Endeavor
STEM Teaching Certificate Project

What have been the contributions of mathematicians, coders, and NASA scientists to help reduce the destruction of wildfires? What can NASA data tell us about interrelated environmental hazards related to wildfires?

Grade/Subject: Multivariable Calculus

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BIG IDEAS

Name the conceptual ideas in STEM that you address in the lesson.

EDUCATION STANDARDS

NGSS Performance Expectation(s)

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts:
HS-ESS2-2 Earth's Systems Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.	Using derivatives to describe the rate of change of one variable with respect to another variable allows students to understand change in a variety of contexts.	cause and effect; systems and system models; energy and matter; Interdependence of Science, Engineering, and Technology

HS-ESS3-1 Earth and Human Activity 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-ESS3-3 Earth and Human Activity Create a computational simulation to illustrate the relationships among management of natural resources, the sustainability of human populations, and biodiversity.	Interpreting context • Analyzing problems in context • Interpreting notational expression MPAC 2: Connecting concepts Students can: a. relate the concept of a limit to all aspects of calculus; b. use the connection between concepts (e.g., rate of change and accumulation) or processes (e.g., differentiation and its inverse process, antidifferentiation) to solve problems; c. connect concepts to their visual representations with and without technology; and d. identify a common underlying structure in problems involving different contextual situations. MPAC 5: Building notational fluency Students can: a. know and use a variety of notations; b. connect notation to definitions (e.g., relating the notation for the definite integral to that of the limit of a Riemann sum); c. connect notation to different representations (graphical, numerical, analytical, and verbal); and d. assign meaning to notation, accurately interpreting the notation in a given problem and across different contexts. MPAC 6: Communicating Students can: a. clearly present methods, reasoning,	

	justifications, and conclusions; b. use accurate and precise language and notation; c. explain the meaning of expressions, notation, and results in terms of a context (including units); d. explain the connections among concepts; e. critically interpret and accurately report information provided by technology; and f. analyze, evaluate, and compare the reasoning of others.	

MEASURABLE STUDENT LEARNING OBJECTIVES

Students will be use NASA data to explore connections between myriad environmental hazards in the United States

Students will use multivariable calculus notational fluency to explain concepts in mean curvature flow.

STEM INTEGRATION

Science, Math, Literacy

NATURE OF STEM

By learning a bit about the history of what mathematicians, coders, engineers, and scientists have done for the last 20 years to try to anticipate, prepare for, and fight wildfires establishes and reinforces the idea that solving complex problems with a complex and interrelated number of factors require trial and error and an evolving process of discovery. This is the nature of science.

Engineers are coding simulations to try to do the same.

(Students will also see that even though wildfires are generally caused by human behavior, other observable environmental factors also greatly contribute to the complexity of the problem.)

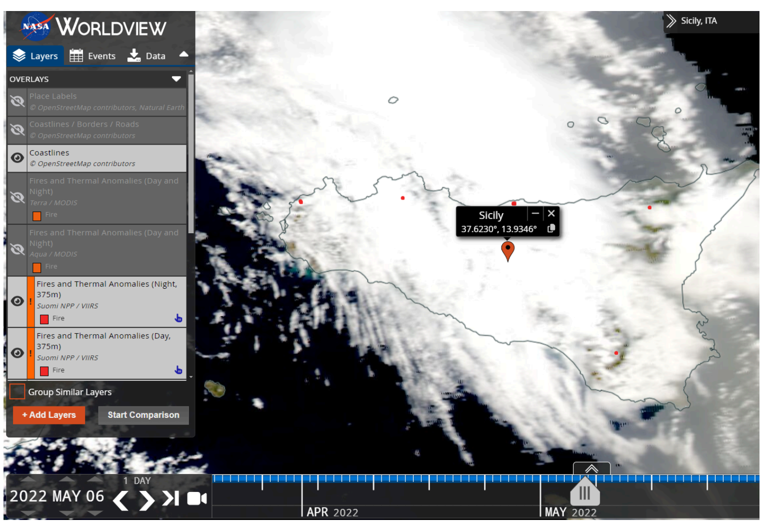
MATERIALS NEEDED

Internet access, NASA data login, basic EXCEL operations and chart creation

ENGAGING CONTEXT/PHENOMENON

NASA's Fire Information for Resource Management System (FIRMS)

