

Spatio-temporal variability of tetrachloroethylene (PCE) in indoor air due to vapor intrusion

A community based, longitudinal approach

Jill Johnston, PhDc

University of North Carolina – Chapel Hill

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OUTLINE

- Background
 - Challenges in defining exposure due to vapor intrusion
- Objectives
- Methodology
 - Passive sampling of indoor air
 - Indoor air source identification
 - Data analysis & regression model
- Results & Conclusions

BACKGROUND

VAPOR INTRUSION

- Huge number of potentially at risk buildings
- Incomplete understanding of the pathway
- Regulatory process requires
 - Determination of whether the pathway is complete
 - If complete, determination of exposure levels and if buildings require remediation



ESTIMATING EXPOSURE

- Indoor air measurements are a key *line of evidence* to evaluate the vapor intrusion pathway
- **House-specific pathway**
 - Difficult to predict
- Analysis requires **robust data sets**
 - Ability to measure very small concentrations
 - Identify/remove indoor sources
 - Invasive evaluation technique

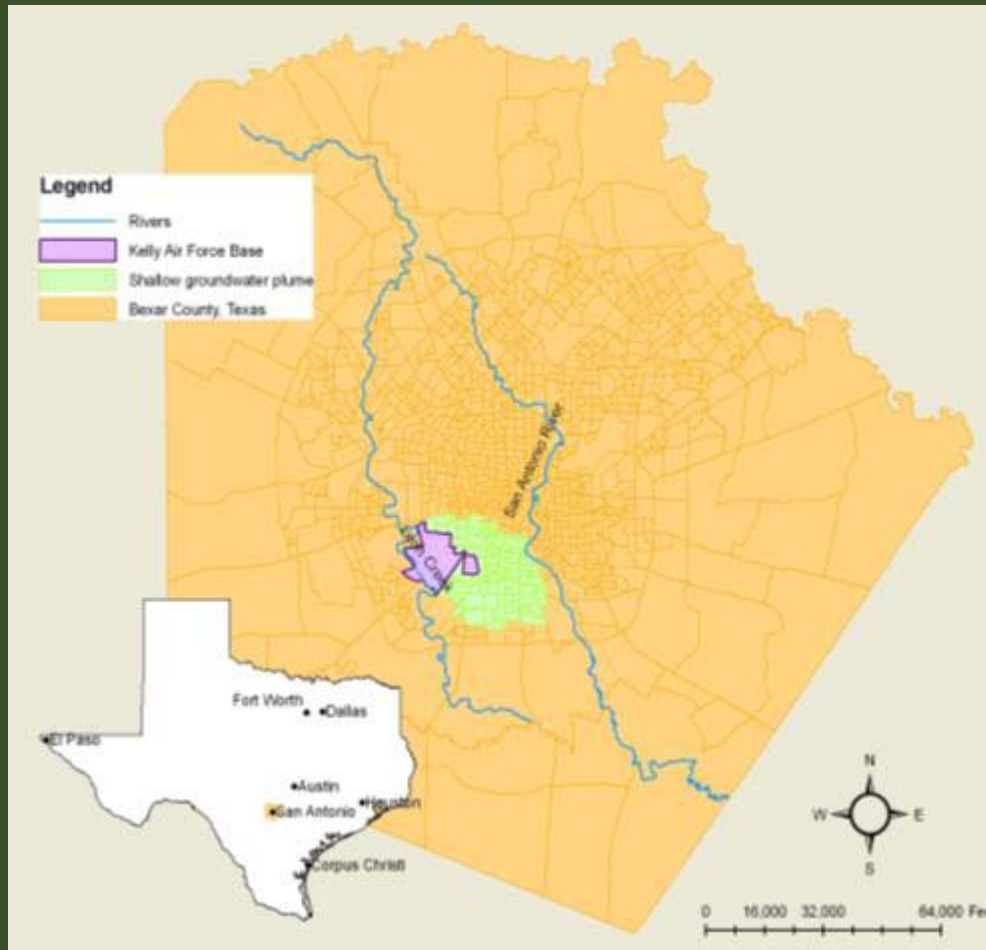


CHALLENGES

- Models are imperfect
- Significant spatial variability across a community
- Temporal variability in vapor intrusion potential
 - Diurnal patterns
 - Seasonal patterns
 - Evidence of short windows of high exposure
 - Over one order magnitude change within 48 hrs
- Current approaches don't provide complete picture of potential vapor intrusion problem in a particular house or a neighborhood

