Modeling Climate Change Effects on Spatiotemporal Distributions of Allergenic Pollen from Trees, Weeds and Grasses

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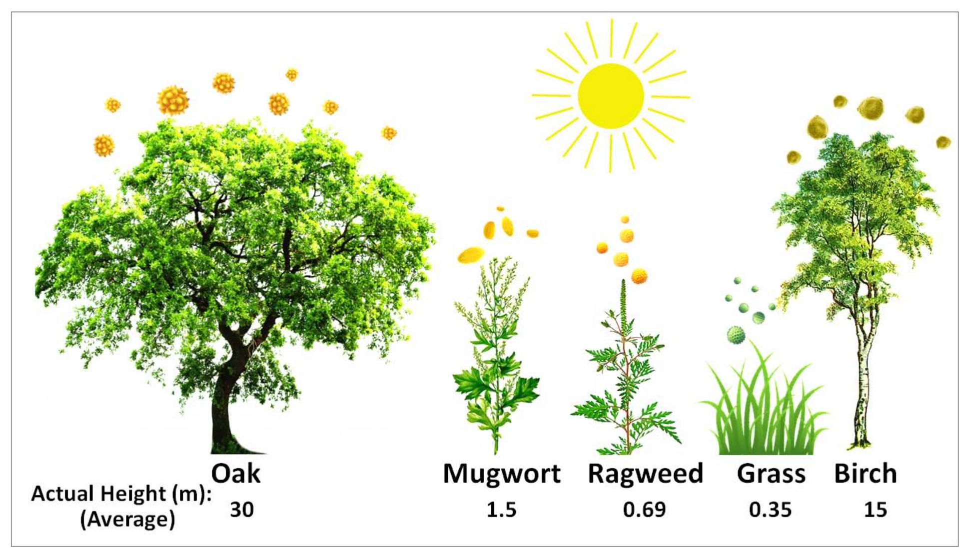
Abstract

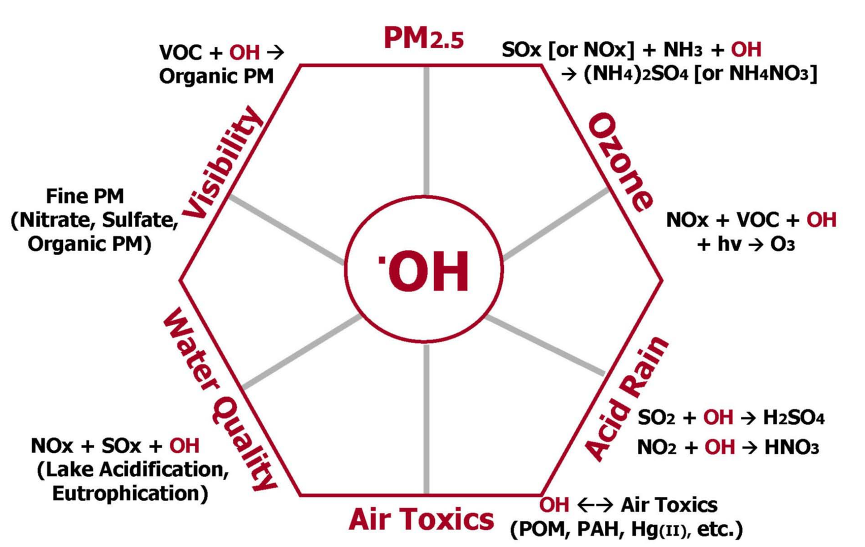
Many diseases are linked with climate trends and variations. In particular, climate change is expected to alter the spatiotemporal dynamics of airborne allergenic pollen and potentially increase occurrence of allergic airway disease. A comprehensive prognostic modeling system, combining climate models and anthropogenic and biogenic emission models with an expanded version of the Community Multiscale Air Quality (CMAQ) Model has been developed to support integrated studies of the impact of climate change on Airway Allergic Disease (AAD). The present work focuses on the mechanistic pollen emission module and the transport module, and their application to model the spatiotemporal distributions of allergenic pollen from representative trees, weeds and grasses. The model system was used to simulate the allergenic pollen season timing and airborne levels of representative trees, weeds and grasses for multiple historical and future years

The predicted mean start dates and season lengths for birch, oak, ragweed, mugwort and grass pollen season in 1994-2010 are mostly within 0 to 6 days of the corresponding observations for the majority of the National Allergy Bureau (NAB) monitoring stations across the contiguous United States (CONUS). Simulated airborne pollen levels are consistent with the observations for oak and ragweed, but do not match observations well for birch, mugwort and grass at some locations. Simulated vertical profiles of pollen concentrations can match well with the observed qualitative profiles reported in the literature. Process analysis indicates that emissions, dry deposition and vertical diffusion dominate the processes determining airborne pollen concentrations most, and that wet removal (cloud process) plays an important role during rain events. The spatially resolved maps for simulated onset, duration and airborne levels of allergenic pollen seasons in the CONUS are consistent with the long term observations. Changes of pollen season timing and airborne levels depend on latitude, and vary in different climate regions.

