AQMEII4 Phase 4: Diagnostic Analysis of Atmospheric Deposition Through Grid and Point Model Intercomparisons

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13) NCAR, USA
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15) TNO, Norway
16) UPM, Spain
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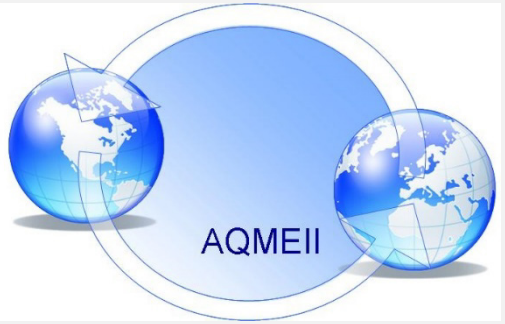
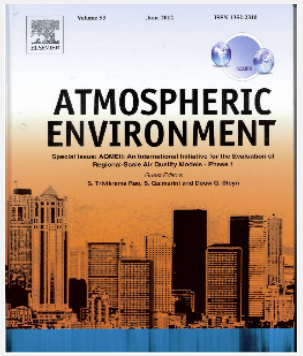
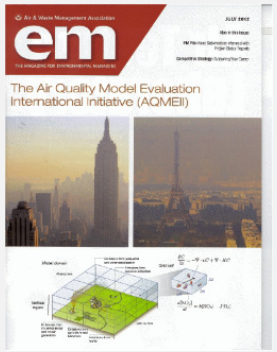
Background

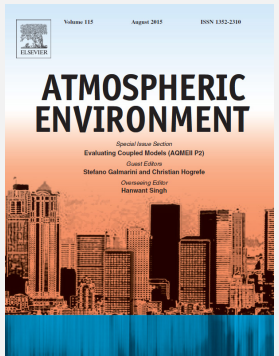


- Since 2009, the Air Quality Modeling Evaluation International Initiative (**AQMEII**) has brought together modeling groups from North America (NA) and Europe (EU)
- Goal: conduct coordinated research projects and model inter-comparisons to advance model evaluation practices and inform model development
- Leadership provided by the Joint Research Centre (**JRC**), **U.S. EPA**, and Environment and Climate Change Canada (**ECCC**)
- AQMEII4 focuses on evaluating and intercomparing wet and dry deposition [Galmarini et al., ACP, 2021]

