Possible Impacts of Climate Change on Fermilab's Radioactive Air Emissions

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SIST Final Presentation

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Causes of Climate Change

Previously, climate change was a natural process

- External changes – solar radiation, volcanic eruptions, changes in Earth's orbit
    - Note: Greenhouse gases (GHG) like CO_2 are the natural result of respiration and volcanic activity
- 800,000 years ago – Ice Age

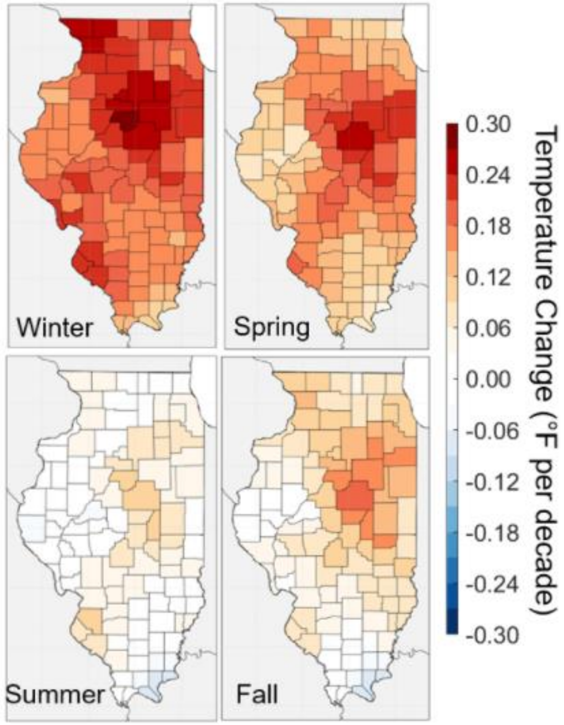
Now, it's manmade

- Greenhouse Effect
    - More GHG -> more infrared energy absorption and reflection back to Earth's surface
- Greenhouse gases alter atmospheric composition
    - Carbon dioxide – fossil fuel combustion
        - Atmospheric levels increased by 47% since 1950s
    - Methane – coal, gas, and oil
        - Less abundant but more potent than CO_2

Climate Change in Northern Illinois

- **Temperature**
  - Dependent on greenhouse gas emissions
    - Rise 4-14 F by 2100
    - Warmer weather increases ground-level ozone production
  - Decreased ice cover in the Great Lakes -> increased summer temperatures
- **Increase in extreme weather events:**
  - Days above 95 F
  - Flooding
    - 2-in rainfall days increased by 40% since 1900
    - Average annual precipitation has increased 5% since 1900
  - Droughts
    - Higher temperatures -> increased evapotranspiration
    - Currently experiencing a severe drought in NE IL
- **Altered wind patterns**
  - Due to changed atmospheric composition

Inevitable – focus on minimizing climate change and adapting to its anticipated effects

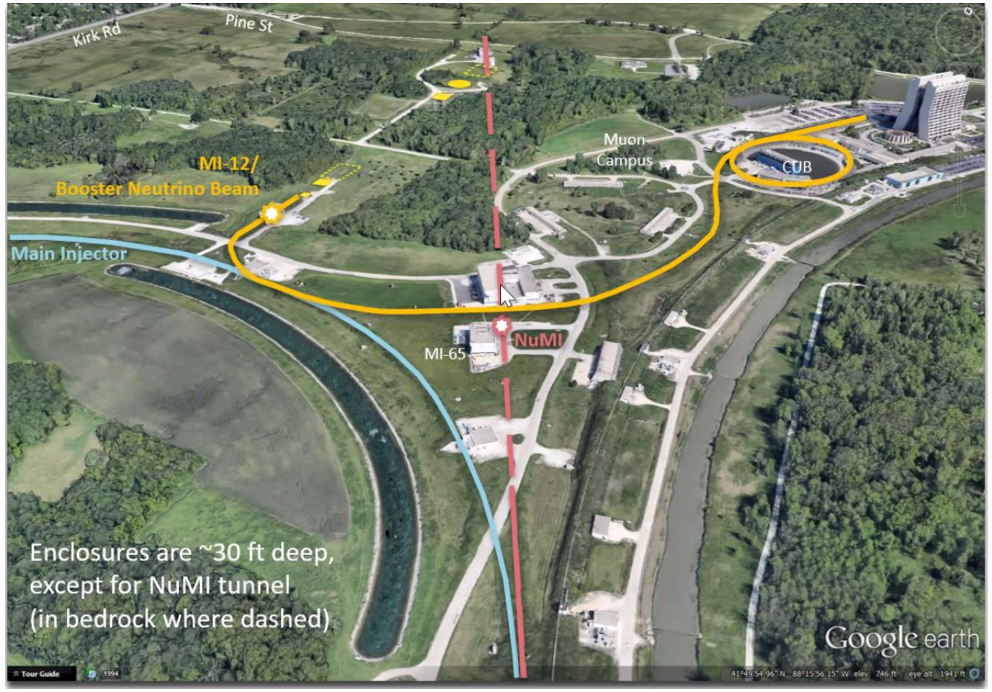


Maps show trends in daily average temperature in degrees Fahrenheit per decade by season and county in Illinois. Trends are calculated using observations between 1900 and 2020.