Background

Climate change impacts pollen dynamics, affecting important metrics such as: annual total count, maximum and mean daily count, start date of season and season length. These indices are useful in characterizing pollen impacts to allergic airway diseases (AAD) and to processes involving genetic manipulation of plants. Birch (*Betula*), Oak (*Quercus*), Ragweed (*Ambrosia*), Mugwort (*Artemisia*) and Grass (*Poaceae*) have been selected as representative species in the present case study.

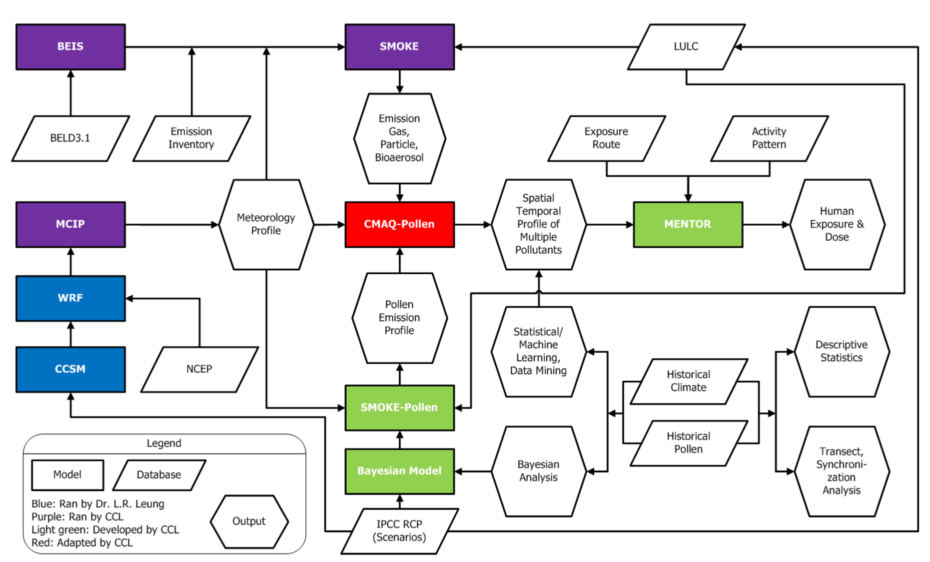




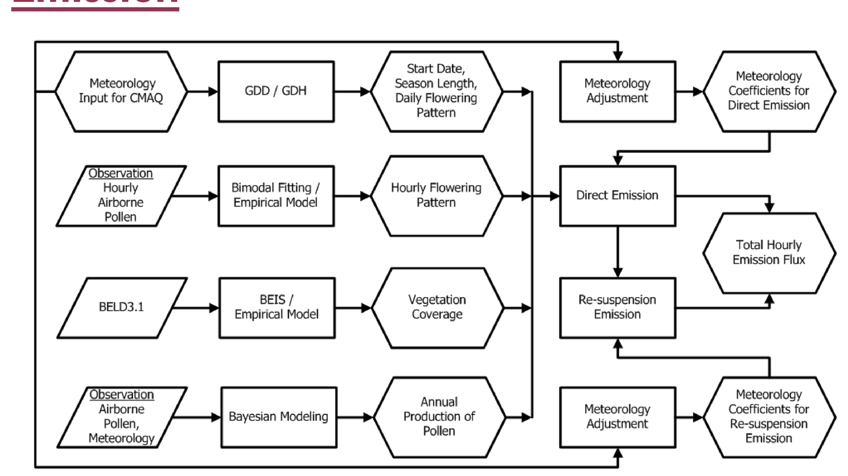
Schematic representation of allergenic plants, flowers and pollen release (left); and atmospheric dynamics of co-occurring air pollutants (right). The present study involves development of modules for investigating the distribution of aeroallergens and co-occurring pollutants in the atmosphere, as part of the existing framework of MENTOR (Modeling ENvironment for Total Risk studies - Georgopoulos and Lioy 2006).