37 groups, 17 countries, 18 different models

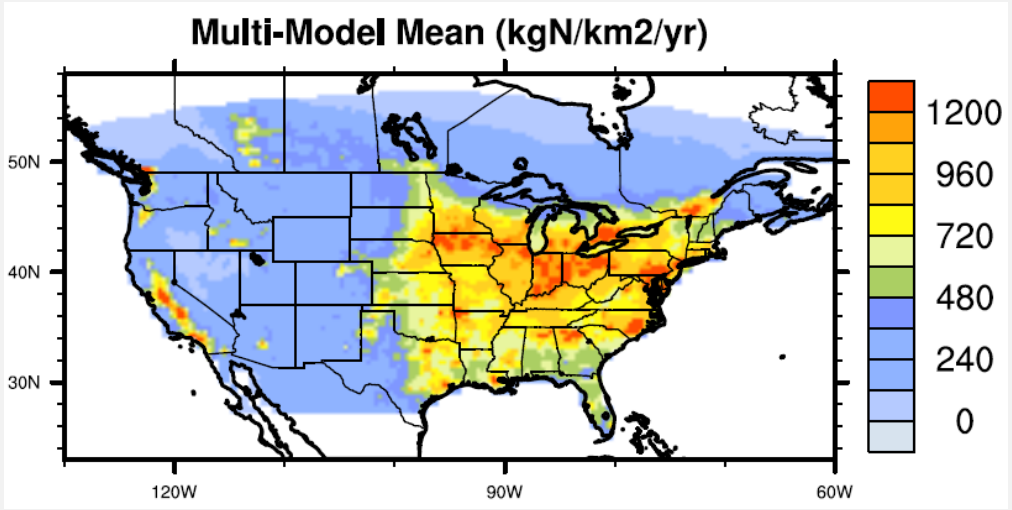


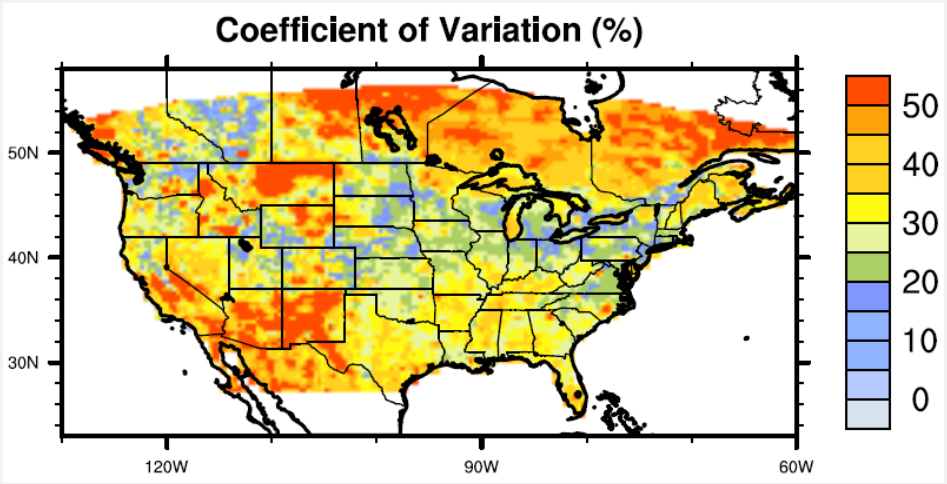


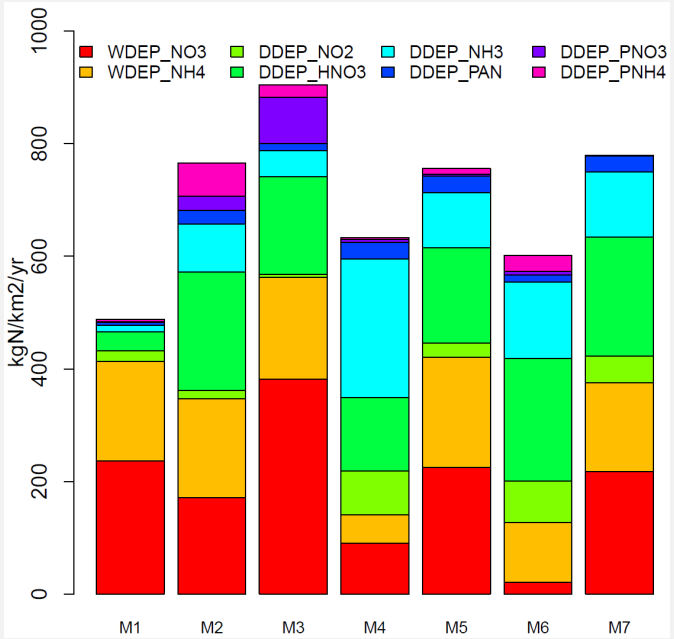


Limited Prior Analysis of Deposition in AQMEII

Example: Total Modeled N Deposition, 2006 North America







Significant variability in total magnitude, pathway (wet vs. dry), and species composition

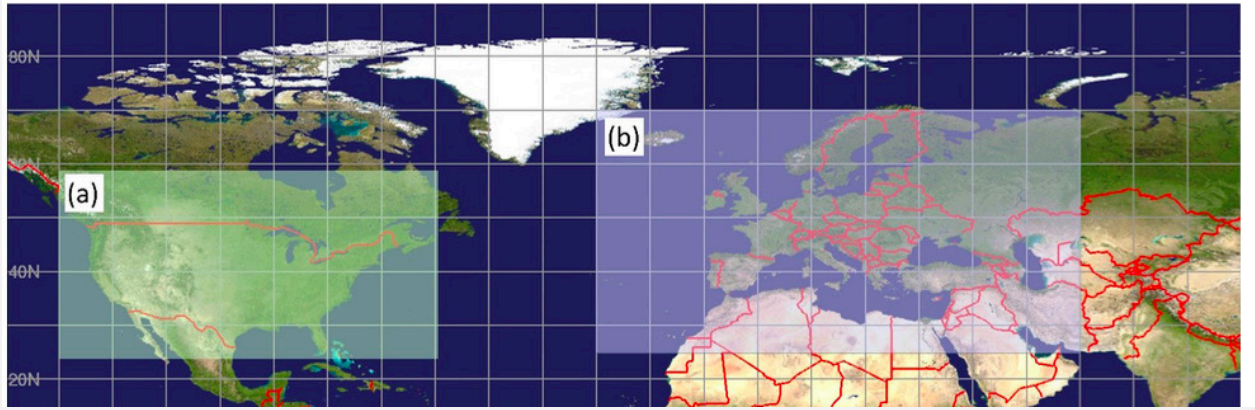
Motivations for AQMEII4:

→ Diagnose drivers of model-to-model differences

→ Inform use of modeled deposition fields for impact assessments and Measurement-Model Fusion (MMF) efforts

AQMEII4 Activity 1: Regional Model Intercomparison

- Annual simulations with common emissions & boundary conditions for 2 years
  - Europe: 2009 and 2010
  - North America: 2010 and 2016
- Archive concentrations, meteorological fields, deposition velocities, and fluxes (including process and land-use (LU) specific diagnostics)
- Common process and LU categories for reporting
- For analysis purposes, native model outputs were regridded to a common latitude/longitude grid with a grid spacing of 0.125 degrees.
- Model output extracted from the common grid for comparisons to observation station data.



Group	Model(s)	Domain
Environment and Climate Change Canada (ECCC)	GEM / MACH (3 configurations)	NA
U.S. EPA	WRF / CMAQ (2 configurations)	NA
NCAR	WRF-Chem	NA
Florida State University	GEOS-CHEM (regional)	NA
Technical University of Madrid (UPM)	WRF-Chem	NA, EU
IASS Potsdam	WRF-Chem	NA, EU
University of Hertfordshire	WRF / CMAQ	EU
TNO	LOTOS / EUROS	EU

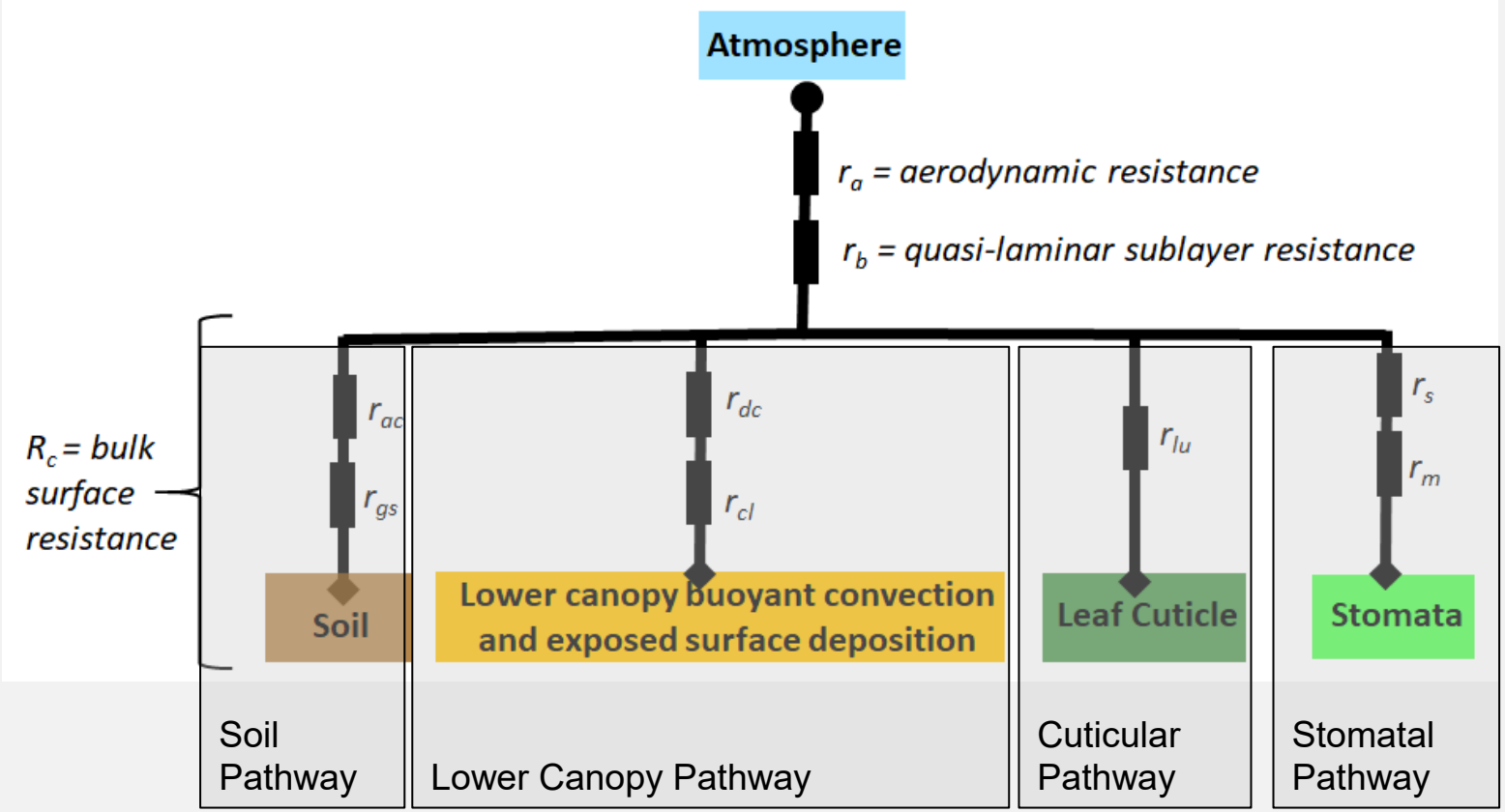
Activity 1 Co-leads: C. Hogrefe, S. Galmarini, P. Makar

