear way. (4 points) Some sections are missing. Results section has visual, but discussion section is missing any mention of source of error. (10-12 points)	Data was collected several times. It was summarized in an unclear way. (4 points) Some sections are present. Results section is missing any type of visual; discussion mentions potential source of error. (13-14 points)	Data was collected several times. It was summarized in a clear way. (5 points) All sections are present. Results has data, graphs, pictures or some type of visual, and discussion mentions potential source of error. (15 points)
Conclusion	Student did not address the questions below, or wrote a conclusion that doesn't match their hypothesis. (4 points)	Student wrote a logical conclusion answering only one of the questions below. (6 points)	Student wrote a logical conclusion answering two of the three questions below. (8 points)	Student wrote a logical conclusion answering the three questions below. (10 points)

Lesson Presentation Slides:



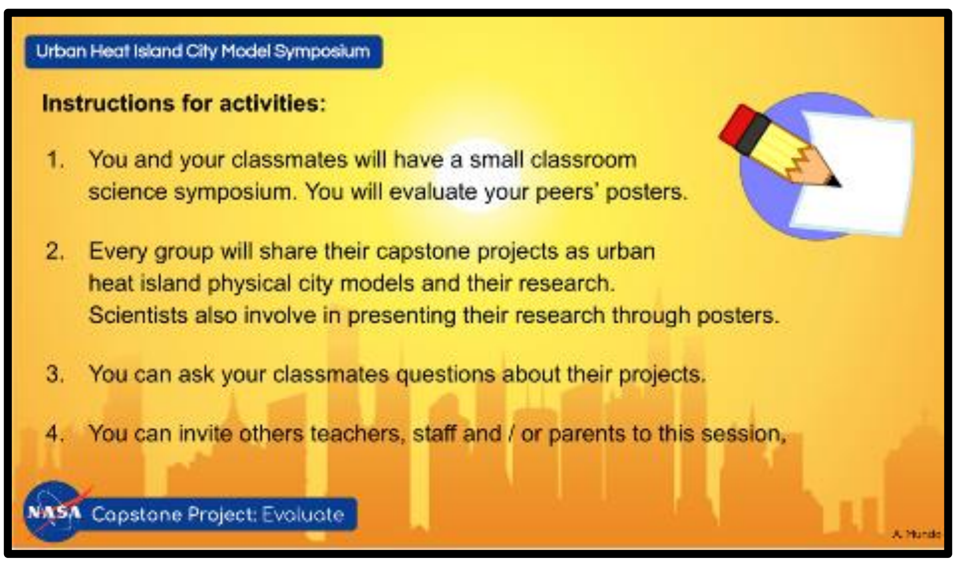

Outside Temperature Recordings Activity
3. You have to take a picture from the top of the model. Its should indicate the areas of heat trap in your image: Red = Heat and Blue = vegetation
4. Include a before version (where heat would be trapped) and the after version (where heat is not trapped anymore).
5. Be careful as you are building your physical model and if you need assistance, ask an adult for assistance.
Capstone Project: Explore


Urban Heat Island City Model Report
Instructions for activities:
1. You will share about your physical model by writing a complete document of what it represents.
2. You should follow the guidelines and answer all questions in a narrative version.
Capstone Project: Explain


Urban Heat Island City Model Report
Think deeper about
What is the regional location of the city?
What is the population of your city?
How has the population changed over time?
Describe the internal migration within the city.
What are the industries and productions within the city based on?
What is the climate of the city?
What is the temperature variation during the year?
How are the Urban Heat Island effects visible in this city? Provide examples.
What type of partnerships and agreements are there within the government of your city to take care of the environment and Urban Heat Island?
What type of mitigations have been implemented recently in your city?
How have the mitigation factors affected the city development over time?
Capstone Project: Explain


Urban Heat Island Model Poster
Instructions for activities:
1. You will create a digital science poster, where you will include the aspects of your city model.
2. The digital poster can be created with the program Microsoft PowerPoint. Also, you can print your poster.
3. Every member of the group should be involved in the development of the poster.
NASA Capstone Project: Extend
A. Mundo


Urban Heat Island Model Poster
Guidelines for your poster:
• A title
• Author names and affiliations (their group roles in the project)
• An introduction
• Methods (use of research tools)
• Results
• Conclusions
• Acknowledgements sections
NASA Capstone Project: Extend
A. Mundo


Urban Heat Island City Model Symposium
Instructions for activities:
1. You and your classmates will have a small classroom science symposium. You will evaluate your peers' posters.
2. Every group will share their capstone projects as urban heat island physical city models and their research. Scientists also involve in presenting their research through posters.
3. You can ask your classmates questions about their projects.
4. You can invite others teachers, staff and / or parents to this session.
NASA Capstone Project: Evaluate
A. Mundo

Differentiated instruction activities

This lesson includes instructional activities that promote differentiation in the following ways:

- Students learn new content in multiple ways including orally (through groups and class discussions), visually (through the use of videos and images), data analysis (through infographics and graphs) and reflection.
- Students use graphic organizers that help them process and organize their understanding of the new content.
- Lessons include graphic organizers with sentence starters that benefit English Language Learners and Special Education students to organize their ideas in better ways.
- Every lesson is adaptable to the personal learning plans of students.