Methods

- The integrated system presented here links climate modeling with emissions, transport, and exposure modeling (shown on right)
- The emissions and transport of pollen were simulated via the combined application of the WRF model, the SMOKE model and a customized version of the CMAQ model.
- CMAQ 4.7.1, contiguous US 50x50 km, 34 Layers; Northeastern US 12x12 km, 34 Layers

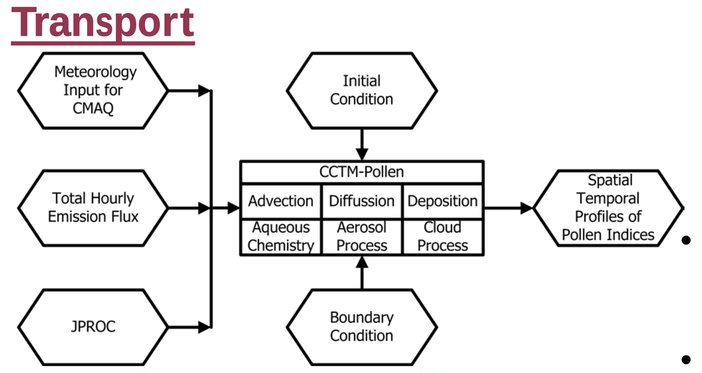


Emission



- The schematic diagram of the pollen emissions model is shown above. Total emissions flux consists of direct emissions and resuspension emissions
- The Start Date (SD) and Season Length (SL) were simulated based on the Growing Degree Days (GDD) model (Zhang et al. 2013a)
- Vegetation coverage was generated using an empirical model (Skjøth et al. 2010)

Transport



$$\underbrace{\frac{\partial \varphi_p^*}{\partial t}}_{(a)} + \overbrace{\nabla_s \cdot \left[\varphi_p^* \hat{\bar{V}}_s\right]}^{(b)} + \underbrace{\frac{\partial(\varphi_p^* \hat{\bar{v}}^3)}{\partial \hat{x}^3}}_{(c)} + \overbrace{\nabla_s \cdot \left[\bar{\rho}\sqrt{\hat{\gamma}}\hat{F}_{q_p}\right]}^{(d)} + \underbrace{\frac{\partial(\bar{\rho}\sqrt{\hat{\gamma}}\hat{F}^3_{q_p})}{\partial \hat{x}^3}}_{(e)}$$

$$= \overbrace{\sqrt{\hat{\gamma}}S_{\varphi_p}}^{(f)} + \underbrace{\left.\frac{\partial \varphi_p^*}{\partial t}\right|_{cld}}_{(g)} + \overbrace{\left.\frac{\partial \varphi_p^*}{\partial t}\right|_{aero}}^{h}$$

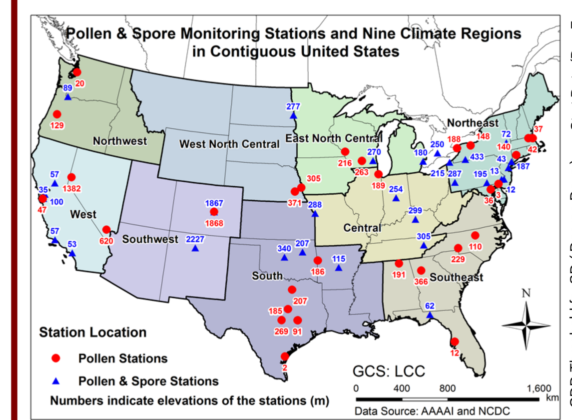
Adapted from Byun and Schere 2006

Evaluation

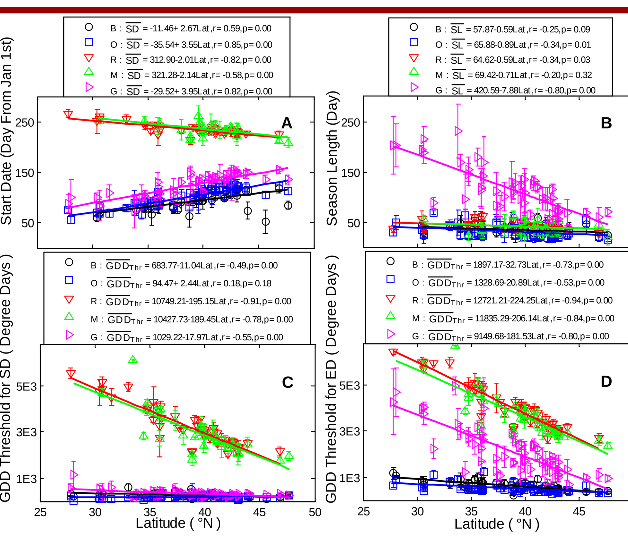
Follow Methods in Zink et al. 2012; Prank et al. 2013; Zhang et al 2014

- Treats pollen grain as coarse mode particulate matter
- Customizes CMAQ by modifying relevant subroutines aero_depv.F, AERO_EMIS.F, AERO_INFO.f and aero_subs.f etc.