Galmarini et al, ACP, 2021

Comparing Dry Deposition Schemes in AQMEII4

Example below: Wesely (1989) Dry Deposition Formulation

Details of dry deposition schemes (e.g., resistance frameworks, parameters) vary considerably across models, challenging the comparison of individual resistances/conductances across models



Four ***pathways*** are common to most schemes: **stomatal**, **cuticular**, **lower canopy**, and **soil**

These pathways may be compared directly using the concept of **effective conductance (ECOND)** across models with different dry deposition schemes:

The contribution of a given depositional pathway to deposition velocity (V_d) (Clifton et al., 2020; Paulot et al., 2018)

Wesely, M.L., Atmos. Env., 23, 1293-1304, 1989.

Clifton, O. E., et al., Journal of Geophysical Research: Atmospheres, 125, e2020JD032398. https://doi.org/10.1029/2020JD032398, 2020

Paulot, F., et al., Atmos. Chem. Phys., 18, 17963–17978, https://doi.org/10.5194/acp-18-17963-2018, 2018.

Activity 1 Gas Phase Dry Deposition Diagnostics

Name	Name of diagnostic
V_d	Dry Deposition velocity
$ECOND_{STOM}$	Effective conductance associated with deposition to plant stomata
$ECOND_{CUT}$	Effective conductance associated with deposition to plant cuticles
$ECOND_{SOIL}$	Effective conductance associated with deposition to soil and un-vegetated surfaces
$ECOND_{LCAN}$	Effective conductance associated with deposition to the lower canopy.
EF_{STOM}	Effective Flux for stomatal pathway
EF_{CUT}	Effective Flux for cuticle pathway
EF_{SOIL}	Effective Flux for soil pathway
EF_{LCAN}	Effective Flux for lower canopy pathway
r_a	Aerodynamic resistance
r_c	Bulk surface resistance
r_{stom}	Net stomatal resistance
r_{meso}	Net mesophyll resistance
r_{cut}	Net cuticle resistance
$r_{b,\ stom}$	Quasi-laminar sublayer resistance associated with stomatal pathway
$r_{b,cut}$	Quasi-laminar sublayer resistance associated with cuticle pathway
$r_{b,soil}$	Quasi-laminar sublayer resistance associated with soil pathway
$r_{b,lcan}$	Quasi-laminar sublayer resistance associated with lower canopy pathway

A survey of the various deposition schemes used by the participating models led to this list of diagnostic variables for analyzing gas phase dry deposition across models.

Galmarini et al, ACP, 2021

AQMEII-4 Activity 1 Land Use Reporting

Development of common LU categories to facilitate comparison of LU-specific diagnostics

- Surveyed participating groups to determine LU schemes
- Defined common categories
- Provided groups with suggested mapping from native to common categories

AQMEII4 LU Categories

AQMEII4_Category	AQMEII4_Description
AQMEII_01	Water
AQMEII_02	Developed / Urban
AQMEII_03	Barren
AQMEII_04	Evergreen needleleaf forest
AQMEII_05	Deciduous needeleaf forest
AQMEII_06	Evergreen broadleaf forest
AQMEII_07	Deciduous broadleaf forest
AQMEII_08	Mixed forest
AQMEII_09	Shrubland
AQMEII_10*	Herbaceous
AQMEII_11	Planted/Cultivated
AQMEII_12	Grassland
AQMEII_13	Savanna
AQMEII_14	Wetlands
AQMEII_15**	Tundra
AQMEII_16	Snow and Ice
*not present in CONUS12 domain with either	
NLCD40 or MODIS	
**not present in CONUS12 domain with NLCD40	