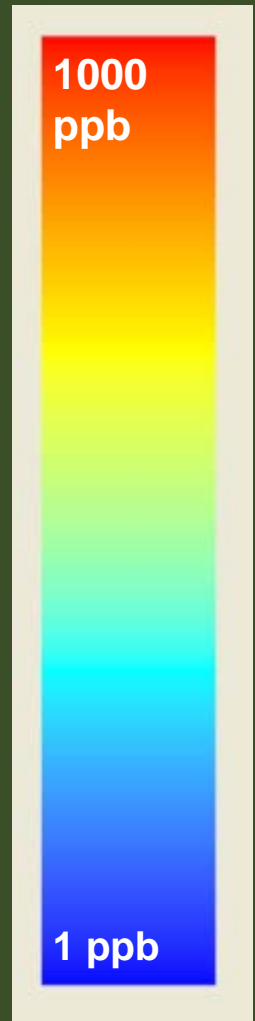
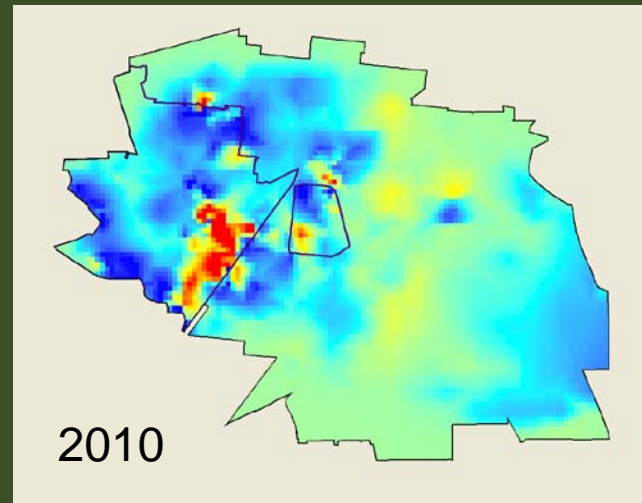
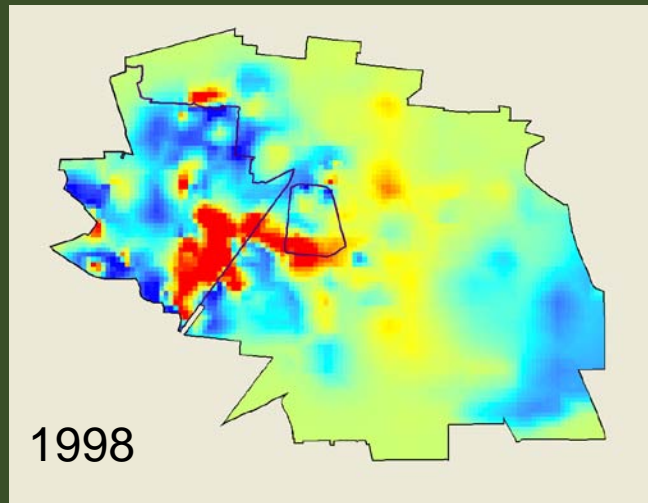
STUDY SITE

KELLY AIR FORCE BASE



- In operation from 1917-2001
- Logistical HQ for the Air Force
- Used PCE on-site
- Caused contamination in shallow aquifer
- Over 31,000 homes sit above plume

PCE PLUME



- 12 square mile PCE plume
- Extends 5 miles from source
- Some plume retraction since remediation

SITE CHARACTERISTICS

- One of the first studies in a Southern climate
- Navarro clay soil
- Typically shallow aquifer, largely rain fed
- 95% Latino, working class community



**~ 70% homes crawl space
~ 30% cement slab**

Older housing stock ('30s-'60s)

PREVIOUS DATA

- EPA study (2008-2009) found elevated levels of PCE and TCE in indoor air and crawl space
 - Confirmed a complete pathway



STUDY OBJECTIVES

POLICY QUESTIONS



- What factors influence the short-term temporal variability of indoor air concentrations of PCE due to vapor intrusion?
- What techniques can help construct a better picture of exposure?
- How can measurement approaches better integrate community and household participation?