Fermilab Emissions

Activated air release from all FNAL sources:	FNAL Total	46.573	Ci

- Fermilab emits radioactive air emissions while running accelerators
- Air emissions deliver doses of radioactive isotopes to people
  - Airborne doses are regulated by the US EPA
- Atmospheric conditions can affect the distribution of these airborne particles → possibly increased exposure to public and impact Fermilab operations



NuMI
^{13}N
^{11}C
^{41}Ar
^{15}O
^{76}Br
^{77}Br
^{82}Br
^{7}Be
^{97}Ru
Tritium

Importance

- Identifying the repercussions of climate change on radioactive air emissions
- Estimate radiation exposure the public may receive after the (possibly) altered emissions
- Possibilities
  - No change → operations not impacted
  - Increased concentrations → possibly develop controls to reduce radioactive emission operations
- 2020: Fermilab’s max dose was only .14% of the EPA’s limit for public dosage
- Fermilab hopes to increase accelerator power in the future
  - Accommodate potential changes in emissions with possible climate change impacts

Process

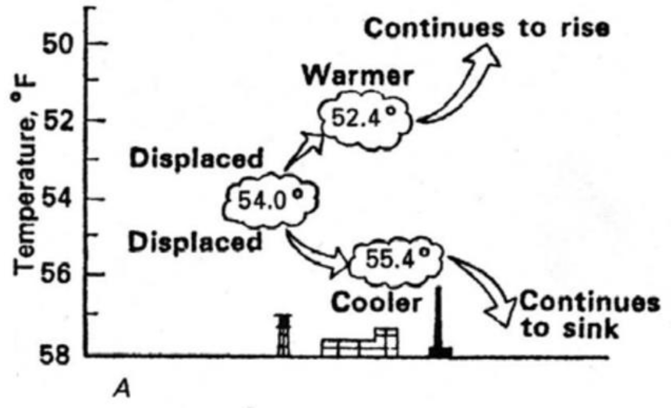
Factors affecting air quality

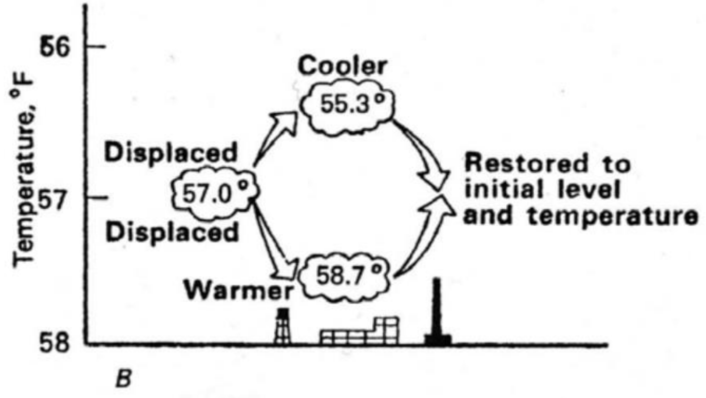
1. Emission sources – stacks
2. Topography
3. Atmospheric chemistry
4. Meteorology - describe air mixing behaviors

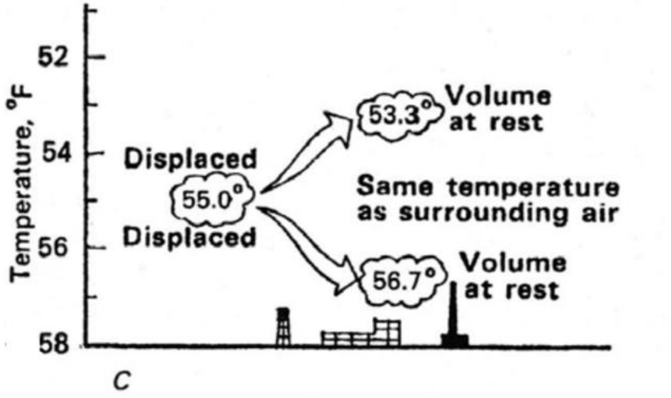
Data to Collect

- **Population** – age, number, estimates at specified year
- **Meteorological** – annual precipitation, ambient temperature, humidity, wind speed/direction
- **Sources** – stacks' heights, diameter, plume type, heat release rate
- **Nuclides -** released, total count, type, release rate
- **Agricultural** – land use, density of livestock & crop

Goal: Use climate modeling to predict future Fermilab doses from air emissions and understand global warming's impacts on Fermilab operations





