Sneeze and Wheeze in a Low Earth Orbit: Forecasting Pollen from Space

Jeremy Hess, MD, MPH
Associate Professor
Emergency Medicine, Environmental & Occupational Health Sciences, Global Health
Director, UW Center for Health and the Global Environment (CHanGE)

Fiona Lo, MS; Cecilia Bitz, PhD; UW Atmospheric Science
Disclosures

> Research funding from the National Institutes of Health (NIH), the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), the National Oceanic and Atmospheric Administration (NOAA), the Wellcome Trust, the UW Global Innovation Fund, and the Ren Che Foundation

> Sponsored travel from NOAA, NSF, Sun-Yat Sen University, and the University College London

> Research consultation for the European Union
Acknowledgements

Funding from NASA: 5-HAQST15-0025
National Allergy Bureau pollen data providers and their clinics:

Alan Goldsobel, MD, FAAAAI, & James Wolfe, MD, FAAAAI, Allergy and Asthma Associates of Northern California, San Jose, CA
Robert Nathan, MD, FAAAAI, & Daniel Soteres, MD, MPH, FAAAAI, Asthma and Allergy Associates, PC, Colorado Springs, CO
Christopher Randolf, MD, FAAAAI, Waterbury, CT
Richard Henry, MD, Asthma & Allergy of Idaho, Twin Falls, ID
Joseph Leija, MD, FAAAAI, Melrose Park, IL
James Sublett, MD, FAAAAI, Family Allergy & Asthma, Louisville, KY
Jonathon Matz, MD, FAAAAI, & David Golden, MD, FAAAAI, Baltimore, MD
Harold Kaiser, MD, FAAAAI, Clinical Research Institute, Minneapolis, MN
Jay Portnoy, MD, FAAAAI, Children’s Mercy Hospital, Kansas City, MO
Rhizza Adams, Springfield-Greene County Health Department, Springfield, MO
Wayne Wilhelm, St. Louis County Health Department, Berkeley, MO
Linda Ford, MD, FAAAAI, The Asthma and Allergy Center, PC, Bellevue, NE
Donald Pulver, MD, FAAAAI, Allergy, Asthma & Immunology of Rochester, Rochester, NY
Andy Roth, RAPCA, Dayton, OH
Warren Filley, MD, FAAAAI, OK Allergy Asthma Clinic, Inc., Oklahoma City, OK
Martha Tarpay, MD, Allergy & Asthma Center, Oklahoma City, OK
Amy Darter, MD, Oklahoma Institute of Allergy & Asthma, Oklahoma City, OK
James Anderson, MLT, OSHTECH, London, ONT
Kraig Jacobson, MD, FAAAAI, Allergy & Asthma Research Group, Eugene, OR
Philip Gallagher, MD, FAAAAI, Allergy & Asthma Associates of Northeastern Pennsylvania, Erie, PA
Neil Kao, MD, FAAAAI, Allergic Disease and Asthma Center, Greenville, SC
Sheila Amar, MD, FAAAAI, FACAII, Allergy & Asthma Center of Georgetown, Austin, TX
David Weldon, MD, FAAAAI, FACAII, Scott & White Clinic, College Station, TX
Tony Huynh, City of Houston, Houston, TX
Robert Gomez, Wiford Hall Ambulatory Surgical Center, San Antonio, TX
Paul Ratner, MD, MBA, FAAAAI, Sylvana Research Associates, San Antonio, TX
Pramila K. Daftary, MD, FAAAAI, Allergy & Asthma Care of Waco, Waco, TX
Duane Harris, MD, FAAAAI, Intermountain Allergy & Asthma Clinic, Draper, UT
Frank Virant, MD, FAAAAI, Northwest Asthma & Allergy Center, Seattle, WA
Robert Bush, MD, FAAAAI, University of Wisconsin Medical School, Madison, WI
Susan E. Kosisky, MHA, US Army Garrison-Forest Glen, Silver Spring, MD
Overview

Allergy Etiology & Epidemiology

Improving Management

Developing Forecasts
ETIOLOGY & EPIDEMIOLOGY

Disease origins and distribution
Pollen Allergy Epidemiology

> Substantial disease burden globally
  - Allergic rhinitis (AR) prevalence estimated 10-30%
  - Allergic asthma estimated at 5-10%

> In US, prevalence estimated at 13% in children and 14% in adults (Meltzer, 2009)
  - AR responsible for 3.5m lost work days and 2m lost schooldays per year (Nathan 2007)
  - Decreased health-related quality of life by 25% (Avarro et al. 2007)
  - Estimated $2-5b costs in US in 2003 (Reed et al. 2004); inflation adjusted $4-7b in $US2018
Allergic Disease

- Allergies immune mediated, driven by immune memory (IgE antibodies)
- Multiple exposures drive allergic disease development and flares
- Generally not life threatening but makes people miserable
- Range of therapies
  - Exposure avoidance
  - Symptom reduction
  - Immune modulation
Sensitization by Age and Exposure

