**Appendix A: Supporting information to**

**Development of a Semi-mechanistic Allergenic Pollen Emission Model**

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**Table of Contents**

* Calculation of area coverage of ragweed
* Table S1. Modeling studies focusing on large-scale emissions and long-range transport of pollen.
* Table S2. Coordinates, elevations, main climate characteristics and years of data for the pollen stations in this study. Observed daily temperatures, precipitation were obtained from the National Oceanic and Atmospheric Administration (NOAA) meteorology stations nearest to the corresponding NAB-AAAAI pollen stations.
* Table S3. Coefficients used in the developed algorithm to calculate the area coverage of ragweed.
* Table S4. Parameters for calculation of hourly flowering likelihood.
* Fig. S1. Diagram of pollen emission model. The mechanistic emission model consists of modules of direct emission, resuspension, meteorology adjustment, vegetation coverage, flowering likelihood, start date and season length.
* Fig. S2. Schematic representation of the algorithm used to estimate ragweed coverage. The ragweed plant coverage is estimated based on land use and land cover information from BELD3.1 and ragweed pollen counts data from NAB-AAAAI.
* Fig. S3. Distribution of the 58 studied pollen stations across the nine climate regions in the contiguous US. The climate regions are classified according to the long term observed temperature and precipitation based on the database of National Climatic Data Center of the National Oceanic and Atmospheric Administration (Karl and Koss, 1984).
* Fig. S4. Spatial patterns of mean, maximum, seasonal total and standard deviation of hourly emission of ragweed pollen. (a) Hourly mean, (b) Hourly maximum, (c) Seasonal total, and (d) Standard deviation.

**Calculation of area coverage of ragweed**

The following discussion focuses on development of ragweed coverage in each 36-km grid covering the CONUS.

Fig. A.2 is a schematic representation of the algorithm for estimation of ragweed coverage in each grid. This is a two stage algorithm similar to the methods reported in the literature (Csornai et al., 2010; Pauling et al., 2012; Skjøth et al., 2010). The first stage is to estimate the ragweed plant coverage in the grids which contain a monitoring station collecting the ragweed pollen count, and to identify the relationship between ragweed coverage and relevant land use and land coverage. The second stage is to estimate the ragweed plant coverage in the remaining grids using the relationship established in the first stage.

The pollen counts collected at each monitoring station are mainly from the ragweed plants in the grid that contains the monitoring station. The assumption of the algorithm is that the average ratio of grass area coverage to mean annual production of grass pollen is roughly the same as the average ratio for ragweed. This assumption is mathematically presented in Eq. (A.1),

 (A.1)

where the and  (pollen/m3) are the mean annual production of ragweed and grass pollen, respectively. The *PR* and *PG* (%) are the area coverage of ragweed and grass plant in the corresponding grids, respectively.

The average ratio for grass, i.e., the right hand side of Eq. (A.1), can be calculated using grassland coverage and mean annual production of grass pollen in each of the grids containing a monitor station. The grassland coverage data are from BELD3.1. The mean annual production data are from grass pollen counts during 1994-2010 at monitor stations of the National Allergy Bureau (NAB) of American Academy of Allergy, Asthma, and Immunology (AAAAI). The area coverage of ragweed plants in the grids (*PRg*) containing monitor stations, can therefore be estimated through Eq. (A.2).

 (A.2)

The mean annual production of ragweed pollen from the available monitor stations was also used as a dependent variable of stepwise regression to select the relevant Land Use Land Coverage (LULC) classes in the corresponding grids. The LULC classes fed to stepwise regression include: urban land, dry crop land, crop grass land, crop wood land, grass land, shrub land, shrub grass land, savanna land, mixed forest land, sparse barren land, and wood tundra land (Essl et al., 2009; Pysek et al., 1998). The area coverage of each LULC class in each grid can be obtained from BELD3.1. It was found that the mean annual production of ragweed pollen was mainly relevant to area coverage of grass land, crop grass land, and savanna land.