RESEARCH OBJECTIVE



- Integrate a longitudinal cross-sectional design to:
 - Determine the indoor concentrations of PCE attributable to vapor intrusion
 - Evaluate the factors that influence temporal variability
 - Demonstrate a community-oriented research design approach

METHODS

STUDY DESIGN

- Partnership with local organization to identify homes in at-risk areas
 - Live in the affected community
 - No smokers in the home
- 20 homes from 4 neighborhoods
- Sampled in July and August 2011
- Subset of 9 re-sampled in February 2012
- Completed survey on household characteristics and daily activity patterns (use of dryer, ventilation, HVAC systems, etc)

SAMPLING DEVICE

- Passive approach
 - No electricity or pumps
 - Comparable results to active sampling
- Stainless steel tubes packed with engineered adsorbent
- Beacon Environmental Services
- Community members assisted with sampling



PROTOCOL

- Duplicate 72-hour samples
- 8-9 sampling periods per home
 - Additional 4 samples from 9 homes in Feb 2012
- Analyzed following EPA TO-17 guidelines
 - Re-collection to allow for secondary analysis
- Concentrations calculated according to established uptake rates
 - Detection limit, on average, 0.13 $\mu\text{g}/\text{m}^3$



Freestanding apparatus located in breathing zone

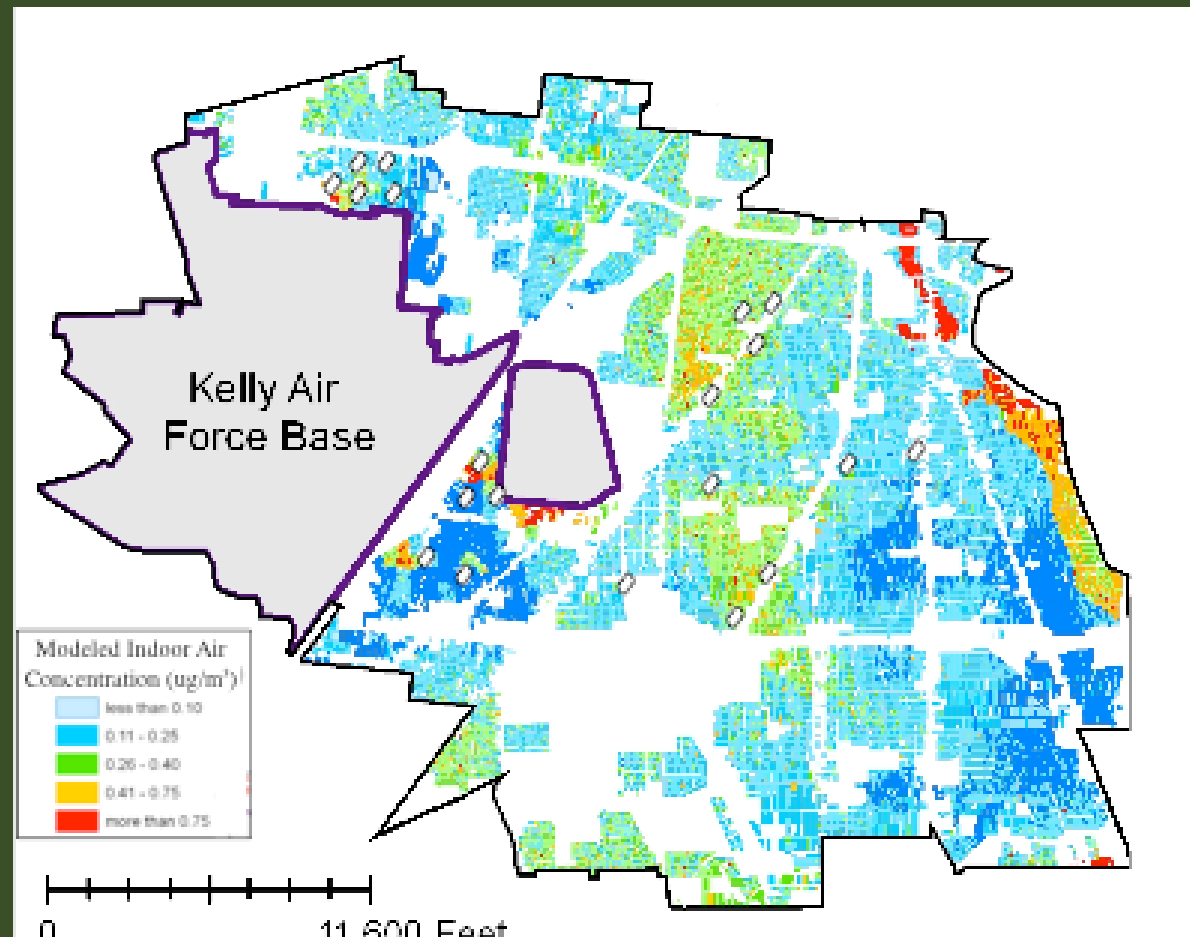
SOURCE IDENTIFICATION

- Identified and removed potential confounding indoor sources
 - Portable air sampler used to ‘sniff’ for PCE
 - Removed potential sources for duration of the study
 - Removed any dry cleaned items
 - Placed monitors after completion of tests for indoor sources
- Interference of air fresheners

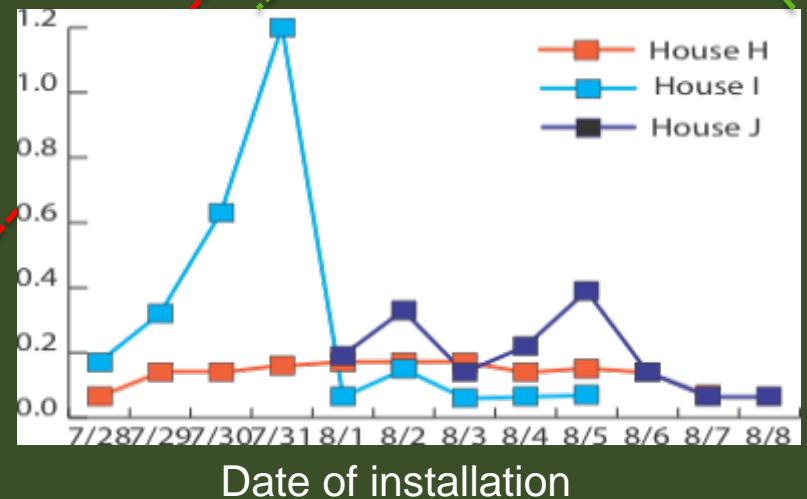
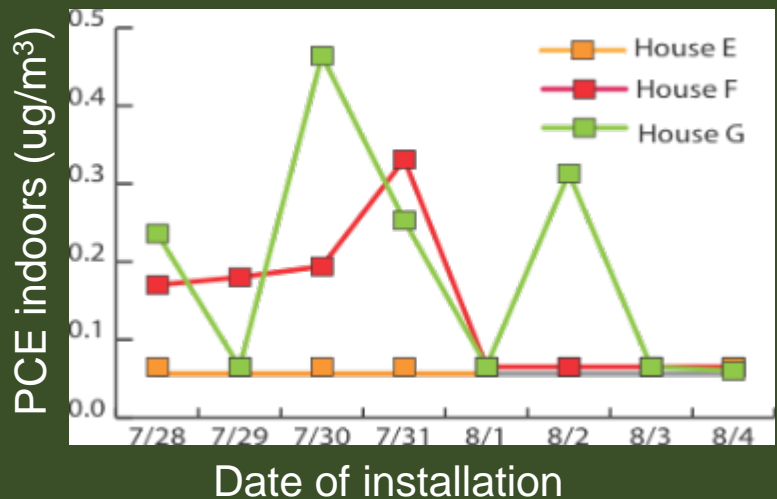
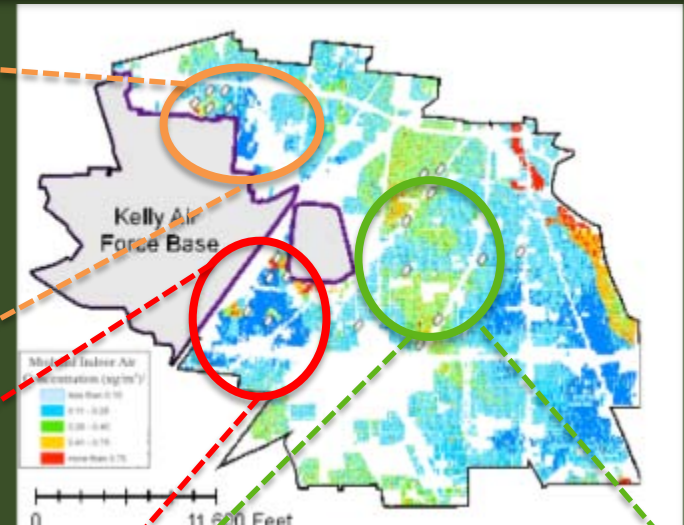
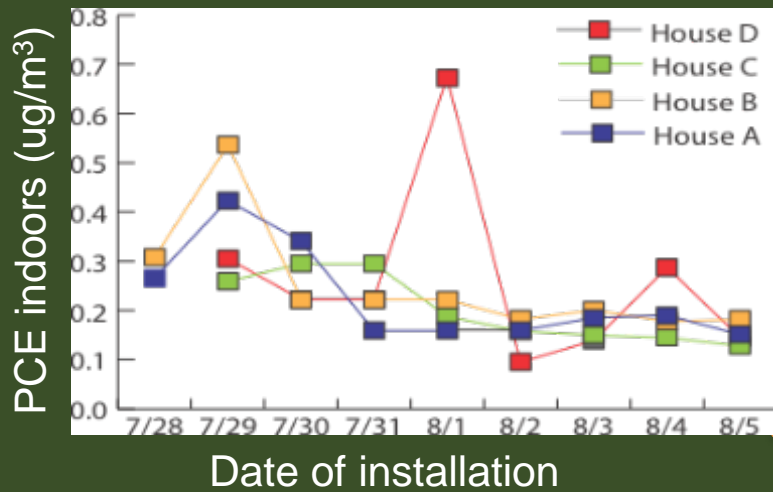