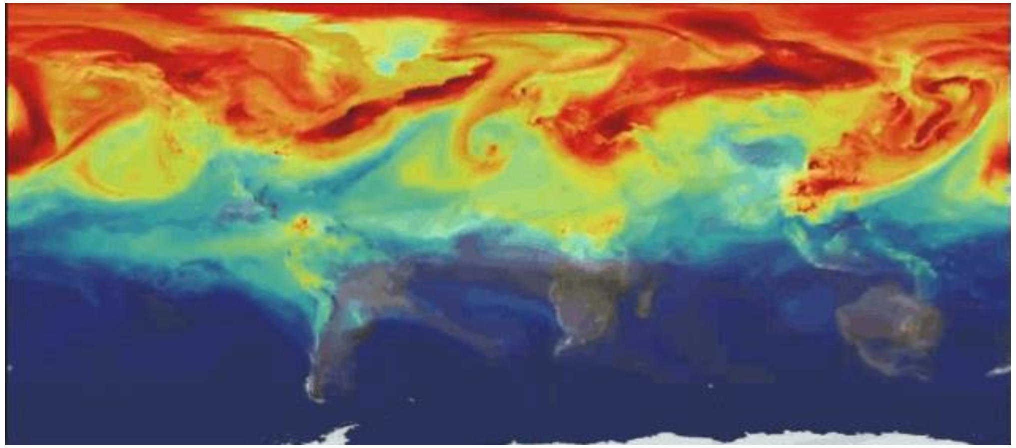


Fermilab

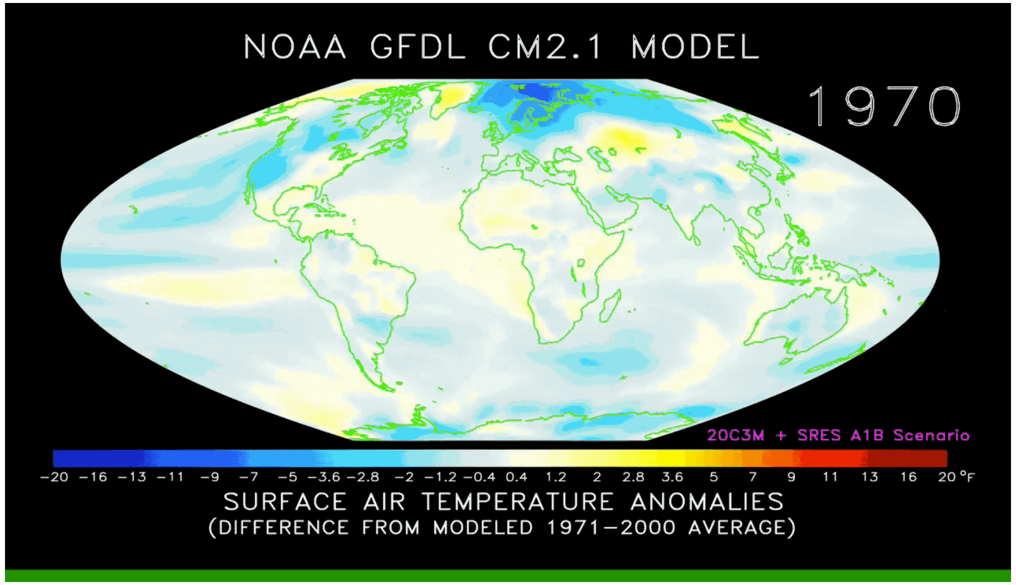
University of Illinois Climate Model

What is a Climate Model?

- Climate Model: computer simulation of the planet’s climate system
  - Calculates atmospheric conditions, temperatures, pressure, wind patterns, and humidity
  - Test hypotheses about future climate systems to predict long-and-short-term climate patterns and weather events



How CO2 moves through Earth’s atmosphere throughout the year



Dynamical Downscaling: utilizes high-resolution simulations to extrapolate the effects that large-scale climate process have on local scales

- Considers the local area’s topography, better capturing spatial & temporal variations → more accurate predictions of the frequency, intensity, and type of extreme weather events in a localized region

Global Climate Models (GCM) Used

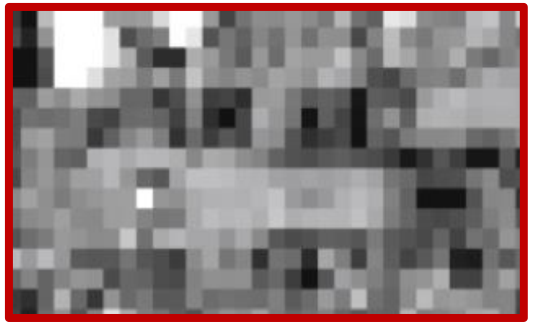
- Why use more than 1?
  - No GCM is better/worse across all analyzed variables → varying accuracy in varying regions for different variables
  - Different temperature increases lead to different projections for weather events, wind patterns, and precipitation

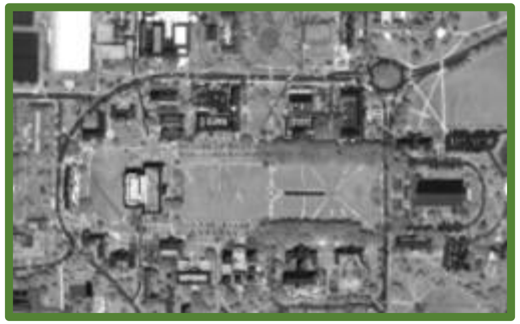
Model	Geophysical Fluid Dynamics Laboratory Earth System Model 2	Community Climate System Model 4	Hadley Centre Global Environment Model Version 2
Developer	NOAA/Geophysical Fluid Dynamics Laboratory	National Center for Atmospheric Research	Met Office Hadley Center, UK
Mean global temperature increase with a doubling of CO2	2.38 C	2.9 C	4.5 C