The estimation of ragweed plant coverage in the remaining grids was generated using Eq. (A.3),

 (A.3)

where *PG*, *PCG* and *PSa* (%) are the area coverage of grass land, crop grass land, and savanna land, respectively. *bG*, *bCG* and *bSa* (dimensionless) are the corresponding coefficients. The coefficient *bG* represents roughly the fraction of grass land area occupied by ragweed plants, likewise for other coefficients. These coefficients were obtained by minimizing Equation under constraints:

 (A.4)

where  is the regressed value ( Eq. (A.3) ) of ragweed plant coverage in grids containing monitor stations.

Table S1. Modeling studies focusing on large-scale emissions and long-range transport of pollen.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Study Location | Resolution, Layers | Plant Taxon | Emissions Model | Vegetation Data, Model | Meteorology Data, Model | Transport Model | Reference |
| Japan | 10x10 km, 1 | Cedar | Meteorological parameterization | Forest maps and remote sensing | AMeDAS weather stations | Gaussian model | Kawashima and Takahashi (1999) |
| Germany | 4x4 km, 35 | Hazel, Alder | Empirical model | Forest maps | KAMM 3-D | DRAlS CTM | Helbig et al. (2004) |
| USA | 12x12 km, 8 | Oak | Uniform diurnal profile | BELD3.1 database | MM5, Eta 3-D | HYSPLIT | Pasken and Pietrowicz (2005) |
| Finland | 1x1 km, 1 | Birch | Aerobiology observations | CORINE, PELCOM, Forest surveys | SILAM | SILAM | Sofiev et al. (2006) |
| Germany | 500x500 m, 32 | Oak | Meteorological parameterization | Forest maps | METRAS | METRAS | Schueler and Schlünzen (2006) |
| Switzerland | 7x7 km, 40 | Birch | Empirical model | National Forest Inventory | COSMO-ART | COSMO-ART | Vogel et al. (2008) |
| NorthEastern USA | 12x12 km, 22 | Birch, Ragweed | Empirical model | BELD3.1, PLANTS, MODIS LAI | MM5 | CMAQ | Efstathiou et al. (2011) |
| California, USA | 12x12 km, 4x4 km, 29 | Multiple Taxa | STaMPS | NASS of USDA, tree inventory | WRF | CMAQ | Duhl et al. (2013);  Zhang et al. (2014) |
| Europe | 0.25ºx0.25º, 40, 74 | Birch | Probabilistic model | CORINE, PELCOM, Forest surveys | ECMWF, HIRLAM | SILAM | Siljamo et al. (2013);  Sofiev et al. (2013) |
| Central Europe | 7x7 km, 40 | Ragweed | Empirical model | Empirical model | COSMO-ART | COSMO-ART | Zink et al. (2012) |
| Europe | 0.25ºx0.25º, 8 | Ragweed | Empirical model | Ecological model | ECMWF | SILAM | Prank et al. (2013) |
| Europe | Multiple resolution and layers | Birch | Probabilistic model | CORINE, PELCOM, Forest surveys | ECMWF, WRF | Multiple Ensemble Members | Sofiev et al. (2015) |
| Europe | Multiple resolution and layers | Olive | Probabilistic model | CORINE | ECMWF, WRF | CAMS | Sofiev et al. (2017) |
| USA | 36x36 km, 34 | Oak, Ragweed | Mechanistic model | BELD3.1, Empirical model | WRF | CMAQ | This study |