RESULTS

STUDY LOCATIONS



PCE INDOORS OVER TIME

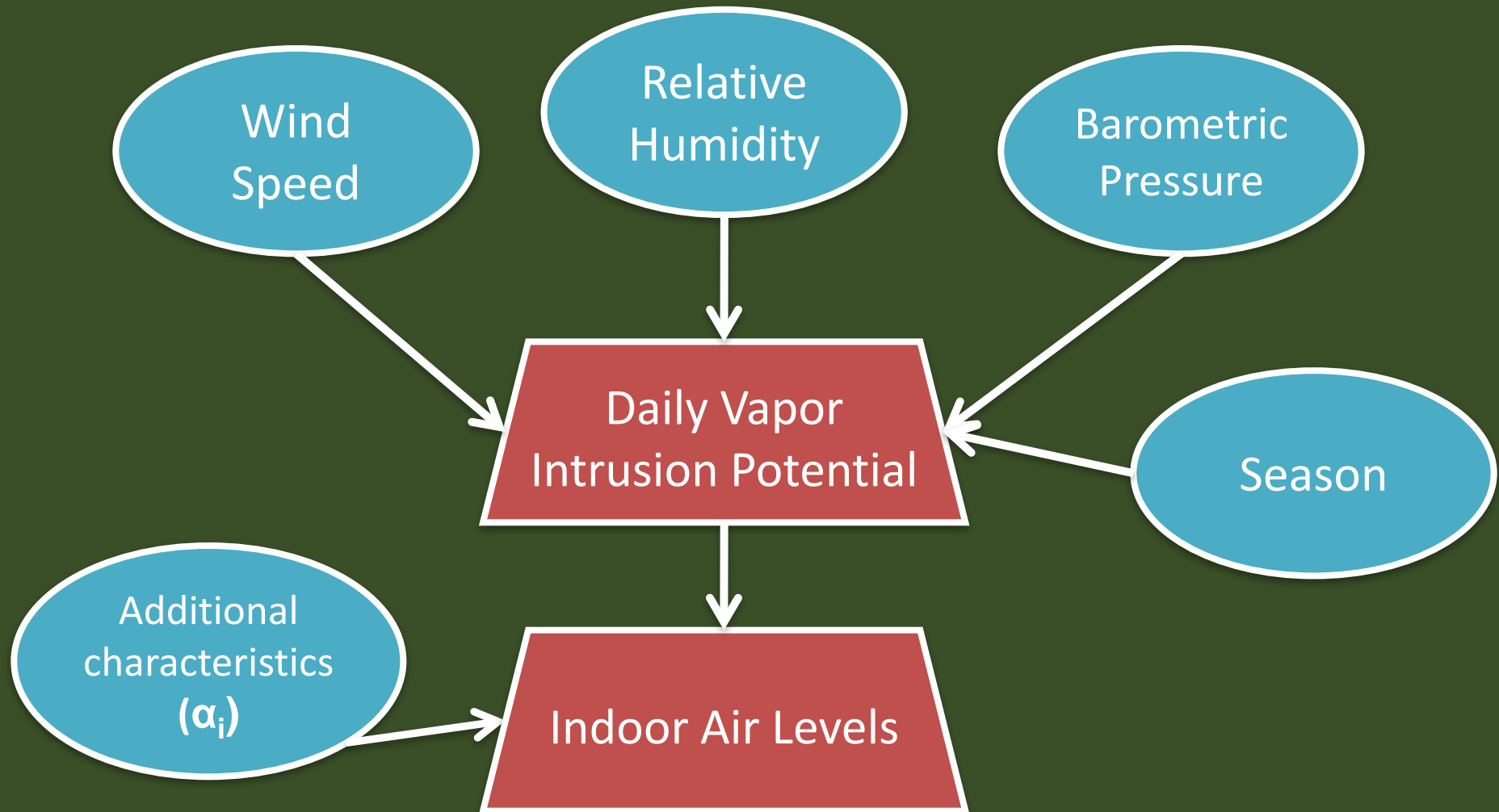


RESULTS: SUMMARY STATS

Variables	Mean All samples (n=170)	Mean Above detection (n=150)
Barometric pressure (in Hg)	29.88	29.89
Wind speed (mph)	54.4	54.5
Household Characteristics		
Crawl space foundation	0.68	0.51
Central A/C	0.32	0.33
Open windows	0.35	0.33