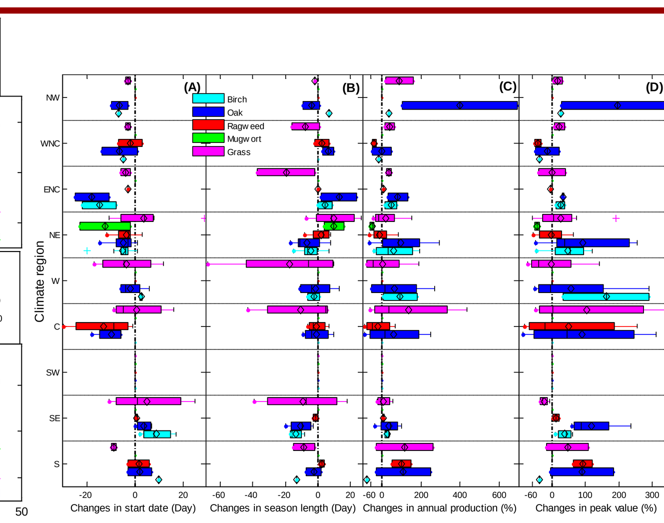
Observation



Distribution of the studied pollen stations (n = 50) across the nine climate regions in the contiguous US. The climate regions are classified according to temperature and precipitation based data from National Climatic Data Center of the National Oceanic and Atmospheric Administration (Karl & Koss, 1984, Zhang *et al* 2014a).

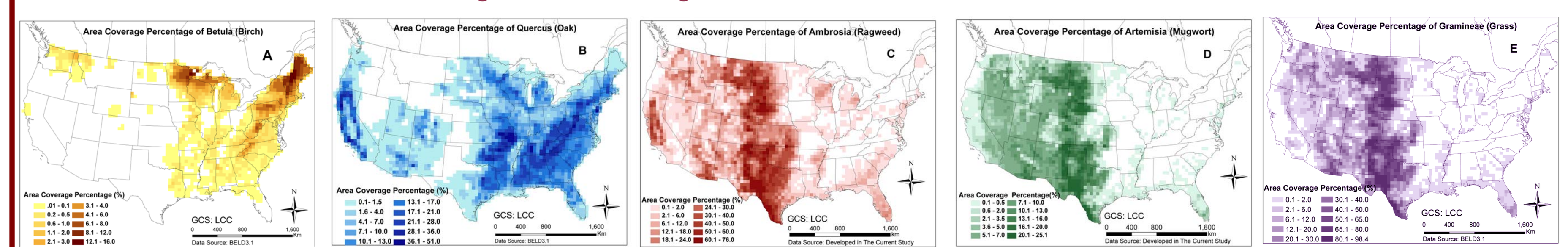


Mean Start Date (SD), Season Length (SL), threshold GDDs and their corresponding standard deviations for birch (B), oak (O), ragweed (R), mugwort (M) and grass (G) across the latitudes. The mean is defined as the average over the observation period of 1994-2010 at a station. (A) SD, (B) SL, (C) GDD threshold for SD, and (D) GDD threshold for ED (Zhang *et al* 2014b).