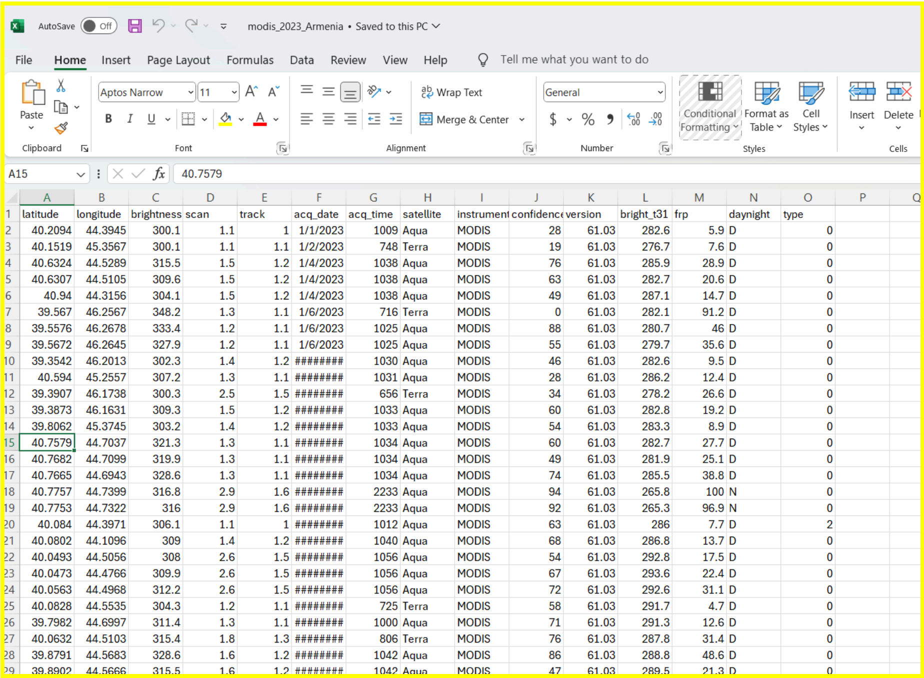
The Fire Information for Resource Management System (FIRMS) provides access, with minimal delay, to satellite imagery, active fire/hotspots, and related products to identify the location, extent, and intensity of wildfire activity. FIRMS tools and applications provide geospatial data, products, and services to support the broader fire management community and to inform the general public. Global data are available within 3 hours of satellite observation; U.S. and Canada active fire detections are available in real-time.



DATA INTEGRATION

The data is used as a motivation for how mathematicians, coders, and engineers use data, NASA maps, and simulations to stop wildfires, and more specifically, to give a frame of reference fow how concepts from multivariable calculus can be used to prevent the spread of wildfire.

OPTION 1:



latitude	longitude	brightness	scan	track	acq_date	acq_time	satellite	instrument	confidence	version	bright_t31	frp	daynight	type
40.2094	44.3945	300.1	1.1	1	1/1/2023	1009	Aqua	MODIS	28	61.03	282.6	5.9	D	0
40.1519	45.3567	300.1	1.1	1.1	1/2/2023	748	Terra	MODIS	19	61.03	276.7	7.6	D	0
40.6324	44.5289	315.5	1.5	1.2	1/4/2023	1038	Aqua	MODIS	76	61.03	285.9	28.9	D	0
40.6307	44.5105	309.6	1.5	1.2	1/4/2023	1038	Aqua	MODIS	63	61.03	282.7	20.6	D	0
40.94	44.3156	304.1	1.5	1.2	1/4/2023	1038	Aqua	MODIS	49	61.03	287.1	14.7	D	0
39.567	46.2567	348.2	1.3	1.1	1/6/2023	716	Terra	MODIS	0	61.03	282.1	91.2	D	0
39.5576	46.2678	333.4	1.2	1.1	1/6/2023	1025	Aqua	MODIS	88	61.03	280.7	46	D	0
39.5672	46.2645	327.9	1.2	1.1	1/6/2023	1025	Aqua	MODIS	55	61.03	279.7	35.6	D	0
39.3542	46.2013	302.3	1.4	1.2	########	1030	Aqua	MODIS	46	61.03	282.6	9.5	D	0
40.594	45.2557	307.2	1.3	1.1	########	1031	Aqua	MODIS	28	61.03	286.2	12.4	D	0
39.3907	46.1738	300.3	2.5	1.5	########	656	Terra	MODIS	34	61.03	278.2	26.6	D	0
39.3873	46.1631	309.3	1.5	1.2	########	1033	Aqua	MODIS	60	61.03	282.8	19.2	D	0
39.8062	45.3745	303.2	1.4	1.2	########	1033	Aqua	MODIS	54	61.03	283.3	8.9	D	0
40.7579	44.7037	321.3	1.3	1.1	########	1034	Aqua	MODIS	60	61.03	282.7	27.7	D	0
40.7682	44.7099	319.9	1.3	1.1	########	1034	Aqua	MODIS	49	61.03	281.9	25.1	D	0
40.7665	44.6943	328.6	1.3	1.1	########	1034	Aqua	MODIS	74	61.03	285.5	38.8	D	0
40.7757	44.7399	316.8	2.9	1.6	########	2233	Aqua	MODIS	94	61.03	265.8	100	N	0
40.7753	44.7322	316	2.9	1.6	########	2233	Aqua	MODIS	92	61.03	265.3	96.9	N	0
40.084	44.3971	306.1	1.1	1	########	1012	Aqua	MODIS	63	61.03	286	7.7	D	2
40.0802	44.1096	309	1.4	1.2	########	1040	Aqua	MODIS	68	61.03	286.8	13.7	D	0
40.0493	44.5056	308	2.6	1.5	########	1056	Aqua	MODIS	54	61.03	292.8	17.5	D	0
40.0473	44.4766	309.9	2.6	1.5	########	1056	Aqua	MODIS	67	61.03	293.6	22.4	D	0
40.0563	44.4968	312.2	2.6	1.5	########	1056	Aqua	MODIS	72	61.03	292.6	31.1	D	0
40.0828	44.5535	304.3	1.2	1.1	########	725	Terra	MODIS	58	61.03	291.7	4.7	D	0
39.7982	44.6997	311.4	1.3	1.1	########	1000	Aqua	MODIS	71	61.03	291.3	12.6	D	0
40.0632	44.5103	315.4	1.8	1.3	########	806	Terra	MODIS	76	61.03	287.8	31.4	D	0
39.8791	44.5683	328.6	1.6	1.2	########	1042	Aqua	MODIS	86	61.03	288.8	48.6	D	0
39.8902	44.5666	315.5	1.6	1.2	########	1042	Aqua	MODIS	47	61.03	289.5	21.3	D	0

ACTIVE FIRE DATA MAP from NASA:
https://www.earthdata.nasa.gov/learn/find-data/near-real-time/firms/active-fire-data

https://worldview.earthdata.nasa.gov/?v=-117.87199724874925,-55.2216694002348,109.15324724874925,61.6904194002348&l=Reference_Labels_15m(hidden),Reference_Features_15m(hidden),Coastlines_15m,MODIS_Terra_Thermal_Anomalies_All(hidden),MODIS_Aqua_Thermal_Anomalies_All(hidden),VIIRS_SNPP_Thermal_Anomalies_375m_Night,VIIRS_SNPP_Thermal_Anomalies_375m_Day,MODIS_Combined_Thermal_Anomalies_All,MODIS_Aqua_SurfaceReflectance_Bands143,MODIS_Aqua_SurfaceReflectance_Bands721,MODIS_Terra_SurfaceReflectance_Bands143,MODIS_Terra_SurfaceReflectance_Bands721,VIIRS_SNPP_CorrectedReflectance_TrueColor(hidden),MODIS_Aqua_CorrectedReflectance_TrueColor(hidden),MODIS_Terra_CorrectedReflectance_TrueColor&lg=false&t=2022-05-06-T14%3A42%3A53Z

Actual data from MODIS satellite by country: https://firms.modaps.eosdis.nasa.gov/country/

(How to use NASA's Fire Data : https://www.youtube.com/watch?v=SSd7KnWN9CM)
https://www.earthdata.nasa.gov/learn/find-data/near-real-time/firms/active-fire-data
https://mynasadata.larc.nasa.gov/basic-page/locating-data-imagery-student-investigations
https://spacemath.gsfc.nasa.gov/media.html

OPTION 2:
https://sedac.ciesin.columbia.edu/data/set/crv-us-climate-risk-proj-county-2040-2049

(I have downloaded and simplified from the above)
https://docs.google.com/spreadsheets/d/1xgCY9VrE7-KhGVz9uI9Mve6-QHrWwyxc8tnUDrbBLzY/edit?usp=sharing