Table S2. Coordinates, elevations, main climate characteristics and years of data for the pollen stations in this study. Observed daily temperatures, precipitation were obtained from the National Oceanic and Atmospheric Administration (NOAA) meteorology stations nearest to the corresponding NAB-AAAAI pollen stations.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ID | Station Name | Latitude (°N) | Longitude (°W) | Elevation (m) | Mean Temp. (°C) | Annual Precip. (mm) | Years of Data (Yrs.) | |
| Oak | Ragweed |
| 1 | Seattle, WA | 47.66 | 122.29 | 20 | 11.9 | 603 | 13 | - |
| 2 | Fargo, ND | 46.84 | 96.87 | 277 | 5.9 | 569 | 11 | 12 |
| 3 | Vancouver, WA | 45.62 | 122.50 | 89 | 12.3 | 960 | 4 | - |
| 4 | Eugene, OR | 44.04 | 123.09 | 129 | 11.3 | 1065 | 13 | - |
| 5 | LaCrosse, WI | 43.88 | 91.19 | 216 | 9.0 | 905 | 10 | 9 |
| 6 | Rochester, NY | 43.10 | 77.58 | 148 | 9.3 | 878 | 14 | 14 |
| 7 | Niagara Falls, ON , CA | 43.09 | 79.09 | 188 | 9.3 | 893 | - | 4 |
| 8 | Madison, WI | 43.08 | 89.43 | 263 | 8.7 | 909 | 7 | 7 |
| 9 | Waukesha, WI | 43.02 | 88.24 | 270 | 9.6 | 557 | 6 | 6 |
| 10 | London, ON, CA | 42.99 | 81.25 | 250 | 8.3 | 476 | 4 | 4 |
| 11 | Albany, NY | 42.68 | 73.77 | 72 | 9.4 | 992 | 5 | - |
| 12 | Chelmsford, MA | 42.60 | 71.35 | 37 | 10.0 | 814 | 9 | 8 |
| 13 | St. Clair Shores, MI | 42.51 | 82.9 | 180 | 9.8 | 863 | 6 | 7 |
| 14 | Salem, MA | 42.50 | 70.92 | 42 | 10.9 | 1082 | 10 | 10 |
| 15 | Erie, PA | 42.10 | 80.13 | 215 | 10.1 | 1002 | 9 | 13 |
| 16 | Olean, NY | 42.09 | 78.43 | 433 | 7.3 | 974 | 8 | 14 |
| 17 | Chicago, IL | 41.91 | 87.77 | 189 | 11.0 | 617 | 7 | 7 |
| 18 | Waterbury, CT | 41.55 | 73.07 | 140 | 11.8 | 665 | 10 | 10 |
| 19 | Omaha, NE | 41.14 | 95.97 | 305 | 10.9 | 854 | 12 | 13 |
| 20 | Armonk, NY | 41.13 | 73.73 | 187 | 11.1 | 865 | 7 | 7 |
| 21 | Lincoln, NE | 40.82 | 96.64 | 371 | 11.0 | 699 | 4 | 5 |
| 22 | Springfield, NJ | 40.74 | 74.19 | 43 | 13.0 | 1213 | 10 | 13 |
| 23 | Pittsburgh, PA | 40.47 | 79.95 | 287 | 11.2 | 858 | 5 | 7 |
| 24 | Philadelphia, PA | 39.96 | 75.16 | 12 | 13.5 | 1106 | 11 | 10 |
| 25 | York, PA | 39.94 | 76.71 | 195 | 13.0 | 948 | 6 | 7 |
| 26 | Cherry Hill, NJ | 39.94 | 74.91 | 13 | 12.7 | 550 | 13 | 14 |
