Climate and Human Health Responders
Course for Health Professionals
Degraded Air Quality
Anthony Gerber, MD: Division of Pulmonary and Critical Care, National Jewish Hospital
Degraded Air Quality

Learning Objectives

- Describe the pathways through which climate change affects ozone, PM2.5, and other ambient respiratory irritants how these pollutants impact climate-sensitive respiratory diseases such as asthma, COPD, chronic lung disease, cardiovascular disease, cerebrovascular, and allergic diseases.

- Describe how climate change might impact indoor air quality (e.g. mold from flooding)

- Analyze data related to hospital and ED usage for respiratory conditions as they relate to meteorological variables

- Describe how climate change makes air quality regulation more complex and difficult

- Identify populations that are vulnerable to degraded air quality. Describe how health professionals can protect these vulnerable patients.

- Explain how wildfires are impacted by climate change and the direct and indirect health implications

- Describe how climate change increases the risk of complex disasters due to combined and cascading events (heatwaves followed by wildfires)

- Identify particularly vulnerable patients and families and teach about risk mitigation, such as limiting outside work and recreation during poor air quality days.
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- Describe how climate change increases the risk of complex disasters due to combined and cascading events (heatwaves followed by wildfires).
- Identify particularly vulnerable patients and families and teach about risk mitigation, such as limiting outside work and recreation during poor air quality days.
Disclosure Information

Consulting agreements last 3 years with:
Pliant Therapeutics
BeiGene
BioScience Pharma
Apellis Pharmaceuticals
Gala Therapeutics

Founder, Psammiard Therapeutics

Chair, Colorado Air Quality Control Commission

None of these relationships influence the content of this presentation
Poorly understood long-term climate variability does not reduce the validity of models predicting short-term impacts of GHGs on climate.
The well-established science of climate change and the central importance of the culprit gases in our economy and lives

- Transportation
- Electricity
- Heating/cooling
- Industrial processes (Steel production, Cement mills)
- Fossil fuel extraction
- Specialty GHGs (CFCs)
Climate change and health

https://www.cdc.gov/climateandhealth/effects/
Climate change and air quality: Multiple and complex direct and indirect interactions

-> Ambient outdoor air pollution

I. Ozone
   a) Ozone forms best on hot days
   b) Frequent co-emission of ozone precursors and greenhouse gases

II. Particulates (wildfire)
   a) Wildfires worsened by climate change
   b) Urban encroachment increase impact
   c) Wildfire smoke can increase Ozone

III. GHGs themselves (e.g. CO2, methane) are NOT, however, typically classified as air pollutants based on traditional parameters.
Climate change and air quality: Multiple and complex direct and indirect interactions

-> **Allergens** - Increased *aeroallergens* from extended growing seasons, increased CO2, expanded plant ranges, intense dust-wind events, and pollutant chemistry

-> Increased flooding **degrading indoor air quality through mold growth**
Degraded air quality and climate change: Impact on allergens and allergic lung diseases (e.g. asthma)

Figure 1. Interplay of air pollution and climate change can promote allergies by influencing the human body and immune system, as well as the abundance and potency of environmental allergens and adjuvants.
Degraded air quality and climate change: Impact on allergens and allergic lung diseases (e.g. asthma)
A note on regulating air pollution in the USA…

1. The EPA, under the clean air act, adopts *science*-based standards for levels of so-called “Criteria pollutants” (and air toxics)

2. PM 2.5 and (especially) ozone are the major criteria pollutants where standards are both becoming more stringent and where there remain significant regions with non-attainment

3. States are tasked with implementing the federal standards through state-based regulations, often promulgated by volunteer commissions (e.g. California ARB, Colorado AQCC)

4. It is impossible for state-based regulations to solve climate change, however:
   a. As we will discuss, climate change is making attainment of EPA standards more difficult.
   b. Reduction of ozone and PM pollution frequently has a GHG co-benefit.
   c. If states don’t act on GHGs, who will?
Some of the underlying science: Exposure to PM 2.5 and Ozone and Increased All-Cause Mortality