U.S. Climate Risk Projections by County, 20		
This spreadsheet includes the component variables for h		
Variable Cod	**Variable**	**Description**
GEOID	FIPS County code	U.S. census designated county code, five digits
Hazard		
TempChg	Temperature change	Mean temperature in the 2040s compared to baseline temperature
PrepChg	Precipitation change	Mean precipitation in the 2040s compared to baseline precipitation
PrepExt	Extreme precipitation	Days exceeding 98th percentile of daily baseline precipitation
ColdExt	Extreme cold	Days below 2 percentiles of the minimum baseline temperature
HeatExt	Heat wave	Days exceeding the 97.5 percentile of daily maximum baseline temperature for 3 consecutive days
DryChg	Dry condition	Standard precipitation index: standardized z score of monthly precipitation in the 2040s compared to baseline
Exposure		
ImpSurface	Impervious surface	Estimated percent impervious surface
HouseDen	Housing density	Estimate based on population values used to drive housing density growth as depicted by the Spatially Explicit Re
PopEst	Population estimate	A demographic model generating county-level population estimates that are distributed by a Spatially Explicit Regi
HouseSLR	Low-lying houses	Houses that would be exposed to 0.6 meters of sea level rise or storm surge above the current level
RoadSLR	Low-lying roads	Roads that would be exposed to 0.6 meters of sea level rise or storm surge above the current level
Indices		
Hazard(H)	Hazard (H)	Composite index of hazard variables
Expos(E)	Exposure (E)	Composite index of exposure variables

TEACHER BACKGROUND KNOWLEDGE

Calc I, II, III and simple understanding of wildfires and their spread; science of air quality

DIFFERENTIATION OF INSTRUCTION

The introduction piece, where students can self-select their reading/video and process the information as a jigsaw with the other students engages different types of learners and supports literacy and processing with small-group discussion.

The discussion of the notation and syntax of the advanced differential equation reinforces and supports notational and math fluency, and spirals this lesson into former courses in calculus.

Students will be able to use the data in whatever level of complexity they choose.

REAL-WORLD CONNECTIONS FOR STUDENTS

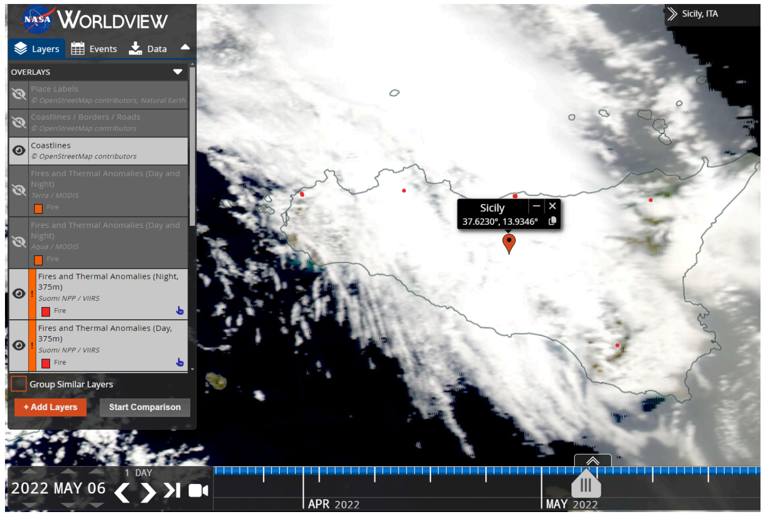
What is more real world than natural disasters? Depending on students' backgrounds and experiences, this topic can be a space for powerful connection… wildfires are a big reality in many places in the planet, including the United States. Also, it is an opportunity for students who (are generally) academically minded to understand and respect the work of firefighters. A nice opportunity for a field trip or a class speaker!

INTEGRATION POSSIBLE MISCONCEPTIONS

Students may think that firefighters just arbitrarily spray water and that fires just “go away” and that science/math/coding are irrelevant in trying to prevent damage.