Evidence of
low levels of
vapor
intrusion in 12
out of 20
homes
studied

CONCEPTUAL MODEL



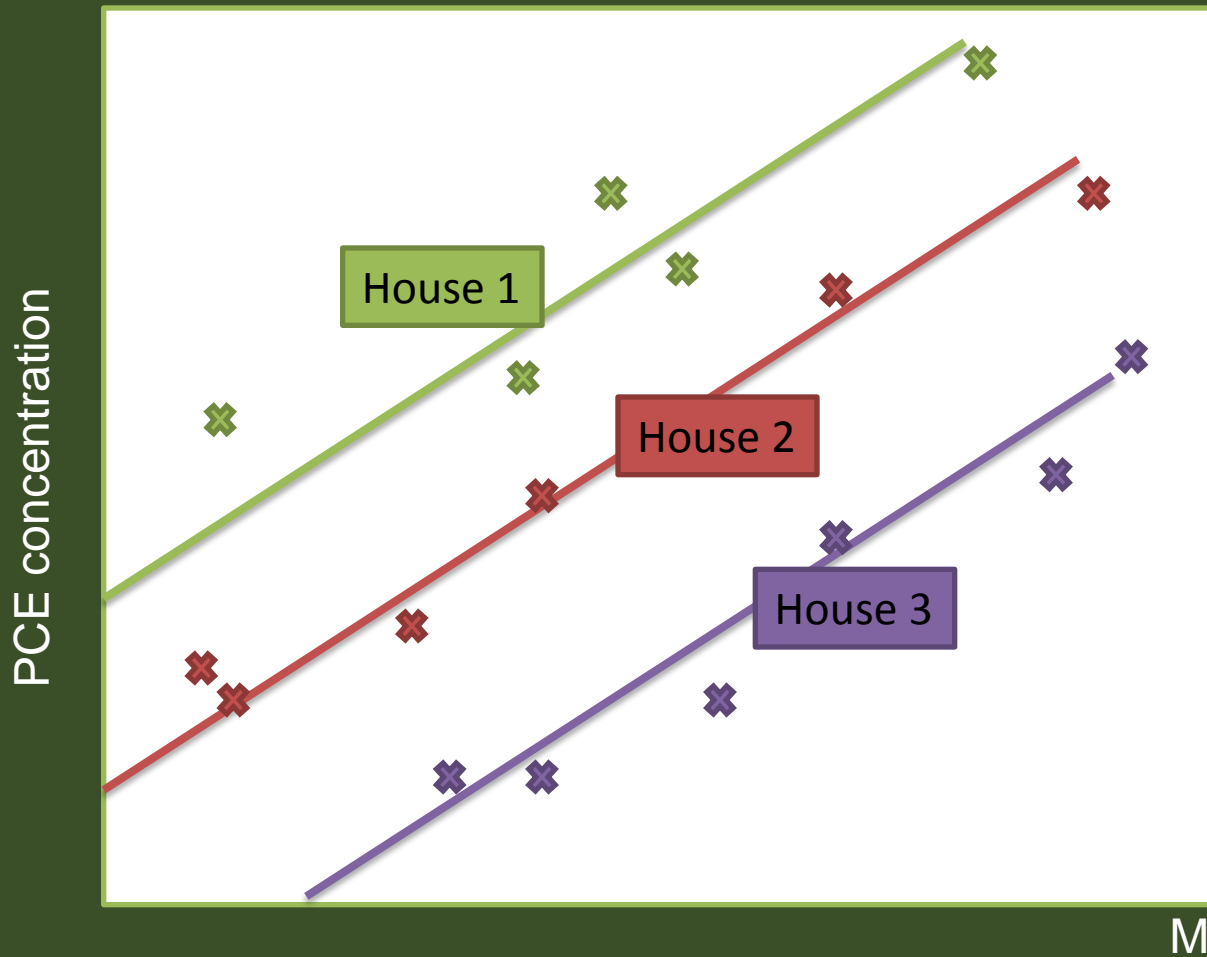
TEMPORAL APPROACH

- What causes changes over time within each home?
- Fixed effect regression approach

$$PCE_{i,t} = \alpha_i + B_1 \text{pressure}_{i,t} + B_2 \text{windspeed}_{i,t} + B_3 \text{humidity}_{i,t} + B_2 \text{season}_{i,t} + \varepsilon_{i,t}$$

- House i , time t
- Examine association between vapor intrusion and weather conditions (barometric pressure and wind speed)
- Estimate house-specific intercept (α_i) for each chemical
- Time invariant factors (soil, foundation, etc) do not bias the model

REGRESSION CONCEPT



Average slope =
marginal effect of
covariate

Intercept, α_i =
'fixed effect'

Model not biased
by unobserved
time invariant
characteristics

NON DETECTION ISSUE

- Ignoring or assigning a common value (1/2 detection limit) biases the results
- **Truncated data regressions (left censored data)**
 - Unbiased maximum likelihood model
 - Likelihood function for censored data represented as a probability of being less than the detection limit (tobit model)
- **Log transformed dependent variable**
 - Indoor air concentration of PCE due to vapor intrusion (log-ug/m³)
 - robust standard errors