| 27 | Indianapolis, IN | 39.91 | 86.2 | 254 | 12.0 | 1095 | 11 | 11 |
| 28 | New Castle, DE | 39.66 | 75.57 | 3 | 13.5 | 1106 | 4 | 5 |
| 29 | Reno, NV | 39.56 | 119.77 | 1382 | 12.1 | 195 | 6 | - |
| 30 | Baltimore, MD | 39.37 | 76.47 | 36 | 13.3 | 1117 | 6 | 10 |
| 31 | Kansas City, MO | 39.08 | 94.58 | 288 | 13.9 | 750 | 8 | 8 |
| 32 | Colorado Springs 2, CO | 38.87 | 104.83 | 1868 | 9.6 | 372 | - | - |
| 33 | Colorado Springs 1, CO | 38.87 | 104.82 | 1867 | 9.8 | 346 | 5 | 4 |
| 34 | Roseville, CA | 38.76 | 121.27 | 57 | 17.0 | 637 | 10 | - |
| 35 | Lexington, KY | 38.04 | 84.5 | 299 | 13.1 | 1225 | 8 | 9 |
| 36 | Pleasanton, CA | 37.69 | 121.91 | 100 | 14.2 | 256 | 10 | - |
| 37 | San Jose 1, CA | 37.33 | 121.94 | 35 | 15.7 | 234 | 10 | - |
| 38 | San Jose 2, CA | 37.31 | 121.97 | 47 | 15.7 | 234 | 6 | - |
| 39 | Las Vegas, NV | 36.17 | 115.15 | 620 | 20.9 | 105 | - | - |
| 40 | Durham, NC | 36.05 | 78.9 | 110 | 15.7 | 1160 | 9 | 8 |
| 41 | Tulsa 1, OK | 36.03 | 95.87 | 207 | 16.2 | 1072 | 4 | 5 |
| 42 | Knoxville, TN | 35.95 | 84.01 | 305 | 15.0 | 1285 | 13 | 12 |
| 43 | Los Alamos, NM | 35.88 | 106.32 | 2227 | 11.8 | 323 | 6 | - |
| 44 | Oklahoma City, OK | 35.61 | 97.6 | 340 | 15.9 | 886 | 7 | 6 |
| 45 | Fort Smith, AR | 35.35 | 94.39 | 186 | 16.5 | 1149 | 4 | - |
| 46 | Charlotte, NC | 35.3 | 80.75 | 229 | 16.0 | 1097 | 8 | 7 |
| 47 | Little Rock, AR | 34.75 | 92.39 | 115 | 17.3 | 1198 | 8 | 8 |
| 48 | Huntsville, AL | 34.73 | 86.59 | 191 | 16.3 | 1325 | 12 | 13 |
| 49 | Santa Barbara, CA | 34.44 | 119.76 | 57 | 14.9 | 354 | 7 | - |
| 50 | Atlanta, GA | 33.97 | 84.55 | 366 | 16.8 | 1286 | 14 | - |
| 51 | Orange, CA | 33.78 | 117.86 | 53 | 17.9 | 170 | 4 | - |
| 52 | Dallas, TX | 33.04 | 96.83 | 207 | 19.3 | 912 | 7 | 7 |
| 53 | Waco, TX | 31.51 | 97.2 | 185 | 19.4 | 945 | 4 | - |
| 54 | Georgetown, TX | 30.64 | 97.76 | 269 | 20.3 | 1009 | 7 | 7 |
| 55 | College Station, TX | 30.64 | 96.31 | 91 | 19.5 | 509 | 10 | 10 |
| 56 | Tallahassee, FL | 30.44 | 84.28 | 62 | 19.7 | 1478 | 6 | 6 |
| 57 | Tampa, FL | 28.06 | 82.43 | 12 | 22.7 | 1101 | 7 | - |
| 58 | Corpus Christi, TX | 27.80 | 97.4 | 2 | 22.2 | 794 | 7 | 6 |