LESSON PROCEDURE

5E	Details of 5E Lesson Implementation
Engage	**Procedure: (Opening activity/motivation):** Tell the students that the world is on fire right now! Ask student if they have any prior understanding or experience with wildfires, and what is done to stop them. This can be from personal experience, or from movies. (One interesting thing I knew was that in order to stop the spread of wildfires, fires are often strategically CREATED to “head them off at the pass.) https://wfca.com/wildfire-articles/prevent-the-spread-of-wildfires/ **Modifications** (Might be triggering to a student who has had a bad experience with fire, otherwise none necessary) **Standards Addressed** HS-ESS3-1, HS-ESS3-3, HS-ESS2-2 **Formative/Summative Assessments** Formative, check for understanding, ask questions about what students want to know about wildfires and where they occur **Resources** NASA’s Fire Information for Resource Management System (FIRMS) The Fire Information for Resource Management System (FIRMS) provides access, with minimal delay, to satellite imagery, active fire/hotspots, and related products to identify the location, extent, and intensity of wildfire activity. FIRMS tools and applications provide geospatial data, products, and services to support the broader fire management community and to inform the general public. Global data are available within 3 hours of satellite observation; U.S. and Canada active fire detections are available in real-time.

	(Give the students time to engage with the map… they can look for their country of origin, or somewhere they have visited, or somewhere they are interested in… there is a search bar at the top where you can input a country or region, or they can just scan the map)  ACTIVE FIRE DATA MAP from NASA: https://www.earthdata.nasa.gov/learn/find-data/near-real-time/firms/active-fire-data https://worldview.earthdata.nasa.gov/?v=-117.87199724874925,-55.2216694002348,109.15324724874925,61.6904194002348&l=Reference_Labels_15m(hidden),Reference_Features_15m(hidden),Coastlines_15m,MODIS_Terra_Thermal_Anomalies_All(hidden),MODIS_Aqua_Thermal_Anomalies_All(hidden),VIIRS_SNPP_Thermal_Anomalies_375m_Night,VIIRS_SNPP_Thermal_Anomalies_375m_Day,MODIS_Combined_Thermal_Anomalies_All,MODIS_Aqua_SurfaceReflectance_Bands143,MODIS_Aqua_SurfaceReflectance_Bands721,MODIS_Terra_SurfaceReflectance_Bands143,MODIS_Terra_SurfaceReflectance_Bands721,VIIRS_SNPP_CorrectedReflectance_TrueColor(hidden),MODIS_Aqua_CorrectedReflectance_TrueColor(hidden),MODIS_Terra_CorrectedReflectance_TrueColor&lg=false&t=2022-05-06-T14%3A42%3A53Z Actual data from MODIS satellite by country: https://firms.modaps.eosdis.nasa.gov/country/ (How to use NASA's Fire Data : https://www.youtube.com/watch?v=SSd7KnWN9CM) https://www.earthdata.nasa.gov/learn/find-data/near-real-time/firms/active-fire-data https://mynasadata.larc.nasa.gov/basic-page/locating-data-imagery-student-investigations https://spacemath.gsfc.nasa.gov/media.html

Explore	**Procedure:** Split students into groups and have them select (or randomly assign) background research from one of these sources. Have the students think about: when was the article (or video) produced? What were the contributions then, and by whom? What did the article/video indicate were next steps, if any, that needed to happen in order to better firefighters do their job? Be prepared to report to the class what you have read. 1. From sciencenews.org: Math on Fire: Mathematicians are building a model to predict wildfire movement https://www.sciencenews.org/article/math-fire 2007 2. From CBS News, 2024: NASA using satellites to identify areas vulnerable to disastrous wildfires https://www.cbsnews.com/sanfrancisco/news/nasa-using-satellites-to-identify-areas-vulnerable-to-disastrous-wildfires/, 3. From Triplebyte, 2020: How Fire Spreads: Mathematical Models and Simulators https://dev.to/triplebyte/how-fire-spreads-mathematical-models-and-simulators-395c 4. From NASA, 2016 NASA Sees Intense Fires around the World https://www.youtube.com/watch?v=TF76ITo3R1U&list=PPSV 5. From The Conversation.com, 2023:Predicting and planning for forest fires requires modelling of many complex, interrelated factors https://theconversation.com/predicting-and-planning-for-forest-fires-requires-modelling-of-many-complex-interrelated-factors-207185 (Teacher note: What they should get out of it… mathematicians are trying to model spread with equations, coders are creating simulations to understand spread, there are many factors that contribute to wildfire spread that makes them unpredictable, NASA has a watch on the earth to anticipate where wildfires start and are going… it is a collaborative effort. ALSO, it will probably be a shock to learn that mathematicians are contributing to the cause.) **Modifications:** Student choice to self-select resource read and choice of group/presenter from group addresses student manner of interaction **Standards Addressed**