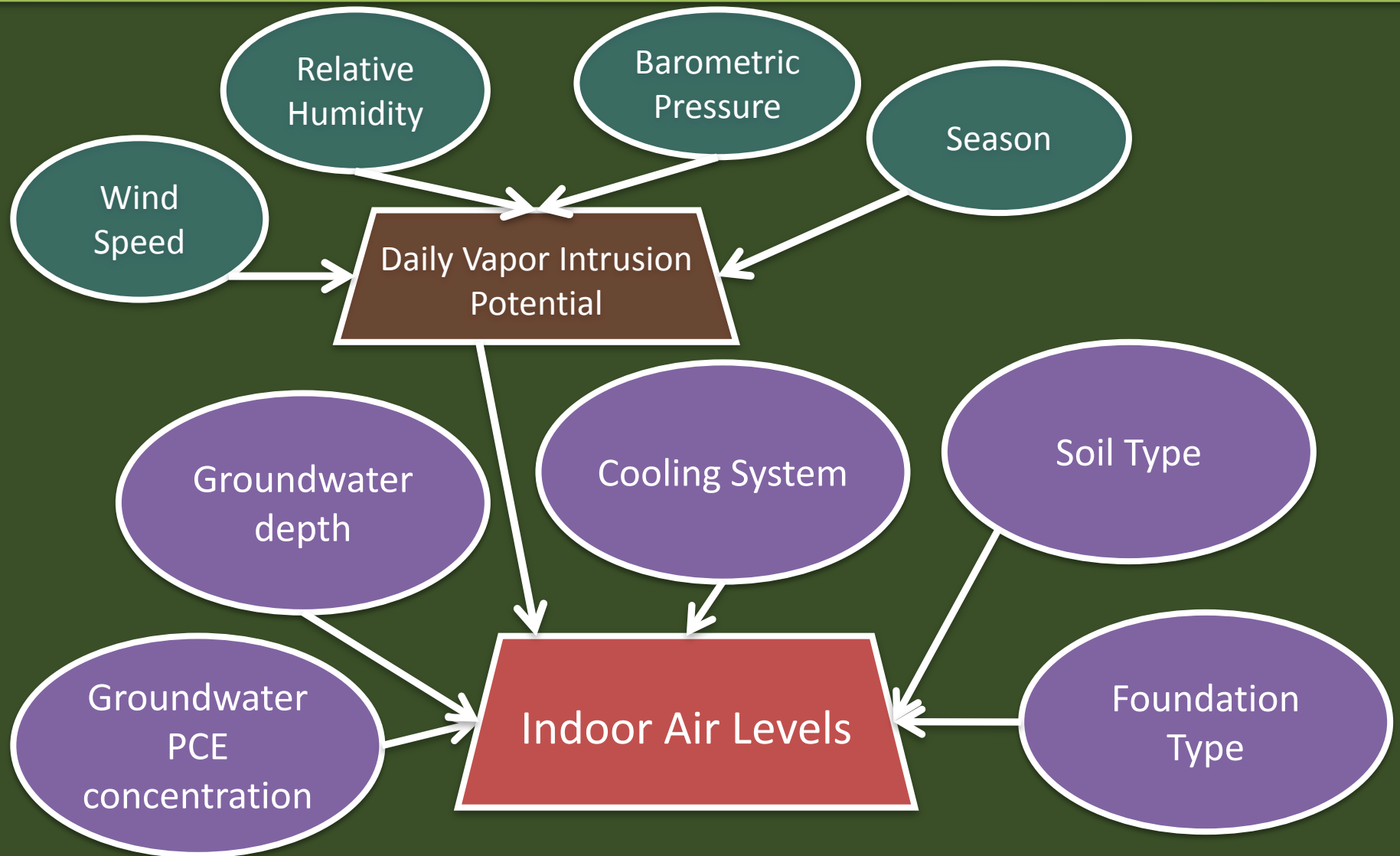
TEMPORAL MODEL RESULTS

Association between barometric pressure and log indoor PCE concentrations due to vapor intrusion

Highest concentrations within a home in high pressure, low wind conditions during the summer season

Variables	Marginal effect (n=120)
Barometric pressure (in Hg)	3.58**
Wind speed (mph)	-0.065*
Relative Humidity (%)	0.018*
Summer	1.14**
** p<0.05 * p<0.10 (clustered robust standard errors)	

SPATIAL MODEL



SPATIAL MODEL RESULTS

Variables	Average Marginal Effect (n=170)
PCE in groundwater (ug/L)	0.29**
Groundwater level (ft)	-0.06
Central A/C	0.21
Crawl Space Foundation	0.38**
Silt Soil	0.29
Barometric pressure (in Hg)	3.45**
Wind speed (mph)	-0.10*
Summer	0.50*

** p<0.05 * p<0.10
(clustered robust standard errors)

Population average approach accounting for data censoring

Higher Risk:

- PCE groundwater concentration increases
- Pressure increases
- Crawl space foundation

INSIGHTS

- Protocol adherence facilitated by simplicity of sampling devices and integration of local organizations
 - Potential for community-led research with passive devices
- PCE concentrations in indoor air vary 2x-3x over a short time period
- Single 24-hour sample of indoor air may not be representative of exposure
- Predictive models may be improved with increased understanding of the association between meteorological conditions, household characteristics, and indoor air concentrations

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THANKS! QUESTIONS?

Jill Johnston, PhDc

jillj@email.unc.edu

University of North Carolina at Chapel Hill