Table S3. Coefficients used in the developed algorithm to calculate the area coverage of ragweed.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Grass  *bG* (unitless) | Crop Grass  *bCG* (unitless) | Savanna  *bSa* (unitless) |
| Ragweed | 0.7684 | 0.5000 | 0.7497 |

Table S4. Parameters for calculation of hourly flowering likelihood.

|  |  |  |
| --- | --- | --- |
| Parameter | Oak | Ragweeda |
| *αd*, day time fraction (unitless) | 0.533 |  |
| *μd*, day time mean (hr) | 4.6 |  |
| *μn*, night time mean (hr) | 17.7 |  |
| *σd*, day time deviation (hr) | 3.4 |  |
| *σn*, night time deviation (hr) | 3.3 |  |
| Reference | Pasken and Pietrowicz (2005) | Martin et al. (2010) |

a, calculated based on method reported by Martin et al. (2010)

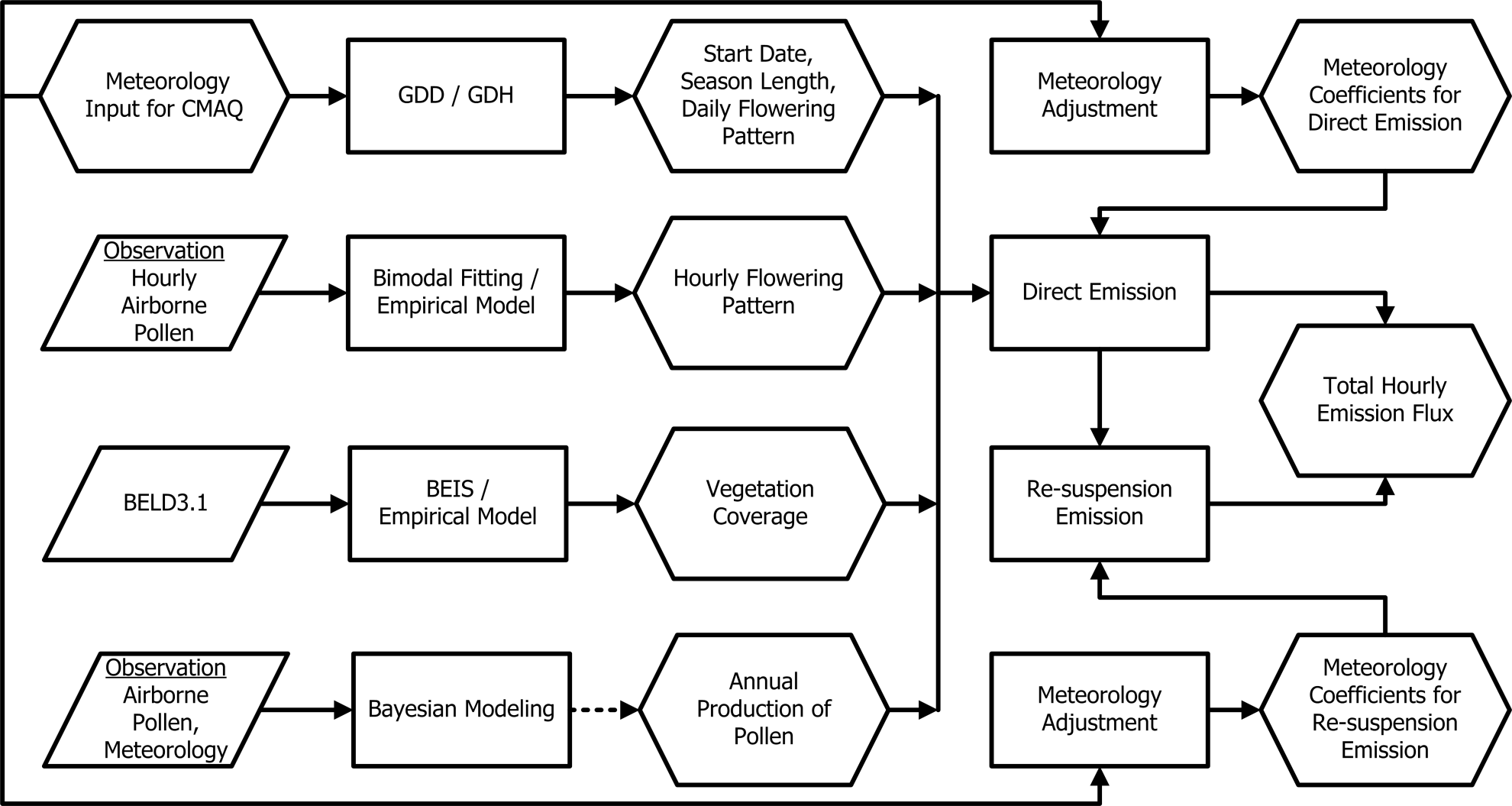


Fig. S1. Diagram of pollen emission model. The mechanistic emission model consists of modules of direct emission, resuspension, meteorology adjustment, vegetation coverage, flowering likelihood, start date and season length.