	HS-ESS3-1, HS-ESS3-3, HS-ESS2-2 LITERACY STANDARDS: Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms. 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. 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 **Formative/Summative Assessments** Check for understanding and allow students to summarize and ask each other questions for understanding **Resources** (indicated above)
Explain	**Procedure:** (Select a student or students to read) From the American Mathematical Society, Explaining Wildfires through Curvature, 2023 https://www.ams.org/publicoutreach/mathmoments/mm168-explaining-wildfires#:~:text=In%202012%2C%20Sharples%20and%20Wheeler%20began%20studying%20a,a%20mathematical%20process%20known%20as%20mean%20curvature%20flow. *"In the summer of 2023, hundreds of wildfires in Canada sent smoke drifting down the North American continent, resulting in dangerous levels of air pollution in New York, Columbus, and other cities. The East Coast was finally tasting the horrific effects of wildfires. In Australia, where wildfires are a concern year-round, residents have already battled those effects for years.*

Researchers in Australia have long tried to model these wildfires, hoping to learn information that can help with firefighting policy. Mathematicians like Jason Sharples and Valentina Wheeler are joining the effort. In 2012, Sharples and Wheeler began studying a particularly dangerous phenomenon: ***When two wildfires meet, they create a new, V-shaped fire whose pointed tip races along to catch up with the two branches of the V, moving faster than either of the fires alone. This is exactly what happens in a mathematical process known as mean curvature flow. Mean curvature flow is a process in which a shape smooths out its boundaries over time. Just as with wildfires, pointed corners and sharp bumps will change the fastest.***

Wheeler, Sharples, and colleagues modeled fires as curvature flows, using equations that specify how curvature affects the way a wildfire front changes in time and space. Though curvature information cannot explain everything about wildfires, it's one simple and effective tool for a problem that will only become more pressing as the climate evolves."

Although "mean curvature flow" is a concept from a course called "differential geometry" and way beyond the scope of this course, we have already spoken about curvature in this course and ordinary first-order differential equations in Calc I.

From https://en.wikipedia.org/wiki/Mean_curvature_flow

Mean curvature flow of a three-dimensional surface [edit]

The differential equation for mean-curvature flow of a surface given by $z = S(x,y)$ is given by

$$\frac{\partial S}{\partial t} = 2D\, H(x,y)\sqrt{1+\left(\frac{\partial S}{\partial x}\right)^2+\left(\frac{\partial S}{\partial y}\right)^2}$$

with D being a constant relating the curvature and the speed of the surface normal, and the mean curvature being

$$H(x,y) = \frac{1}{2}\frac{\left(1+\left(\frac{\partial S}{\partial x}\right)^2\right)\frac{\partial^2 S}{\partial y^2} - 2\frac{\partial S}{\partial x}\frac{\partial S}{\partial y}\frac{\partial^2 S}{\partial x \partial y} + \left(1+\left(\frac{\partial S}{\partial y}\right)^2\right)\frac{\partial^2 S}{\partial x^2}}{\left(1+\left(\frac{\partial S}{\partial x}\right)^2+\left(\frac{\partial S}{\partial y}\right)^2\right)^{3/2}}.$$

In the limits $\left|\frac{\partial S}{\partial x}\right| \ll 1$ and $\left|\frac{\partial S}{\partial y}\right| \ll 1$, so that the surface is nearly planar with its normal nearly parallel to the z axis, this reduces to a diffusion equation

$$\frac{\partial S}{\partial t} = D\,\nabla^2 S$$

Standards Addressed

MPAC 2, MPAC 5, MPAC 6

Formative/Summative Assessments

Reviving background knowledge:

1. What makes the first equation given a “differential equation?”
2. What about the first equation and the given information indicate that it is a “related rate” situation?
3. Why is the partial notation $\frac{\partial S}{\partial t}, \frac{\partial S}{\partial x}, \frac{\partial S}{\partial y}$ used instead of $\frac{dS}{dt}, \frac{dS}{dx}, \frac{dS}{dy}$?
4. The part of the first equation $\sqrt{1 + \left(\frac{\partial S}{\partial x}\right)^2 + \left(\frac{\partial S}{\partial y}\right)^2}$ should look familiar, even though we have not seen it using partials notation. What is it and what is it used for?
5. In the $H(x, y)$ equation the notations $\frac{\partial^2 S}{\partial x^2}$ and $\frac{\partial^2 S}{\partial x \partial y}$ are used. Explain what these notations indicate, in words.