Representative Control Pathways (RCP): GHG concentration projections assigned by the Intergovernmental Panel on Climate Change

- Depend on human activity (GHG emissions)
  - RCP4.5: +1.8 C in 2100; regulations occur
  - RCP8.5: +3.7 C in 2100; "business as usual"

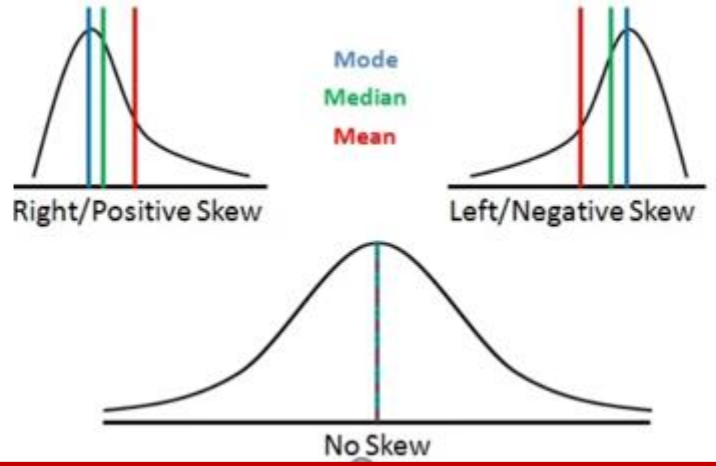
Improvements





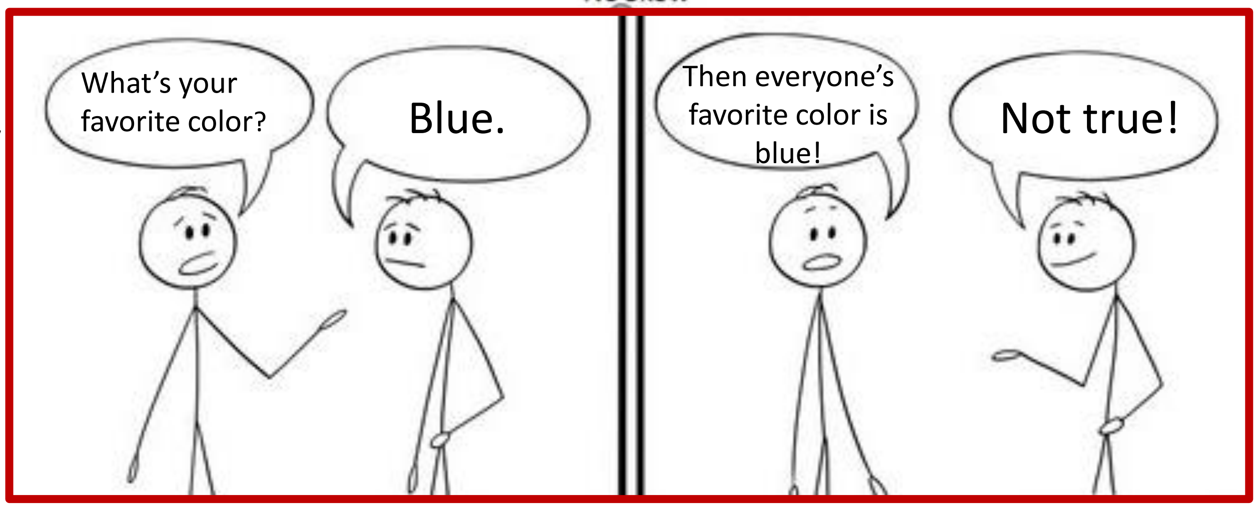
Other climate models:

- Low spatial resolution (100+ km)
  - Global-scale
  - Cannot capture localized landscape features and weather events influencing atmospheric conditions
- Uses mean-based statistics
  - Outliers skew values
- Systematic bias from limited model input
  - Certain models over/under-estimate events → bias



This climate model:

- High spatial resolution (12km)
  - Simulates localized climate and weather events accurately
- Uses median-based statistics
  - Mediates outlier values for weather/climate
  - Organizes data to identify high/low extremes
- Overcomes bias by combining 3 different climate models