Underlying science: Short-term associations between ambient air pollutants and pediatric asthma emergency department visits (Atlanta area)

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Overall RR (95% CI) (Jan–Dec)</th>
<th>Warm Season RR (95% CI) (May–Oct)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ozone†‡</td>
<td>1.062 (1.031–1.093)</td>
<td>1.082 (1.043–1.123)</td>
</tr>
<tr>
<td>Nitrogen dioxide†</td>
<td>1.036 (1.018–1.055)</td>
<td>1.066 (1.038–1.095)</td>
</tr>
<tr>
<td>Carbon monoxide†</td>
<td>1.023 (1.006–1.041)</td>
<td>1.068 (1.034–1.102)</td>
</tr>
<tr>
<td>Sulfur dioxide†</td>
<td>1.012 (0.994–1.030)</td>
<td>1.030 (1.002–1.058)</td>
</tr>
<tr>
<td>PM$_{10}$§</td>
<td>1.020 (1.003–1.038)</td>
<td>1.026 (1.001–1.051)</td>
</tr>
<tr>
<td>PM$_{10–2.5}$†</td>
<td>1.034 (1.011–1.057)</td>
<td>1.025 (0.991–1.059)</td>
</tr>
<tr>
<td>PM$_{2.5}$†</td>
<td>1.020 (1.002–1.039)</td>
<td>1.043 (1.016–1.070)</td>
</tr>
</tbody>
</table>

Ozone levels are associated with increased disease-specific mortality

<table>
<thead>
<tr>
<th></th>
<th>Ozone Average May to September</th>
<th>Ozone Average Spring and Autumn</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HR</td>
<td>95% CI</td>
</tr>
<tr>
<td>CHF</td>
<td>1.06</td>
<td>1.03–1.08</td>
</tr>
<tr>
<td>MI</td>
<td>1.09</td>
<td>1.06–1.12</td>
</tr>
<tr>
<td>Diabetes</td>
<td>1.07</td>
<td>1.05–1.10</td>
</tr>
<tr>
<td>COPD</td>
<td>1.07</td>
<td>1.04–1.09</td>
</tr>
</tbody>
</table>

Ozone and PM2.5 in Metropolitan Areas and Asthma

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Count</th>
<th>Quartile</th>
<th>Reference</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>O₃</td>
<td>18,746</td>
<td>1st (lowest)</td>
<td>Reference</td>
<td>Reference</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2nd</td>
<td>1.01 (0.88, 1.16)</td>
<td>0.99 (0.78, 1.26)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3rd</td>
<td>1.09 (0.89, 1.34)</td>
<td>1.09 (0.85, 1.41)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4th</td>
<td>1.19 (0.84, 1.68)</td>
<td>1.56 (1.15, 2.10)</td>
</tr>
<tr>
<td>PM2.5</td>
<td>27,462</td>
<td>1st (lowest)</td>
<td>Reference</td>
<td>Reference</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2nd</td>
<td>1.13 (0.97, 1.32)</td>
<td>1.04 (0.89, 1.22)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3rd</td>
<td>1.03 (0.86, 1.24)</td>
<td>1.00 (0.83, 1.21)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4th</td>
<td>1.13 (0.82, 1.56)</td>
<td>1.43 (0.98, 2.10)</td>
</tr>
</tbody>
</table>

Odds ratios by pollutant quartile for having asthma or at least one asthma attack in the previous year.

Akinbami et al. Environ Res. 2010 Apr;110(3):294-301
Climate change and degraded air quality: GHG emissions, particulates and ozone formation

Carbon dioxide (minimal direct effect on health)
Particulate Matter
Air Toxics

Nitrogen Dioxide and VOCs (+sun and heat)

OZONE
Ozone formation and climate change

- The underlying chemistry of ozone formation works best on hot days.
- Ozone formation also requires sunlight.
- Typically, the sites of highest ozone do not directly overlap with areas of production of ozone precursors:
  - Chemical scavenging
  - Meteorology
- Extreme heat from climate change can directly impact achieving NAAQS levels.
- Wildfire smoke can also provide ozone precursors.
- Exceptional events or the new reality?
Climate change -> Hotter days → more ozone days
Climate change -> Hotter days \(\rightarrow\) Higher ozone

Ozone concentrations across the modeling domain during the high ozone period (June–August) under the observed 2010s climate and the difference between the observed and counterfactual climates.