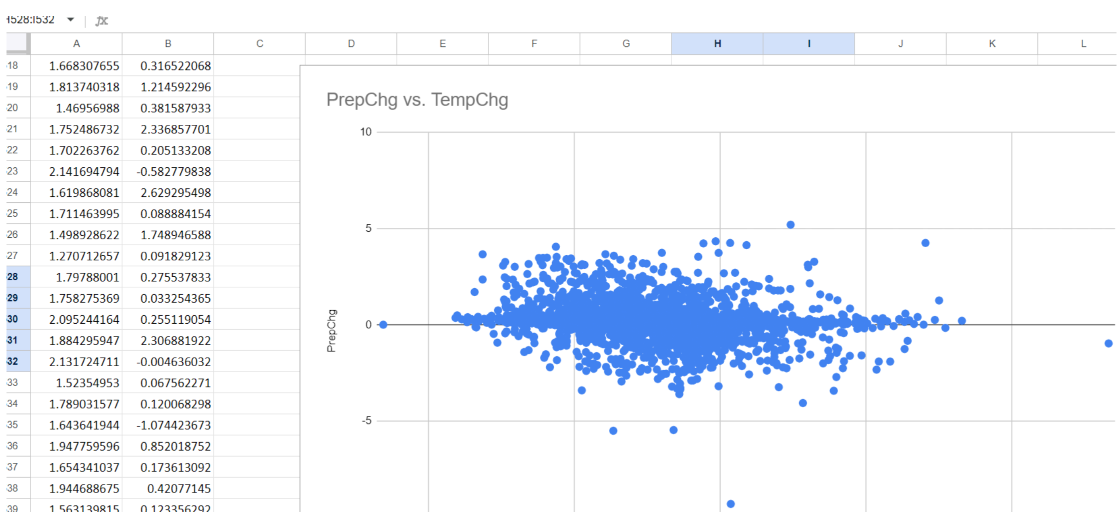
Resources: Listed above

Elaborate

Procedure: Teacher facilitates discussion on how wildfires contribute to environmental hazards, and that the hazards are interrelated.

https://sedac.ciesin.columbia.edu/data/set/crv-us-climate-risk-proj-county-2040-2049

Students will choose data of interest from here, and explore the relationship between hazards, if any. For example, choosing temperature change versus precipitation change:



	A	B
18	1.668307655	0.316522068
19	1.813740318	1.214592296
20	1.46956988	0.381587933
21	1.752486732	2.336857701
22	1.702263762	0.205133208
23	2.141694794	-0.582779838
24	1.619868081	2.629295498
25	1.711463995	0.088884154
26	1.498928622	1.748946588
27	1.270712657	0.091829123
28	1.79788001	0.275537833
29	1.758275369	0.033254365
30	2.095244164	0.255119054
31	1.884295947	2.306881922
32	2.131724711	-0.004636032
33	1.52354953	0.067562271
34	1.789031577	0.120068298
35	1.643641944	-1.074423673
36	1.947759596	0.852018752
37	1.654341037	0.173613092
38	1.944688675	0.42077145
39	1.563139815	0.123356292

Students will need basic Excel operation background.

	This may be helpful background info: https://airquality.gsfc.nasa.gov/particulate-matter **Standards Addressed** HS-ESS3-1, HS-ESS3-3, HS-ESS2-2 **Resources (listed above)**
Evaluate	**Procedure:** (Summative) Students working in groups or individually will present their findings using data (rubric needs to be created) and a discussion on what, if any, connection to wildfires there may be.

REFERENCES

https://www.biointeractive.org/classroom-resources/impact-wildfires

NGSS Search tool:
https://www.nextgenscience.org/search-standards?keys=&tid%5B%5D=107&tid_4%5B%5D=43

Mathematical Practices for AP Calculus (MPACs)
https://apcentral.collegeboard.org/media/pdf/ap-calculus-unit-guide-2018-2019.pdf#:~:text=Mathematical%20Practices%20for%20AP%20Calculus%20%28MPACs%29%3A%20The%20MPACs,linked%20to%20one%20or%20more%20of%20the%20MPACs.

Reading Standards for Literacy in Science and Technical Subjects 6–12
https://www.thecorestandards.org/wp-content/uploads/ELA_Standards1.pdf