An example of systematic bias due to limited input

CAP-88

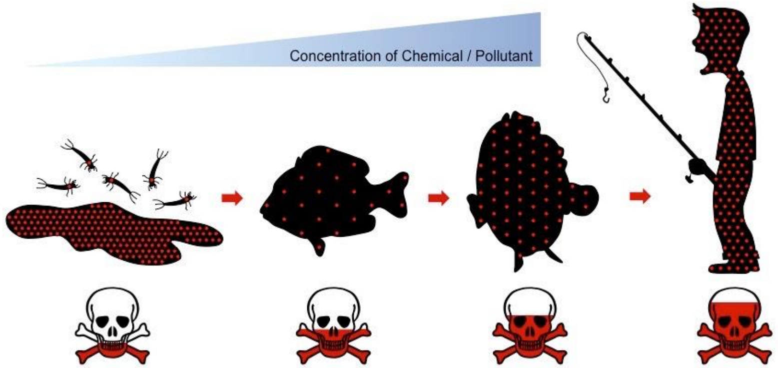
Clean Air Act Assessment Package, 1988

Background

- US EPA computer model
- Compliance tool under the National Emissions Standard for Hazardous Air Pollutants
- **Purpose**: Estimates dosage and risk from radionuclide emissions in the air

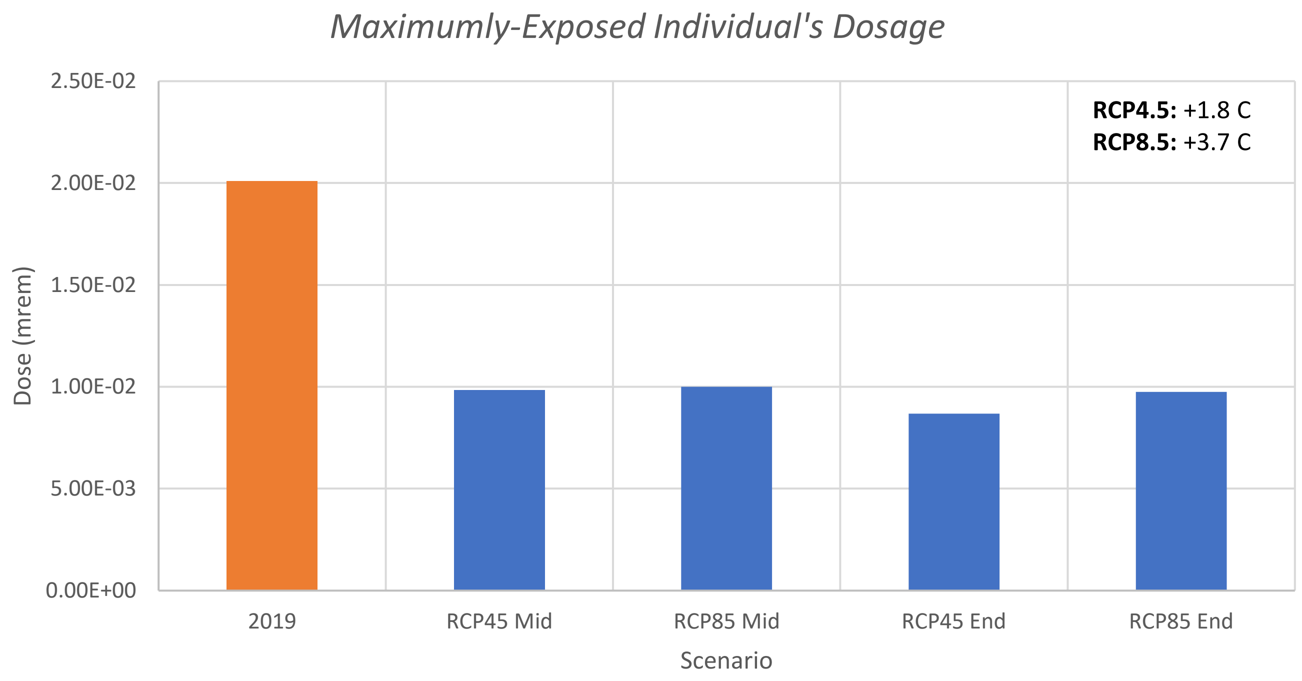
Capabilities

- **Gaussian plume modeling - Momentum**
  - Estimate average dispersion of radionuclides emitted
  - Assumes uniform distribution within 80 km radius
- **Radionuclide concentration modeling**
  - Rate of deposition on surfaces
    - Concentration in vegetation → food: vegetables, milk, and meat
  - Inhalation of airborne nuclide estimations
- **Risk estimate modeling**
  - Evaluates low-level chronic exposure



Results

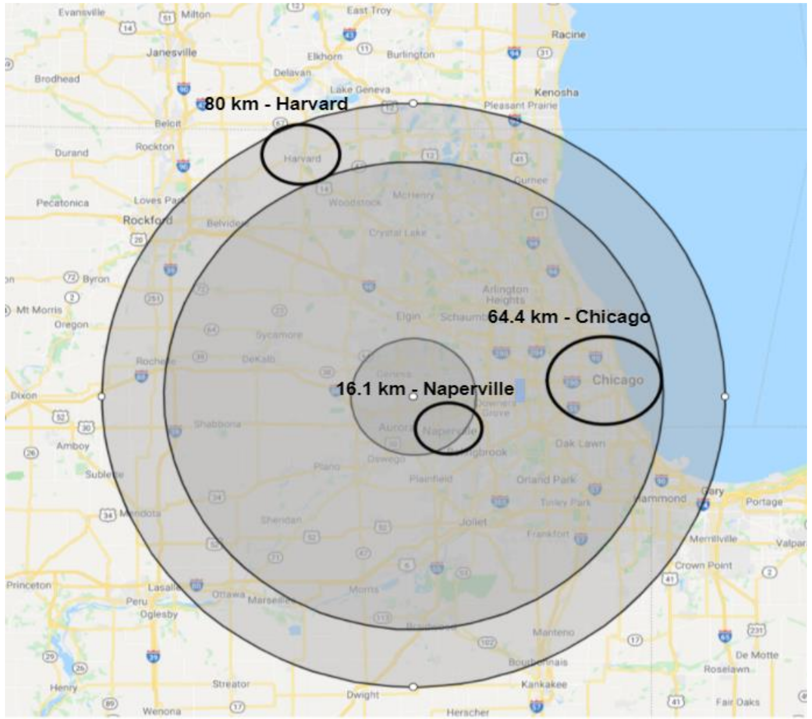
Maximumly-Exposed Individual (MEI)