Prevalence of IgE sensitization among children with allergic rhinitis

6-7-year-old children

<table>
<thead>
<tr>
<th>Pollen</th>
<th>Positive percent of 56 children</th>
</tr>
</thead>
<tbody>
<tr>
<td>Russian thistle</td>
<td>68%</td>
</tr>
<tr>
<td>Pigweed</td>
<td>61%</td>
</tr>
<tr>
<td>Sagebrush</td>
<td>49%</td>
</tr>
<tr>
<td>Saltgrass</td>
<td>58%</td>
</tr>
<tr>
<td>Timothy</td>
<td>48%</td>
</tr>
<tr>
<td>Bermuda</td>
<td>45%</td>
</tr>
<tr>
<td>Johnson</td>
<td>45%</td>
</tr>
<tr>
<td>Willow</td>
<td>39%</td>
</tr>
<tr>
<td>Sweet gum</td>
<td>32%</td>
</tr>
<tr>
<td>Mulberry</td>
<td>36%</td>
</tr>
</tbody>
</table>

Prevalent allergens in the Great Basin

Wong et al. 2012
# Pollen Types and Seasons

Johns Hopkins University Division of Allergy and Clinical Immunology

## Pollen Types

### Tree Pollens

<table>
<thead>
<tr>
<th>Month</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walnut</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Birch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alder</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poplar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beech</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sycamore</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ash</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oak</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hickory</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Willow</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Juniper</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Grass Pollens

<table>
<thead>
<tr>
<th>Month</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>July</th>
<th>Aug</th>
<th>Sept</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timothy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orchard</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bermuda</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Weed Pollens

<table>
<thead>
<tr>
<th>Month</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>July</th>
<th>Aug</th>
<th>Sept</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sorrel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plantain</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lambsquarters</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pigweed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ragweed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Seasonal Chart

<table>
<thead>
<tr>
<th>Region</th>
<th>Jan</th>
<th>Feb</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>Aug</th>
<th>Sept</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northeast</td>
<td>Trees</td>
<td></td>
<td>Grasses</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mid-Atlantic</td>
<td>Trees</td>
<td></td>
<td>Grasses</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Southeast</td>
<td>Trees</td>
<td></td>
<td>Grasses</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Midwest</td>
<td>Trees</td>
<td></td>
<td>Grasses</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northwest</td>
<td>Trees</td>
<td></td>
<td>Grasses</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Southwest</td>
<td>Trees</td>
<td></td>
<td>Grasses</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Nowak-Wegrzyn A.  
Up To Date, 2017
Pollen and Health - Methods

- Retrospective analysis of associations between tree, weed, and grass pollen and several morbidity measures in the continental US, controlling for particulate air pollution, ozone, and influenza-like illness

- Set season start at cumulative count of 50 grains/m$^3$ unless mean seasonal total count $\leq$ 2,000 grains, then 2.5%

- Metropolitan Statistical Area (MSA) linked with NAB stations, county PM$_{2.5}$ and O$_3$, weekly CDC ILI prevalence

- GEEs used to estimate daily counts
RR Prescription Med Refill High Tree Pollen Days

Location
Overall (random effect)
Atlanta, GA
Austin, TX
Baltimore, MD
Chicago, IL
College Station, TX
Colorado Springs, CO
Dayton, OH
 Erie, PA
Eugene, OR
Greenville, SC
Houston, TX
Kansas City, MO
Louisville, KY
Madison, WI
Minneapolis, MN
Oklahoma City, OK
Omaha, NE
Rochester, NY
Saint Louis, MO
Salt Lake City, UT
San Antonio, TX
San Jose, CA
Seattle, WA
Springfield, MO
Tulsa, OK
Waco, TX
Washington, DC
Waterbury, CT
York, PA

0-17 years age group

18-54 years age group

Saha et al. in preparation
An Increasingly Common Picture
Warming and Plant Hardiness

1990 Map

2006 Map

Zone Change
- + 2
- + 1
- no change
- - 1
- - 2
Warming and Allergic Plant Suitability

2100 Tree Habitat Distribution—High Emissions Scenario

Allergen Hotspots
States with a risk of large increases in allergenic tree pollen:
Arkansas
Iowa
Maine
Minnesota
New Hampshire
New York
Pennsylvania
Vermont
West Virginia

States with a risk of moderate increases in allergenic tree pollen:
Connecticut
Illinois
Kentucky
Massachusetts
Mississippi
Tennessee
Wisconsin
CO₂ and Warming Double Whammy

**US EPA**

**Climate Central**

MORE CO₂ = MORE POLLEN

<table>
<thead>
<tr>
<th>Year</th>
<th>CO₂ Level</th>
<th>Pollen Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>1900</td>
<td>280 ppm</td>
<td>5</td>
</tr>
<tr>
<td>2000</td>
<td>370 ppm</td>
<td>15</td>
</tr>
<tr>
<td>2060</td>
<td>600 ppm</td>
<td>25</td>
</tr>
</tbody>
</table>

Pollen Production: Grams Per Ragweed Plant
Source: Ziska et al. 2000
Sensitization and Pollen Levels


Annual sensitization rates to weed pollen allergens according to age. Weed pollen included ragweed, Japanese hop and mugwort.