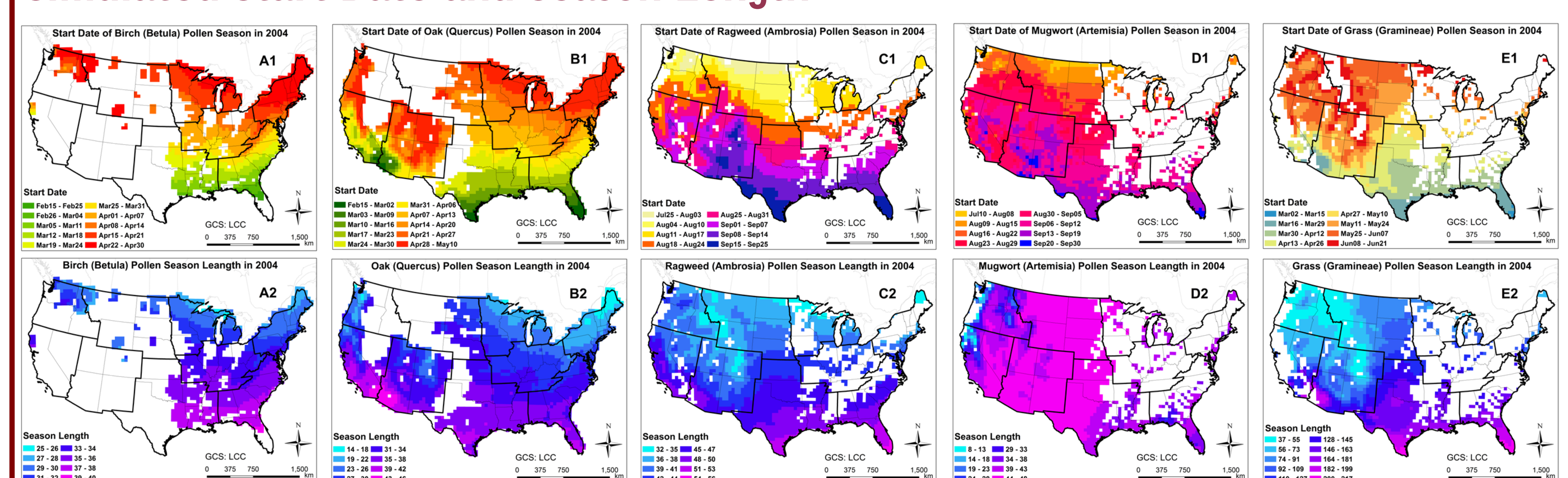


Changes in mean pollen indices during period of 2001-2010 from the means during 1994-2000 in nine climate regions across the contiguous US. (a) SD, (b) SL, (c) Annual Production, and (d) Peak Value. A negative number indicates earlier pollen season start date, shorter season length, and decreasing pollen levels (Zhang *et al* 2014a).

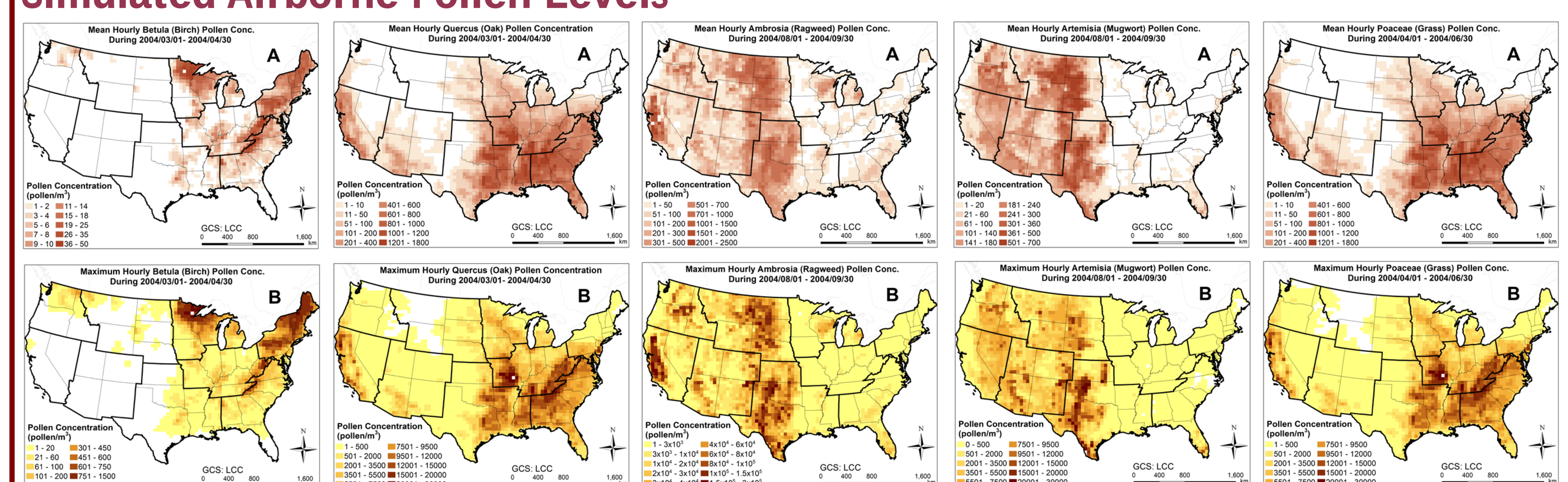
Simulated Area Coverage of Allergenic Plants