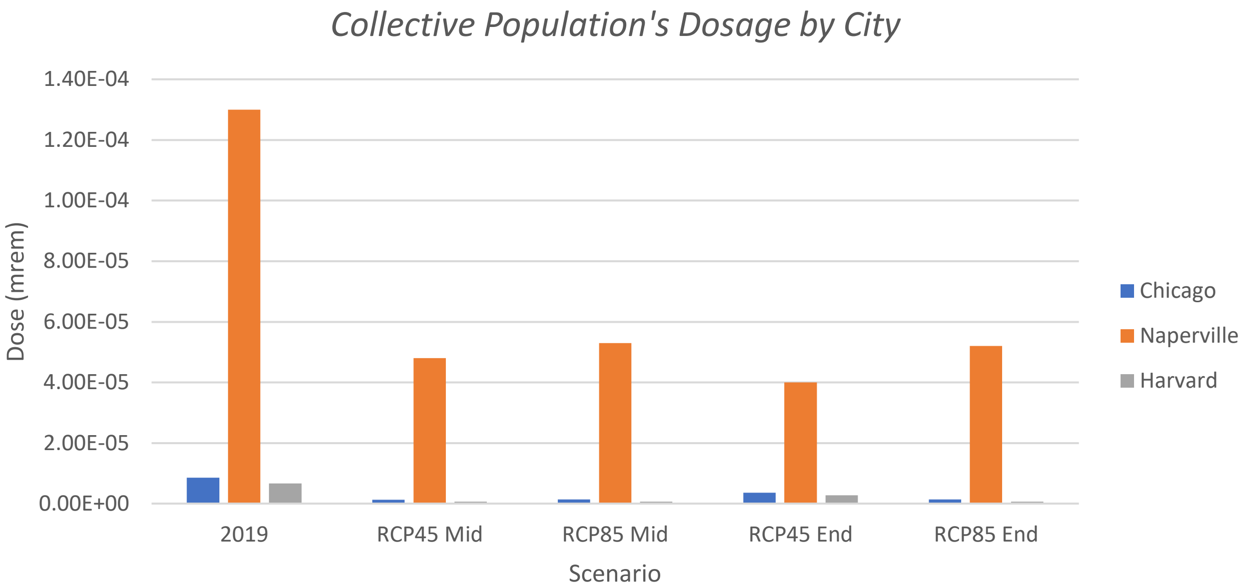


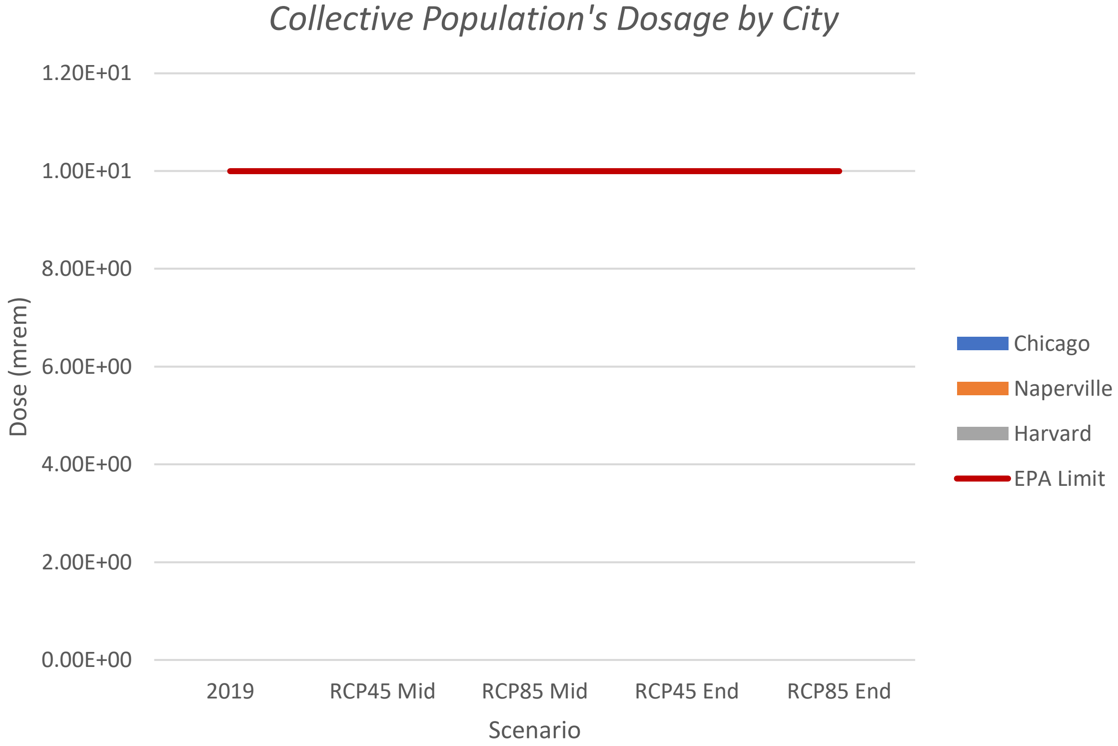
- RCP45 dosages < RCP85's dosages
- MEI shares location across all 4 scenarios – **800 m NW**
- Lower than 2019 because altered wind patterns are stronger and less stable, spreading radioactive nuclides further
  - Decreases MEI, but increases the range of dosage distributed