Climate change → Hotter days → Higher ozone

Average Annual Change in Tropospheric Ozone

<table>
<thead>
<tr>
<th>Ozone (ppb)</th>
<th>Combined</th>
<th>Climate Change</th>
<th>Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; -8</td>
<td><img src="image1" alt="Map" /></td>
<td><img src="image2" alt="Map" /></td>
<td><img src="image3" alt="Map" /></td>
</tr>
<tr>
<td>RCP 4.5</td>
<td><img src="image4" alt="Map" /></td>
<td><img src="image5" alt="Map" /></td>
<td><img src="image6" alt="Map" /></td>
</tr>
<tr>
<td>RCP 8.5</td>
<td><img src="image7" alt="Map" /></td>
<td><img src="image8" alt="Map" /></td>
<td><img src="image9" alt="Map" /></td>
</tr>
<tr>
<td>&gt; 8</td>
<td><img src="image10" alt="Map" /></td>
<td><img src="image11" alt="Map" /></td>
<td><img src="image12" alt="Map" /></td>
</tr>
</tbody>
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Regulating ozone levels and climate change (part 1)

- Hotter temperatures increase risk of high ozone days
- Climate change is increasing the number of hot days
- This means deeper reductions in ozone precursors are required to achieve a similar impact on ozone levels in comparison to a stable climate where average summer temperatures are constant
- Example – oil and gas Leak Detection and Repair (LDAR) in Colorado
  - 2017 – LDAR only required for larger production facilities
  - 2021 – Annual LDAR for all facilities, monthly LDAR in areas of non-attainment for most facilities (note co-benefit GHG reductions)
Wildfires, degraded air quality and climate change: A growing particulate matter problem with profound health impact and grossly inadequate immediate solutions
Wildfires, degraded air quality and climate change: Dangerous combusted products
Climate change is driving wildfires


John T. Abatzoglou, and A. Park Williams PNAS doi:10.1073/pnas.1607171113
Climate change is driving wildfires

Evolution and trends in western US forest fuel aridity metrics over the past several decades.

John T. Abatzoglou, and A. Park Williams PNAS doi:10.1073/pnas.1607171113
Health effects of wildfires

Wildfires: a significant cause of mortality

Global mortality from wildfire smoke:
Estimated to be 339,000 persons/year
Percentage Change in Hospitalization Rate by Cause per 10 ug/m3 Increase in PM2.5 for the US Eastern and Western Regions for all Outcomes

Ample evidence associated wildfire smoke with adverse health outcomes: The science in this area would ordinarily lead to regulations

### Association of wildfire smoke and morbidity: MULTIPLE LINES OF EVIDENCE

<table>
<thead>
<tr>
<th>Morbidity</th>
<th>Respiratory</th>
<th>Increased</th>
<th>Very Strong</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asthma</td>
<td>Increased</td>
<td>Very Strong</td>
<td>+ Lui et al., 2017a; Lui et al., 2017b; + Tinling et al., 2016; + Reid et al., 2016b; + Parthum et al., 2017; + Le et al., 2014*</td>
<td></td>
</tr>
<tr>
<td>COPD</td>
<td>Increased</td>
<td>Very Strong</td>
<td>+ Vicedo-Cabrera et al., 2016; + Reid et al., 2016b; + Alman et al., 2016; + Parthum et al., 2017, – Kollanus et al., 2016</td>
<td></td>
</tr>
<tr>
<td>Infection</td>
<td>Increased</td>
<td>Strong</td>
<td>+ Reid et al., 2016b; Alman et al., 2016; + Parthum et al., 2017, – Kollanus et al., 2016; +Le et al., 2014*</td>
<td></td>
</tr>
</tbody>
</table>

This image is intended for educational purposes only and cannot be copied or redistributed.
Kelowna, Australia: Impact of 2003 bush fires on PM10 and weekly MD visits

Projected Change from 1981–2000 to 2080–2099 in Frequency of Wildfires and Length of Wildfire Season, According to Global Mean Surface-Temperature Increase.