Kim et al. 2011
Take-Home Findings

> Widespread, significant disease burden
> Increasing with socioeconomic development
> Pollen exposure is a strong driver of incidence
> Increases in temperature and CO$_2$ will very likely increase allergic disease burden
MANAGEMENT

What to do, and not do, for pollen allergies
Allergic Disease Management

- Medication
- Exposure Reduction
- Immune Therapy
Symptoms and Pollen Counts

Kim et al. 2011
Pollen Types and Seasons

Nowak-Wegrzyn A.  
Up To Date, 2017

Johns Hopkins University Division of Allergy and Clinical Immunology

UNIVERSITY of WASHINGTON  
SCHOOL OF PUBLIC HEALTH
NAB Data

Lo et al. 2019

US Army Centralized Allergen Extract Lab, Silver Spring, MD

Start Date: London ON

Pollen concentration (grain/m³)
Pollen Calendar NAB Data

Total Pollen Count 2003-2016
by latitude

Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec

Lo et al., 2019
Allergenic Trees

Lo et al., 2019
Allergenic Weeds

Urticaceae

Ambrosia

Plantago

Chenopodiaceae/Amaranthaceae

Lo et al., 2019
Allergenic Grass
Gramineae / Poaceae 2003-2016
by latitude

Gramineae/Poaceae

Lo et al., 2019
Site-specific Exposures - Seattle

Pollen Taxa, % abundance

- Total Pollen, 100.0%
- Cypress, 37.2%
- Alder, 28.8%
- Birch, 11.0%
- Pine, 6.8%
- Poplar, 5.1%
- Grass, 2.9%
- Oak, 1.9%
- Unidentified Pollen, 1.6%
- Nettle, 1.3%
- Ash, 0.9%

Seattle WA: Percent of total API

Lo et al., 2019
Start Date, Season Duration, Latitude

Lo et al., 2019
FORECASTING

Building better forecasts
Forecast Model Goals

> Develop model(s) that:
  – Work for all three major types (trees, weeds, grasses) and for specific taxa
  – Work across wide range of geographies
  – Capture start date a week in advance
  – Capture high counts several days in advance
  – Capture season end for ragweed

> Accurately support the decisions patients, clinicians, and others need to make
Factors Associated with Pollen in the Air

- Temperature
- Humidity
- Solar radiation
- Wind speed

Seattle, 19 March 2019
75F, very dry, high winds

Courtesy of Jeff Baars, UW Atmospheric Science
Factors Associated with Pollen Overall


Land Surface Temperature (daytime)

Vegetation Index (NDVI)

March 2000
Model Development

- Machine learning random forest decision tree model
- Ensemble of decision trees to build predictive model
- Computationally efficient, captures nonlinear relationships
- Example: Predicting rainfall for a specific season

Figures from medium.com
Lo et al. 2019

US Army Centralized Allergen Extract Lab, Silver Spring, MD

Pollen concentration (grain/m$^3$)

- Atlanta: Quercus - Oak
- Kansas City: Ambrosia – Ragweed
- Flower Mound: Cupresseceae – Cedar
- Eugene: Graminae/Poaceae - Grass
Atlanta – Quercus - Oak

Atlanta 2017: Quercus

Pollen concentration (grains/m³)

Mar

Apr

May

observed
no pollen collected
P7
P7reg
Kansas City – Ambrosia - Ragweed

KansasCity 2017: Ambrosia

Pollen concentration (grains/m$^3$)

Aug | Sep | Oct | Nov

0 | 100 | 200 | 300 | 400 | 500 | 600

- observed pollen
- no pollen collected
- P7
- P7reg

UNIVERSITY of WASHINGTON
SCHOOL OF PUBLIC HEALTH

CHanGE
Center for Health and the Global Environment
UNIVERSITY of WASHINGTON | SCHOOL OF PUBLIC HEALTH
Flower Mound – Cupressaceae - Cedar

FlowerMound 2016-2017: Cupressaceae

- Observed pollen
- No pollen collected
- P7
- P7reg

Pollen concentration (grains/m³)

Oct  Nov  Dec  Jan  Feb  Mar  Apr
Role of Regional Data

Atlanta Oak

Kansas City Ragweed

FlowerMound Cypress

Eugene Grass

MAE (grains/m²)

forecast horizon (days)
Accuracy – Atlanta – 1, 2, and 3 days

Mean average error Atlanta pollen season start date 14 day forecast: 4.7 days
Daily Oak Pollen Concentration

01 Mar 2009
Next Steps

> Refine models for each taxon
> Develop regional models
  – Produce hindcast gridded estimates
  – Produce climate change projections
> Link with health damage functions
> Incorporate weather forecast data
> Bring forecast products online
Thank You!

jjhess@uw.edu