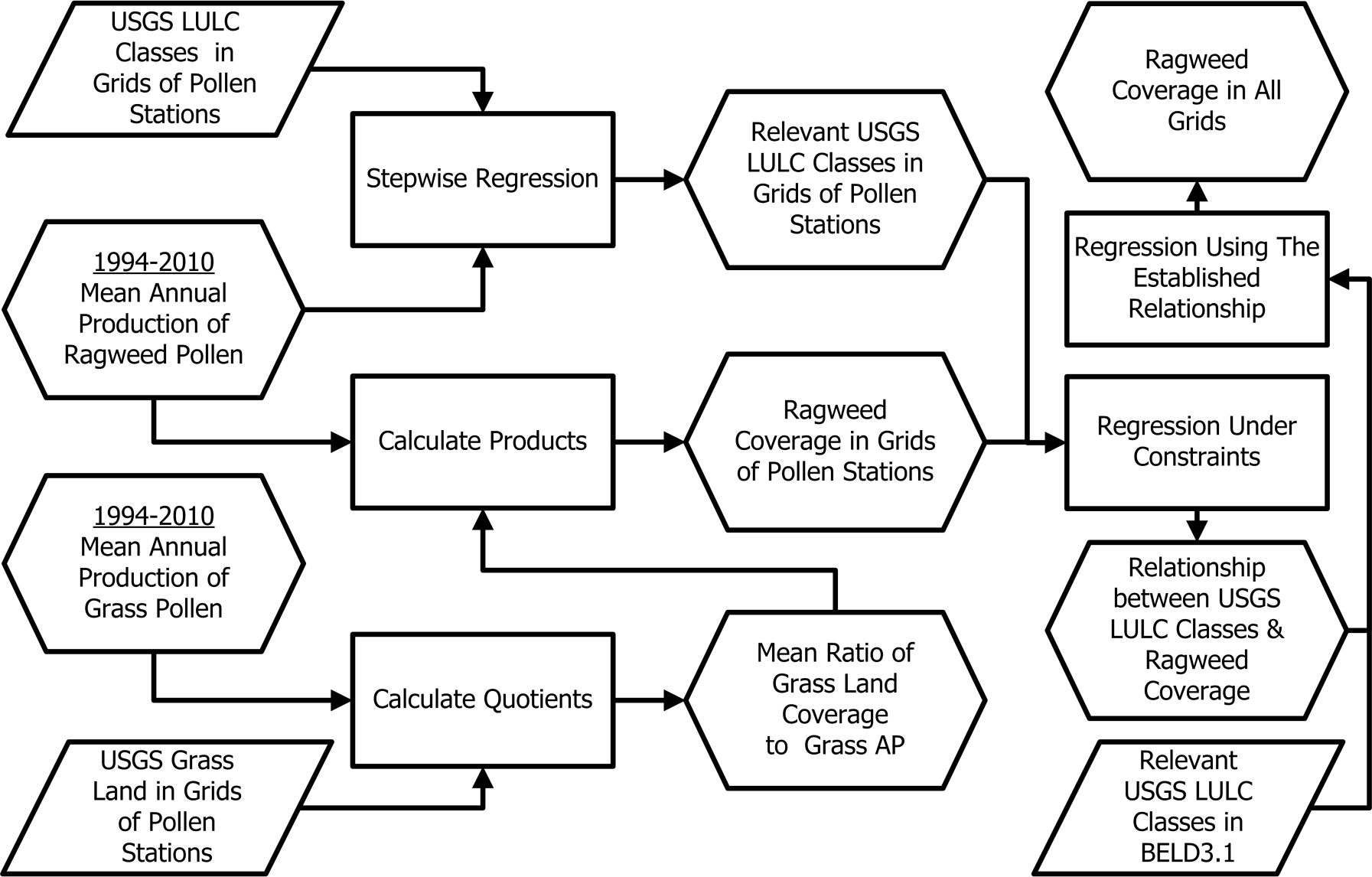


Fig. S2. Schematic representation of the algorithm used to estimate ragweed coverage. The ragweed plant coverage is estimated based on land use and land cover information from BELD3.1 and ragweed pollen counts data from NAB-AAAAI.