Simulated Start Date and Season Length

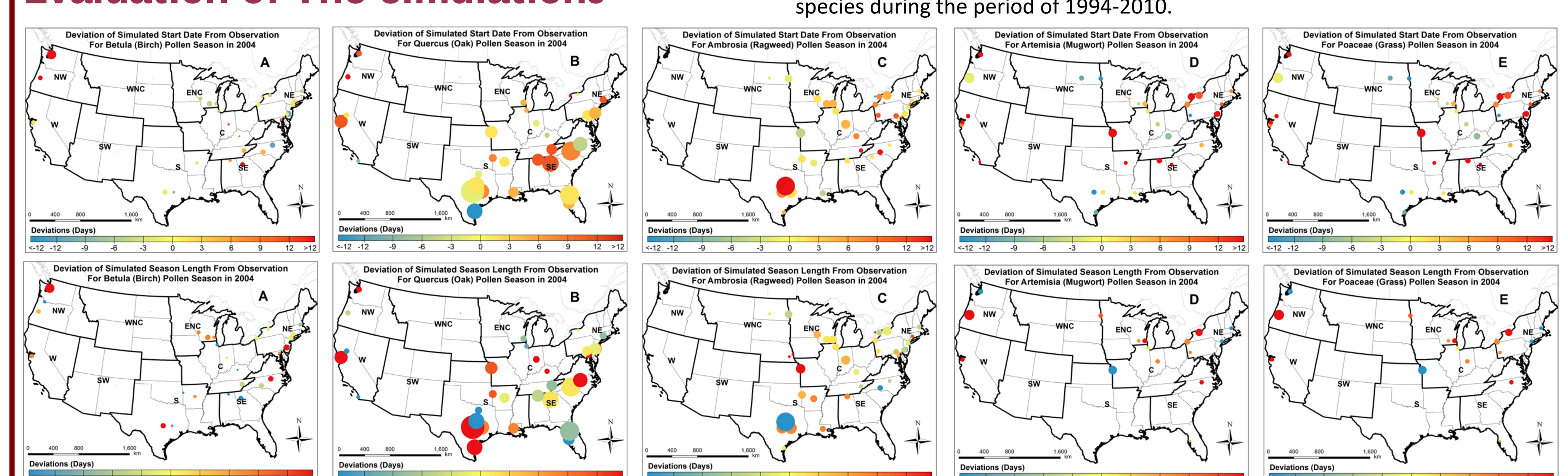


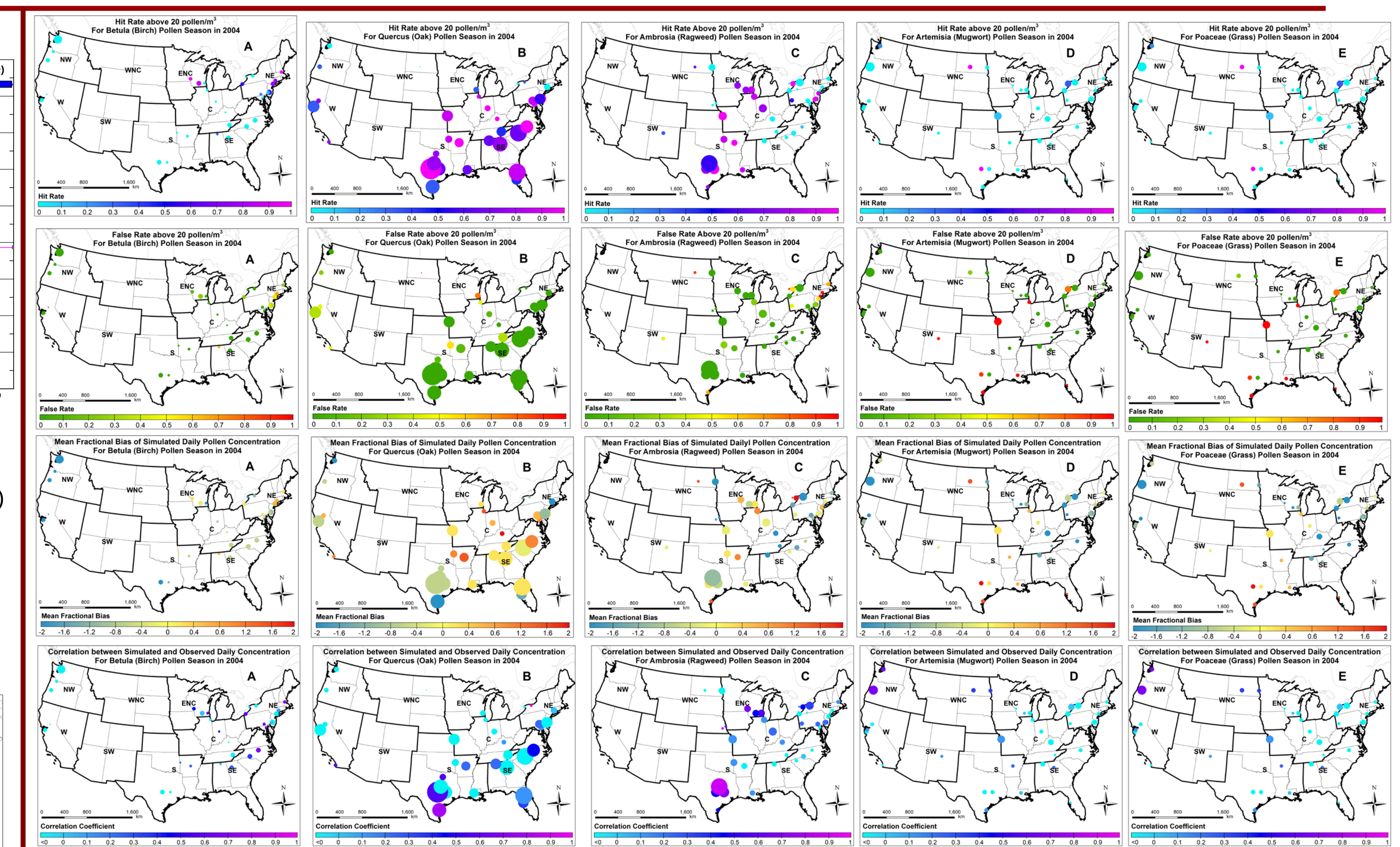
Simulated Airborne Pollen Levels



Evaluation of The Simulations

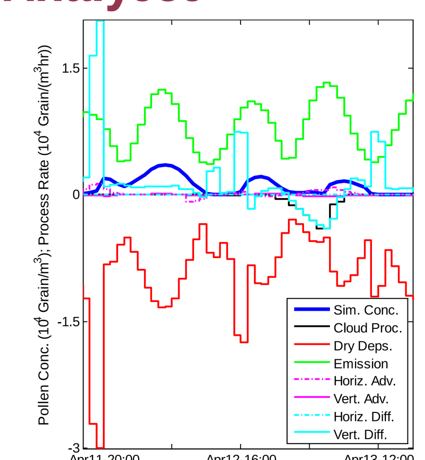
The size of the circle indicates the average pollen abundance for a given species during the period of 1994-2010.