11. Conclusion and linkage to next lesson:

This has been the fifth and final lesson of this climate unit plan which had a focus on land surface temperatures and its variations. During this fifth lesson, students had the opportunity to learn about the type of roofs used for mitigation aspects in urban settings and determine the ways in which green roofs benefit cities more than white roofs. In addition, students create a physical model of a city that is based on knowledge and understanding of the Urban Heat Island Effects and remote sensing as well as write a paper of the physical city model to explain city development and mitigation factors. Furthermore, students research tools like EarthExplorer and Google Earth Engine App to gather data about the chosen city and create a science poster about their group’s capstone project. The completion of all worksheets, tasks and activities with a high rubric grade demonstrates assessment quantification of student’s learning,

Glossary:

Albedo: The proportion of the incident light or radiation that is reflected by a surface, typically that of a planet or moon.

Artemis: Is a lunar exploration program that we will use innovative new technologies and systems to explore more of the Moon than ever before.

ASTER: Advanced Spaceborne Thermal Emission and Reflection Radiometer. ASTER is a TERRA's instrument used to create detailed maps of Earth's temperature, emissivity, reflectance, and elevation.

Blackbody Object: Blackbody is a surface that absorbs all radiant energy falling on it.

CERES: The Clouds and the Earth's Radiant Energy System. CERES is an TERRA's instrument that gets information about the Earth's radiation balance.

Climate Change: Refers to any significant change in the measures of climate lasting for an extended period of time. It includes major changes in temperature, precipitation, or wind patterns, among other effects, that occur over several decades or longer.

Climate Variability: Variability is the range of climate compared to its average. The fluctuations comprising climate variability can influence patterns of rainfall, temperature and other variables on timescales anywhere from a few weeks to a few decades.

Common Core: A set of educational standards for teaching and testing English and mathematics between kindergarten and 12th grade.

EarthExplorer: The USGS EarthExplorer (EE) tool provides users the ability to query, search, and order satellite images, aerial photographs, and cartographic products from several sources.

EarthNow: Explores a real-time data visualization of NASA's Earth-orbiting satellites and the data they collect about climate change.

Electromagnetic Spectrum: The electromagnetic spectrum is the range of frequencies of electromagnetic radiation and their respective wavelengths and photon energies.

Emissivity: The relative power of a surface to emit heat by radiation: the ratio of the radiant energy emitted by a surface to that emitted by a blackbody at the same temperature.

GISS: Goddard Institute for Space Studies research at the NASA emphasizes a broad study of global change, which is an interdisciplinary initiative addressing natural and man-made changes in our environment that occur on various time scales

GLOBE: Global Learning and Observations to Benefit the Environment is an international science and education program that provides students and the public worldwide with the opportunity to participate in data collection and the scientific process, and contribute meaningfully to our understanding of the Earth system and global environment.

Google Earth Engine: is a service that runs in the Google Cloud and combines a multi-petabyte catalog of satellite imagery and geospatial datasets with planetary-scale analysis capabilities and makes it available for scientists, researchers, and developers to detect changes, map trends, and quantify differences on the Earth's surface

Green roofs: A green roof is a layer of vegetation planted over a waterproofing system that is installed on top of a flat or slightly–sloped roof.

Image analysis: Image analysis is the process of taking information through images using digital processing techniques.

James Webb Space Telescope: James Webb Space Telescope will be the largest infrared telescope with a 6.5-meter primary mirror and it will study every phase in the history of our Universe.

Juno: is a NASA spacecraft. It is exploring the planet Jupiter. Juno launched from Earth in 2011. It reached Jupiter in 2016. That was a five-year trip!

Landsat: A series of satellites equipped with sensors that observe and capture information using images of the Earth’s surface and coastal regions.

Land Surface Temperature: The temperature at the ground. It is calculated by analyzing the radiation of thermal energy. It is measured through remote sensing or sensors to determine how hot the Earth’s surface is at a particular location.

MISR: The Multi-angle Imaging SpectroRadiometer. MISR is a new type of instrument of TERRA designed to see Earth with cameras pointed at nine different angles and it can distinguish different types of clouds, aerosol particles, and surfaces.

Mitigation: The use of actions to limit the rate of climate change and its effects including the reduction of human emissions of greenhouse gases.

MODIS: Moderate Resolution Imaging Spectroradiometer. TERRA’s instrument has a sensor that observes where and when disasters strike—such as volcanic eruptions, floods, severe storms, droughts, and wildfires.

MOPITT: Measurements of Pollution In The Troposphere. It is an instrument of TERRA designed to enhance our knowledge of the lower atmosphere and to observe how it interacts with the land and ocean biosphere.

NASA: The National Aeronautics and Space Administration is an independent agency of the United States Federal Government responsible for the civilian space program, as well as aeronautics and space research.

NGSS: Next Generation Science Standards are K–12 science content standards. The NGSS were developed by states to improve science education for all students.

Perseverance Rover: mission is on its way to the Red Planet to search for signs of ancient life and collect samples to send back to Earth.

Remote Sensing: The process of acquiring information on the physical characteristics of an object or emitted by means of its reflected radiation without making contact with it. For example, the land surface temperature. It can be measured through a satellite or an aircraft.

Solar radiation: Is radiant energy emitted by the sun from a nuclear fusion reaction that creates electromagnetic energy.

Sustainability: The quality of not being harmful to the environment or depleting natural resources, and thereby supporting long-term ecological balance.

TERRA: Is the flagship of NASA's Earth Observing System. The satellite's five instruments concurrently observe Earth atmosphere, ocean, land, snow and ice providing insights into Earth systems such as the water, carbon and energy cycles. Terra's instruments are: ASTER, MOPITT, MISR, CERES and MODIS.

Urban Heat Island: A phenomenon that occurs in cities that record a higher temperature than their surroundings. It can be caused by changes in the land surface by urban development along with waste heat generated by energy use. As population centers grow, they tend to change greater areas of land which then undergo a corresponding increase in average temperature.

USGS: The United States Geological Survey. The USGS is a bureau of the United States Department of the Interior.

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