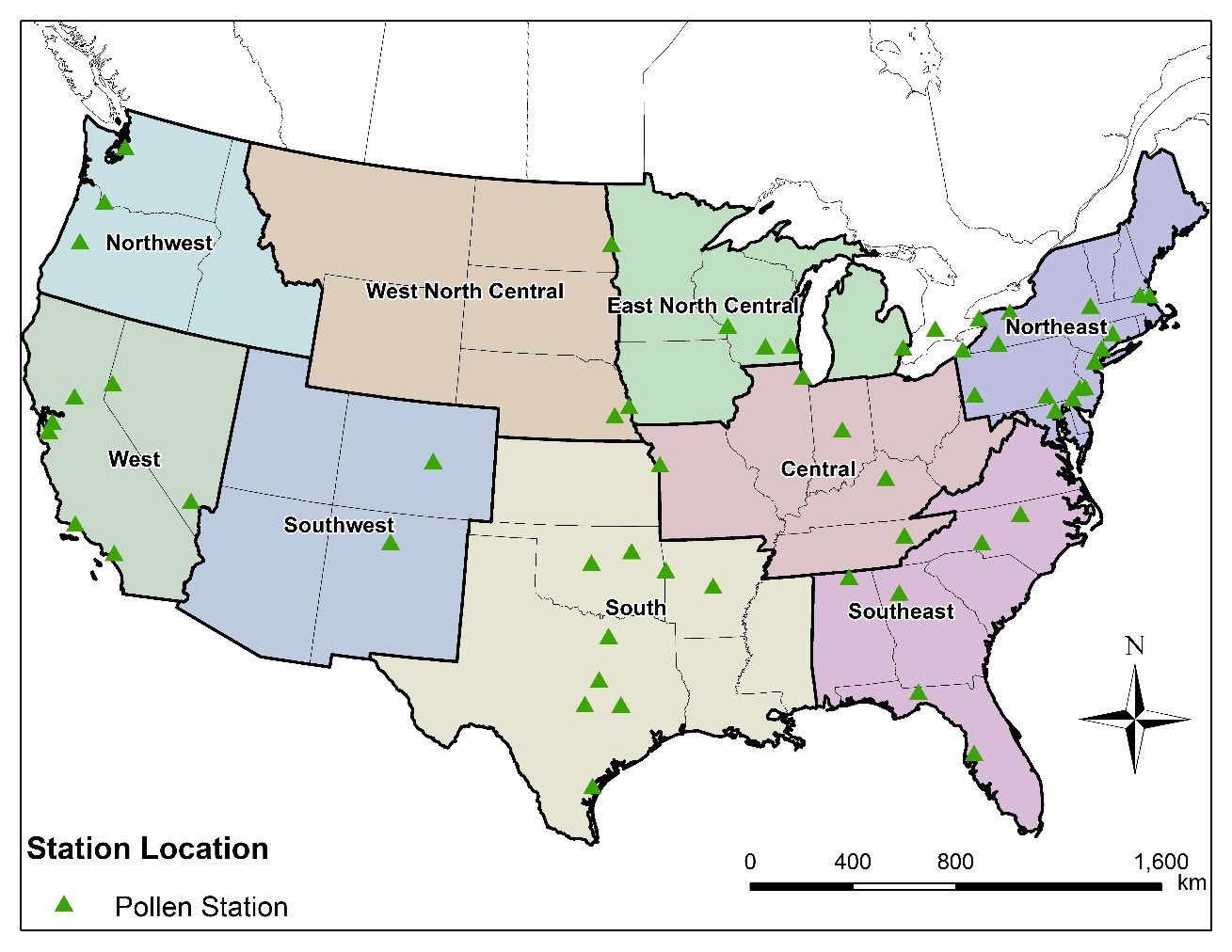
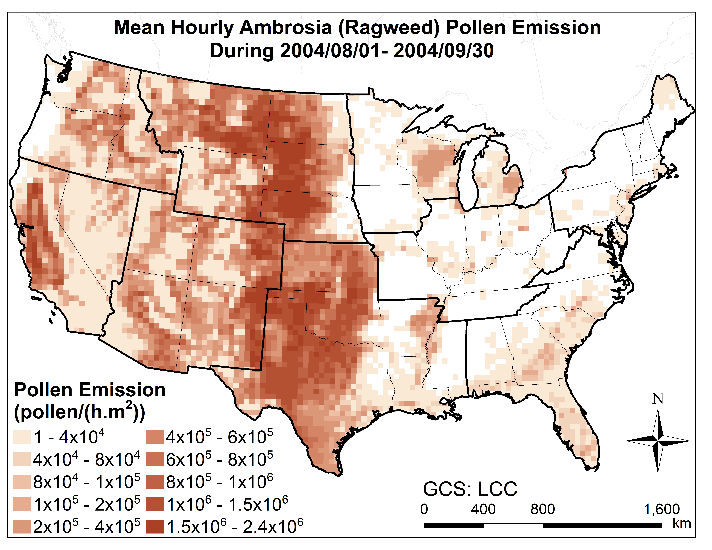
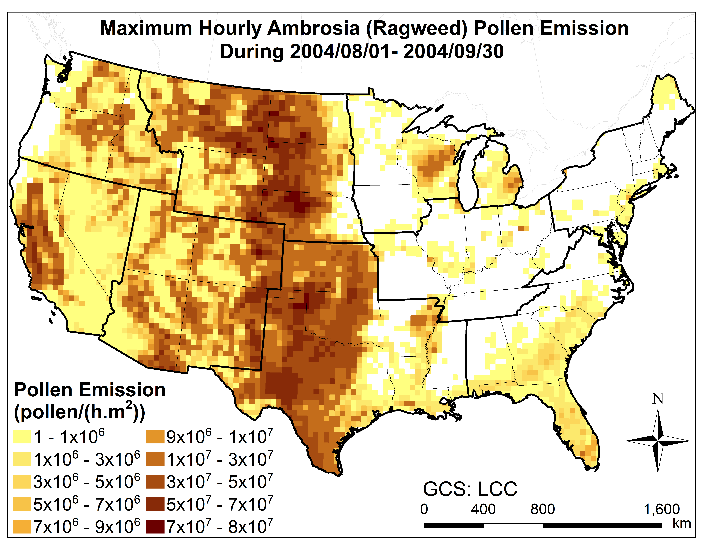
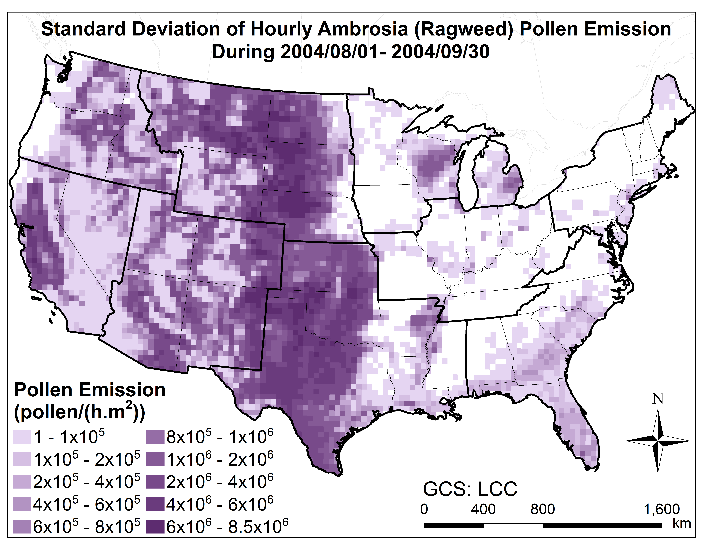
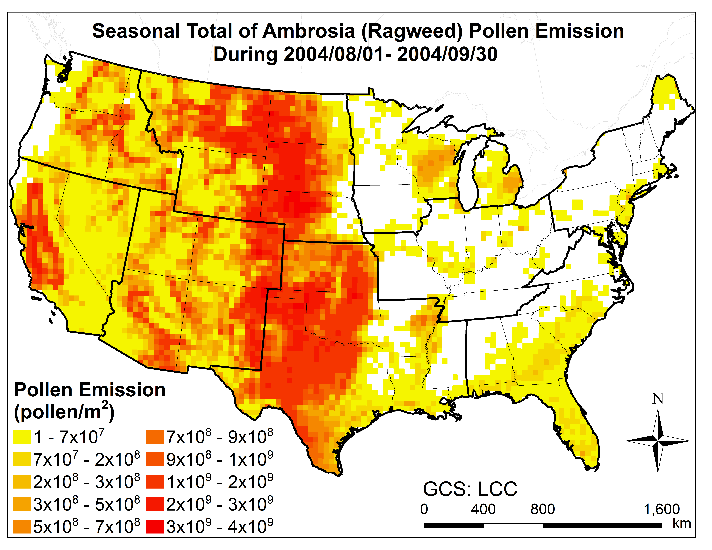


Fig. S3. Distribution of the 58 studied pollen stations across the nine climate regions in the contiguous US. The climate regions are classified according to the long term observed temperature and precipitation based on the database of National Climatic Data Center of the National Oceanic and Atmospheric Administration (Karl and Koss, 1984).

(a) (b)



(c) (c)

Fig. S4. Spatial patterns of mean, maximum, seasonal total and standard deviation of hourly emission of ragweed pollen. (a) Hourly mean, (b) Hourly maximum, (c) Seasonal total, and (d) Standard deviation.

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