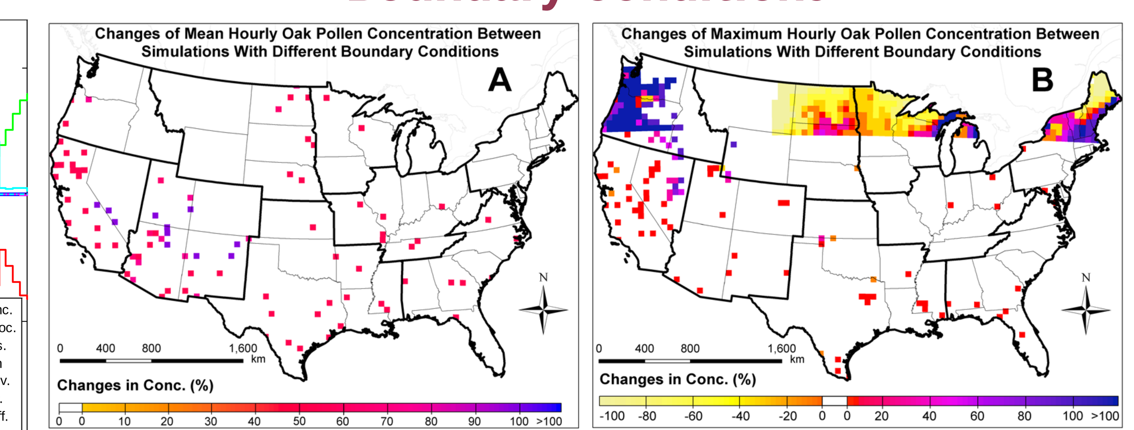


Process Analyses

Oak pollen concentrations between 2004/04/11-17:00 and 2004/04/13-17:00 at Newark, NJ



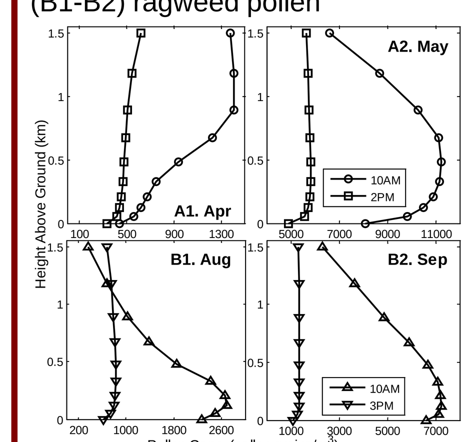
Boundary Conditions



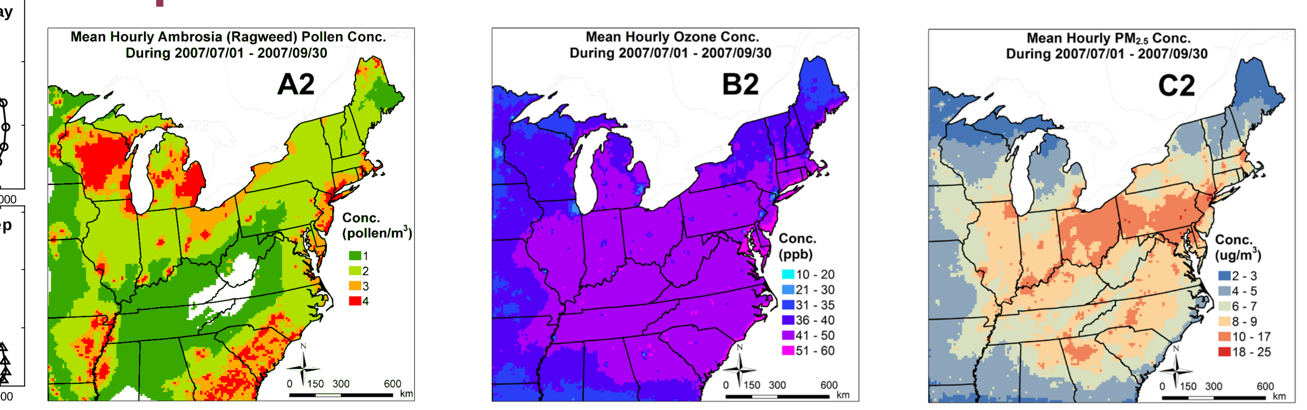
Oak pollen between 2004/03/01-00:00 and 2004/04/30-23:00; BC1=0, BC2=10 pollen grains / m^3