Distance Vs. Exposure

- As distance from Fermilab's emission sources increases, the collective population dose decreases
  - Naperville's distance < Chicago's distance < Harvard's distance
  - Naperville's dosage > Chicago's dosage > Harvard's dosage
  - Collective dose is 1000x < MEI
- Wind direction events may alter the radionuclide paths, but the correlation between distance and dosage is more relevant than direction and dosage







Limitations

Cap-88

- **Averaged values by day, year, and decade**
- **Population:** 2020 census not released → estimations from 2019 projections
- **Stacks:** only 6 inputs for 10 stacks → merge inputs

Climate model

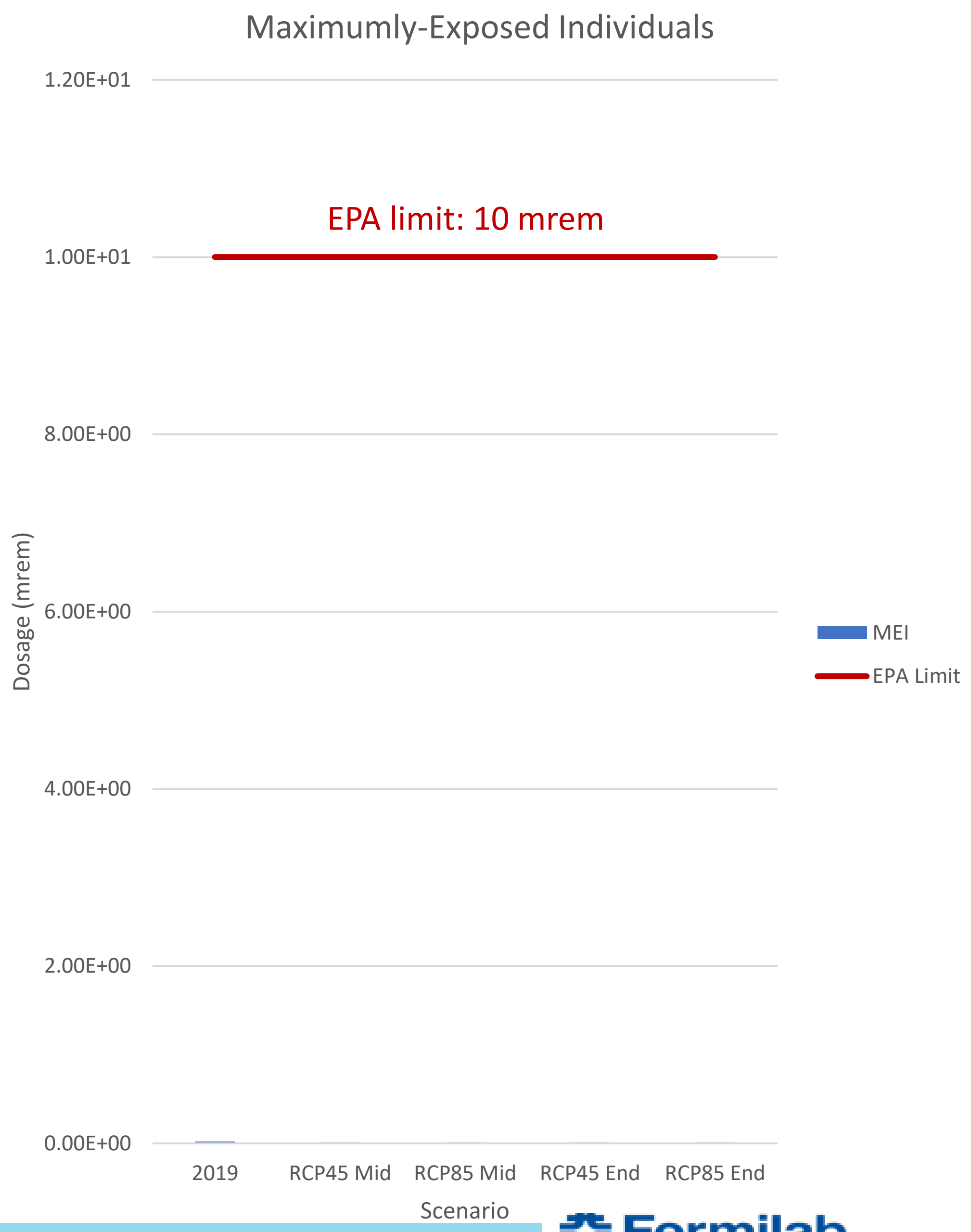
- **Missing analog data** → years left out of analysis
- **12x12km resolution** → not zeroed-in on Fermilab
- **Only 2 temperature scenarios**: does not analyze in-between scenarios