Example Mapping: NLCD40 → AQMEII4

NLCD40_Cat	NLCD40_Name	AQMEII4_Cat
17	water	AQMEII_01
18*	water	AQMEII_01
19*	water	AQMEII_01
20*	water	AQMEII_01
21*	water	AQMEII_01
13	Urban and Built-up	AQMEII_02
23	Developed open space	AQMEII_02
24	Developed Low Intensity	AQMEII_02
25	Developed Medium Intensity	AQMEII_02
26	Developed High Intensity	AQMEII_02
16	Barren or Sparsely Vegetated	AQMEII_03
27	Barren Land	AQMEII_03
1	Evergreen Needleleaf Forest	AQMEII_04
29	Evergreen Forest	AQMEII_04
3	Deciduous Needleleaf Forest	AQMEII_05
2	Evergreen Broadleaf Forest	AQMEII_06
4	Deciduous Broadleaf Forest	AQMEII_07
28	Deciduous Forest	AQMEII_07
5	Mixed Forest	AQMEII_08
30	Mixed Forest	AQMEII_08
6	Closed Shrublands	AQMEII_09
7	Open Shrublands	AQMEII_09
32	Shrub/Scrub	AQMEII_09
34*	Sedge/Herbaceous	'AQMEII_10
12	Croplands	'AQMEII_11
14	Cropland-Natural Vegetation Mosaic	'AQMEII_11
37	Pasture/Hay	'AQMEII_11
38	Cultivated Crops	'AQMEII_11
10	Grasslands	'AQMEII_12
33	Grassland/Herbaceous	'AQMEII_12
8	Woody Savanna	'AQMEII_13
9	Savanna	'AQMEII_13
11	Permanent Wetlands	'AQMEII_14
39	Woody Wetland	'AQMEII_14
40	Emergent Herbaceous Wetland	'AQMEII_14
31*	Dwarf Scrub	'AQMEII_15
35*	Lichens	'AQMEII_15
36*	Moss	'AQMEII_15
15	Snow and Ice	'AQMEII_16
22*	Perrenial Ice/snow	'AQMEII_16
*not present / not used in CONUS12 domain		