A Change in Frequency of Wildfires, 1.5°C Increase
B Change in Length of Wildfire Season, 1.5°C Increase
C Change in Frequency of Wildfires, 2.0°C Increase
D Change in Length of Wildfire Season, 2.0°C Increase
E Change in Frequency of Wildfires, RCP 8.5
F Change in Length of Wildfire Season, RCP 8.5

This image is intended for educational purposes only and cannot be copied or redistributed.

Main Actions That Individual People Can Take to Reduce Exposure to Wildfire Smoke and Its Health Risks.

**Personal Actions**

- **Elimination**
  - Reduces exposure by 100%
  - Close doors and windows
  - Set air conditioners in recirculation mode
  - Use portable air cleaners with HEPA filters or central air conditioners with filters

- **Engineering controls**
  - Reduce exposure by 20 to 90%, depending on quality of filters or air cleaners
  - Stay indoors
  - Avoid heavy or prolonged physical activity

- **Administrative controls**
  - Reduce exposure by approximately 50%
  - Wear a face mask

- **Personal protective equipment**
  - Reduces exposure by ≥90% if well fitted but nearly 0% if poorly fitted

**Limitations or Concerns**

- Relocation increases costs and stress and has unpredictable duration.
- Wildfire particulate matter and ozone may extend thousands of kilometers.
- Relocation may not be feasible.
- Effectiveness varies greatly with ventilation and filtration rates.
- Most filters reduce only particulate matter and not gaseous pollutants (e.g., ozone).
- Cost is prohibitive for some.
- Strategies are less effective for “leaky” houses.
- Exposure to indoor air pollution (e.g., cooking smoke and aldehydes from paints and furnishings) is increased.
- Insufficient physical activity may lead to adverse health effects.
- Strategies are impractical for outdoor workers.

Only certain face masks (e.g., N95 or P100) can reduce exposure to particulate matter. Effectiveness depends on fit, and fit testing is not generally available.

Masks cannot protect against gaseous pollutants.

Masks may provide a false sense of security and thus increase outdoor time and actual exposure.

Masks may cause physical stress due to increased work of breathing, heat, and discomfort.

Masks are not suitable for children, people with facial hair, and those with lung or heart diseases.

Cost is prohibitive for some.

The challenge of managing climate change driven degraded air quality and risks to individual and public health
AQI forecasts: Lack granularity to be useful
Regional and microscale air pollution during wildfires: What we see and how we are warned

**Detailed Air Quality Summary for 09/26/20**

Learn more about monitoring sites: site descriptions and real-time monitoring map.

All data are collected real-time and have not been corrected nor validated.