+ 1.8 C	**???**	**+ 3.7 C**

Fermilab Operations

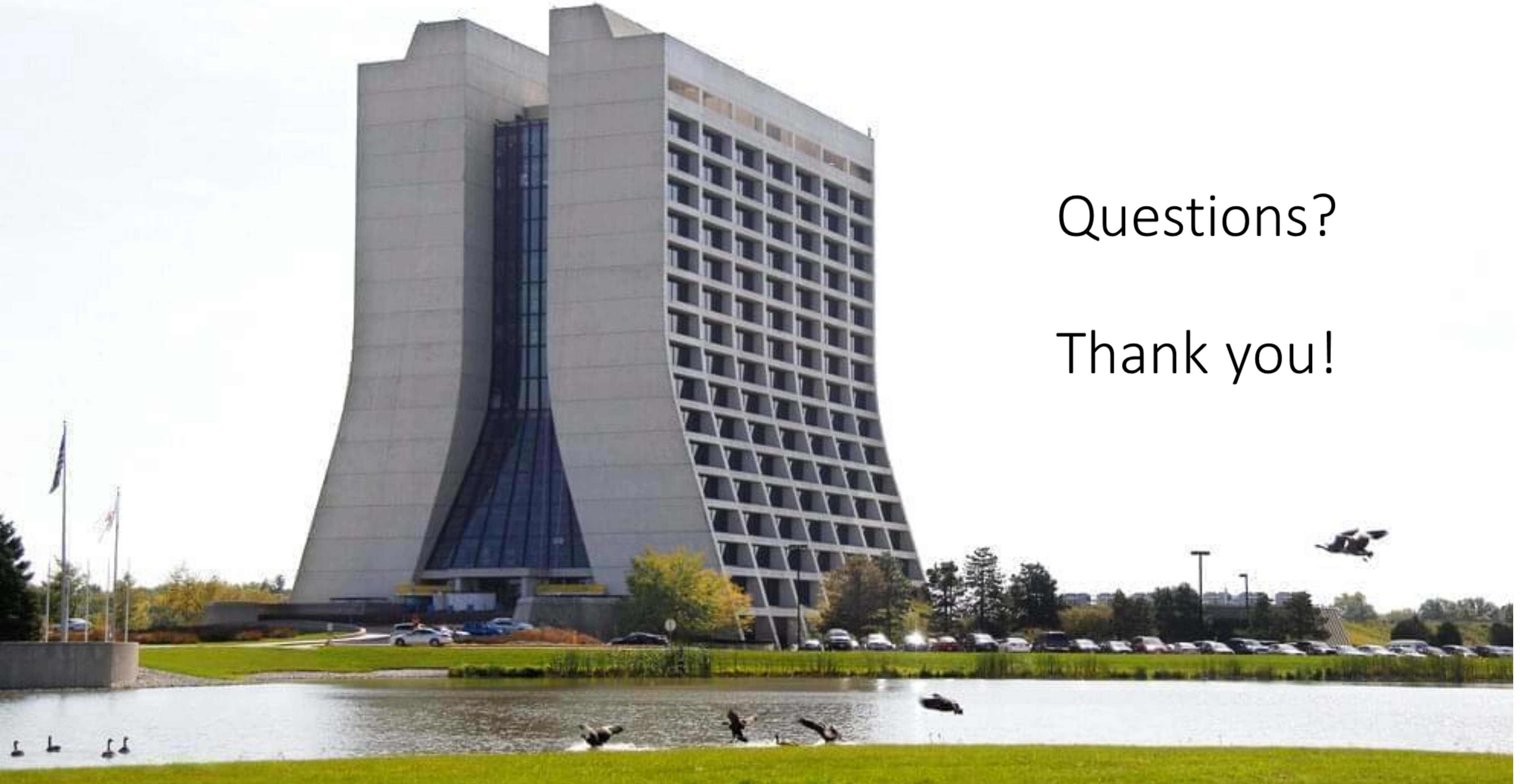
Conclusion:

Climate change will **not** have a significant impact on Fermilab's emission levels → operations may continue and increase power, but these projects must perform their own design calculations to determine the resulting air emissions



New operations planned:

- Varies by project – each has its own nuclides and emission rates
    - Depends on shielding and target materials



Questions?

Thank you!