Vertical Profiles

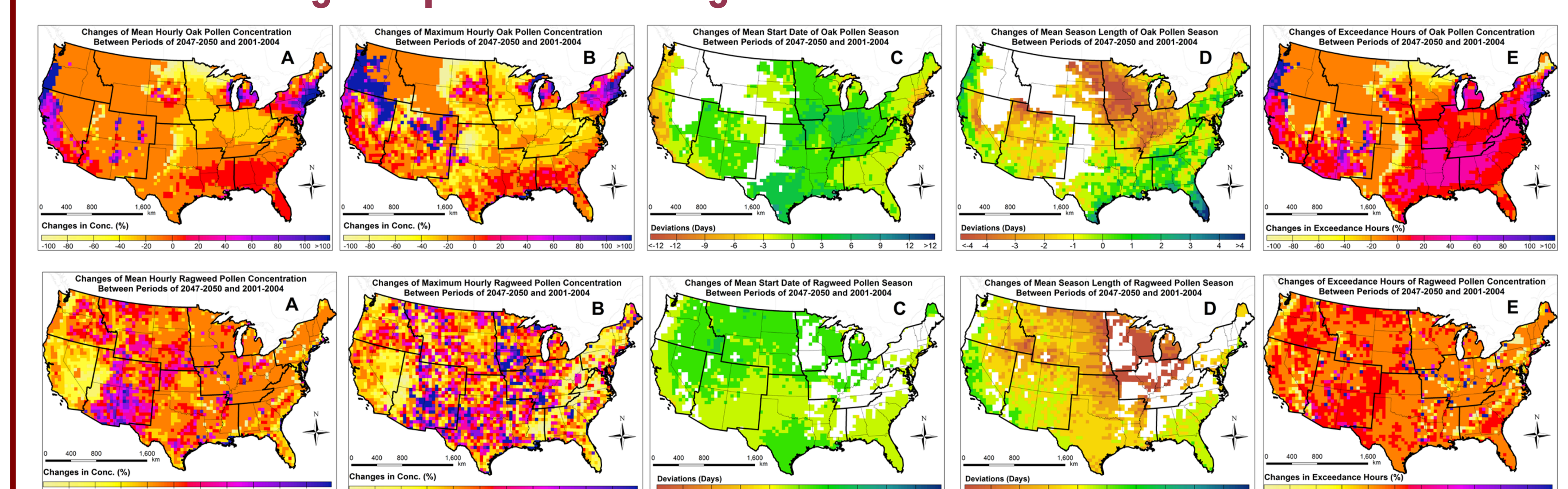
Newark NJ, 2004; (A1-A2) oak pollen, (B1-B2) ragweed pollen



Simulation of pollen, ozone and particulate matter distribution in one run



Climate Change Impacts on Allergenic Pollen



References

Byun and Schere (2006) Applied Mechanics Reviews 59 (1-6):51-77
Georgopoulos and Lioy (2006) Journal of Toxicology and Environmental Health, Part B 9, 457-483
Karl and Koss (1984) Regional and National Monthly, Seasonal, and Annual Temperature Weighted by Area, 1895-1983, Historical climatology series 4-3. Asheville, NC: National Climatic Data Center.
Prank et al. (2013) Agricultural and Forest Meteorology 182–183, 43-53
Skjøth et al. (2010) Agricultural and Forest Meteorology 150, 1203-1210
Zhang, Bielory and Georgopoulos (2013a). International Journal of Biometeorology (in press). DOI:10.1007/s00484-013-0674-7
Zhang et al. (2013) Atmospheric Environment 68, 64-73
Zhang, et al. (2014) Biogeosciences 11, 1461-1478
Zhang, et al. (2014a) Global Change Biology, DOI: 10.1111/gcb.12755
Zhang, et al. (2014b) Atmospheric Environment, under review
Zink et al. (2012) International Journal of Biometeorology 56, 669-680

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CCL Computational Chemodynamics Laboratory
CEED Center for Environmental Exposures and Disease
EOHSI Environmental & Occupational Health Sciences Institute
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