**Daily Highs:**

| Area                      | Site          | Air Quality | Max AQI | Pollutant            | Conc. | Period  | Time (
<table>
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</tr>
</thead>
<tbody>
<tr>
<td>Denver METRO (exposed)</td>
<td>NH</td>
<td>Unhealthy for Sensitive Groups</td>
<td>106</td>
<td>Particulate &lt; 2.5 micrometers</td>
<td>38 μg/m³</td>
<td>24-hour</td>
<td>8 PM</td>
</tr>
<tr>
<td>Ft. Collins - Greeley (exposed)</td>
<td>GREEH</td>
<td>Moderate</td>
<td>67</td>
<td>Particulate &lt; 2.5 micrometers</td>
<td>34 μg/m³</td>
<td>24-hour</td>
<td>6 PM</td>
</tr>
<tr>
<td>Colorado Springs (exposed)</td>
<td>CCOl</td>
<td>Moderate</td>
<td>67</td>
<td>Particulate &lt; 2.5 micrometers</td>
<td>20 μg/m³</td>
<td>24-hour</td>
<td>12 AM</td>
</tr>
<tr>
<td>Grand Junction (exposed)</td>
<td>GJPB</td>
<td>Good</td>
<td>48</td>
<td>Particulate &lt; 2.5 micrometers</td>
<td>11 μg/m³</td>
<td>24-hour</td>
<td>1 AM</td>
</tr>
<tr>
<td>Colorado River Valley (exposed)</td>
<td>RIFLO3</td>
<td>Good</td>
<td>45</td>
<td>Ozone</td>
<td>49 PPM</td>
<td>8-hour</td>
<td>7 PM</td>
</tr>
<tr>
<td>Four Corners (exposed)</td>
<td>CTZ</td>
<td>Good</td>
<td>49</td>
<td>Ozone</td>
<td>53 PPM</td>
<td>8-hour</td>
<td>6 PM</td>
</tr>
<tr>
<td>Other (exposed)</td>
<td>ASPN2</td>
<td>Good</td>
<td>48</td>
<td>Particulate &lt; 2.5 micrometers</td>
<td>11 μg/m³</td>
<td>24-hour</td>
<td>10 PM</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Area</th>
<th>Site</th>
<th>Visibility</th>
<th>Max VSI</th>
<th>4-hour Average (µg/m³)</th>
<th>Beta Extinction (µg/m³)</th>
<th>Time (EST)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denver</td>
<td>DES</td>
<td>Poor</td>
<td>126</td>
<td>0.065</td>
<td>0.082</td>
<td>3 PM</td>
</tr>
</tbody>
</table>
Public health recommendations for areas affected by smoke:
If smoke is thick or becomes thick in your neighborhood you may want to remain indoors. This is especially true for those with heart disease, respiratory illnesses, the very young, and the elderly. Consider limiting outdoor activity when moderate to heavy smoke is present. Consider relocating temporarily if smoke is present indoors and is making you ill. IF VISIBILITY IS LESS THAN 5 MILES IN SMOKE IN YOUR NEIGHBORHOOD, SMOKE HAS REACHED LEVELS THAT ARE UNHEALTHY.
The problem of degraded air quality from climate change: The patient perspective

- 66 year-old man with chronic obstructive lung disease
- Exercise is known to improved COPD outcomes, so patient was encouraged by his MD to exercise daily
- Due to wildfires to the West, PM levels are in the unsafe range in Denver metro, and predicted to stay that way for at least a week
- Should patient be told to stay inside and not go for walks?
Blister versus bunion: A key concern for parents in relationship to air pollution

Do acute symptoms from wildfire pollution portend long term damage to the lungs, especially in kids?
How does wildfire smoke that causes “at risk” AQI levels impact health and activity?

- 15 year-old male with body mass index of 28 and asthma
- Family and primary care provider are trying to encourage more physical activity
- Summer of 2020 – patient needed rescue inhaler 4 times during a moderate wildfire AQI event after walking family dog

- *Should patient always avoid exercise/outdoors when AQI is bad?*
- *How does he know AQI in real time where he lives?*
- *Preventive use of inhalers prevent his symptoms= Is it OK for him to exercise after using albuterol?*
How does wildfire smoke that causes “at risk” AQI levels impact health and activity?

- 8-year old female on soccer team
- History of intermittent asthma symptoms after upper respiratory tract infections treated with sporadic albuterol

1. Should she skip soccer practice?
2. What if poor AQI event lasts for 4 weeks?
3. **Could exercise during poor AQI events cause her asthma to get worse in the long-term?**
Current “best” recommendations

- Education for parents and families about potential risks
- Children, adolescents, the elderly and those with lung disease are more susceptible to the effects of air pollution than healthy adults
- Individual sensitivity to pollution should be primary guide for activity recommendations (outside of known very high-risk groups)
  - History of symptom flares requiring step-up in therapy
  - Fairness issues (held inside for recess?).
  - Miss practices?
- No clear data to support blanket activity limitations during short term moderately poor AQI events
- **Prolonged and recurrent wildfire-driven AQI events are an increasing concern that require more research to enable evidence-based recommendations**
Gauderman et al: The Effect of Air Pollution on Lung Development from 10 to 18 Years of Age
Public Health Goal: Developing personalized and granular health and activity recommendations
References

3. Akinbami et al Environ Res. 2010 Apr;110(3):294-301