Galmarini et al, ACP, 2021

AQMEII-4 Activity 1 Chemical Species Reported

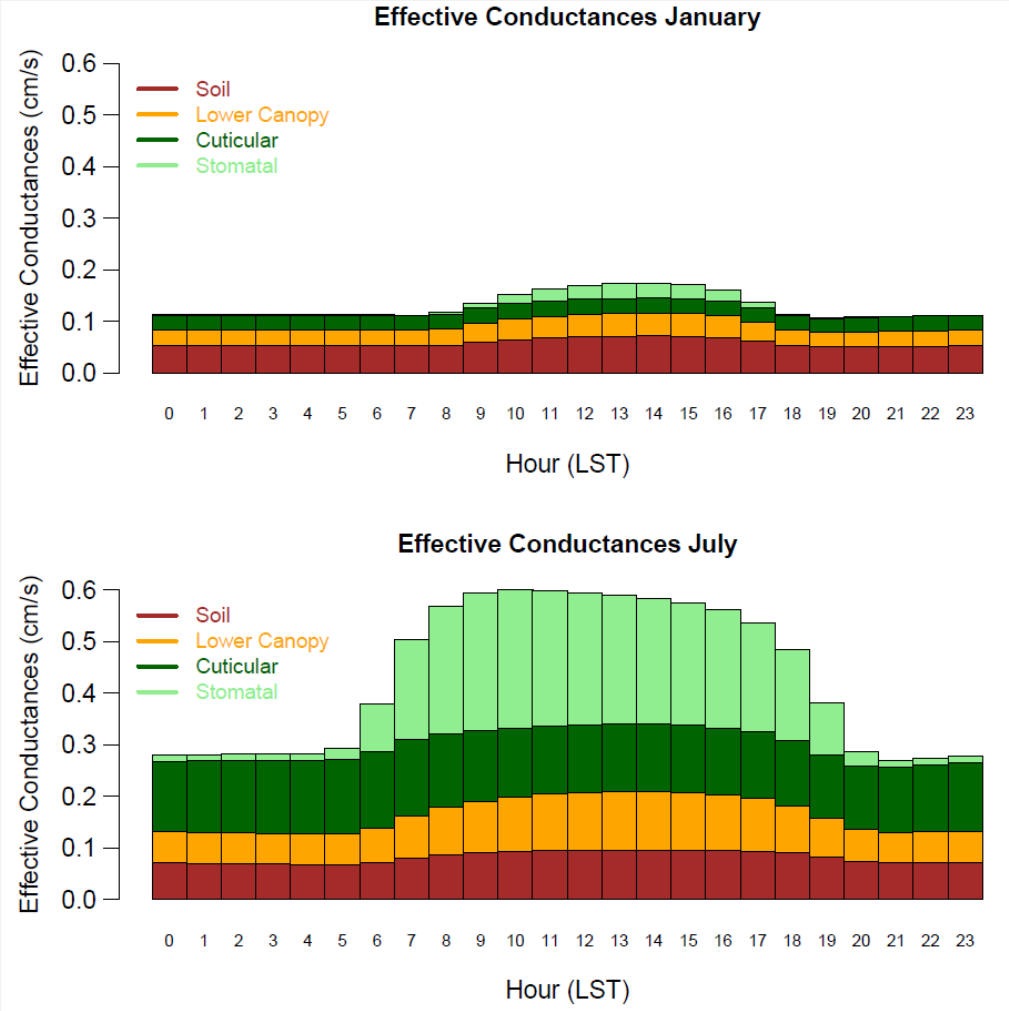
- Gases:
  - SO_2, NO_2, NO, HNO_3, NH_3, PAN, HNO_4, N_2O_5, organic nitrates, O_3, H_2O_2 and HCHO
  - V_d for each of the 16 AQMEII4 LU types as well as for the net grid-scale values
  - Effective conductances and process-specific resistance terms, both grid-scale net values and by AQMEII4 LU type
  - Grid-scale net dry fluxes (DDEP) and effective fluxes (EF) for these gases
- Particles: Grid-scale DDEP for particle sulfate, nitrate, ammonium, total carbon, elemental carbon, base cations, sea-salt, crustal material, and $PM_{2.5}$
- Ions: wet fluxes (eq ha^{-1}) of HSO_3^-, $SO_4^=$, NO_3^-, NH_4^+, base cations, and total organic carbon
- Precipitation

Galmarini et al, ACP, 2021

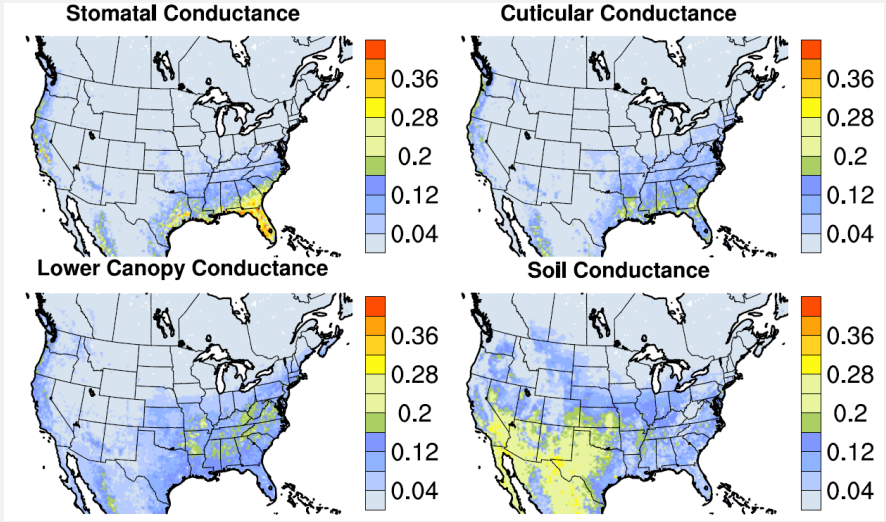
Current Status and Preliminary Results, Activity 1

- Iterations!
  - All of the models that submitted data required re-runs
    - Set-up issues, input emissions issues, diagnostic additions issues
    - + Pandemic.
- However, the reruns are completed and analysis is back on track.
- The next few slides are examples from the model outputs currently in the AQMEII4 database; all results are preliminary.

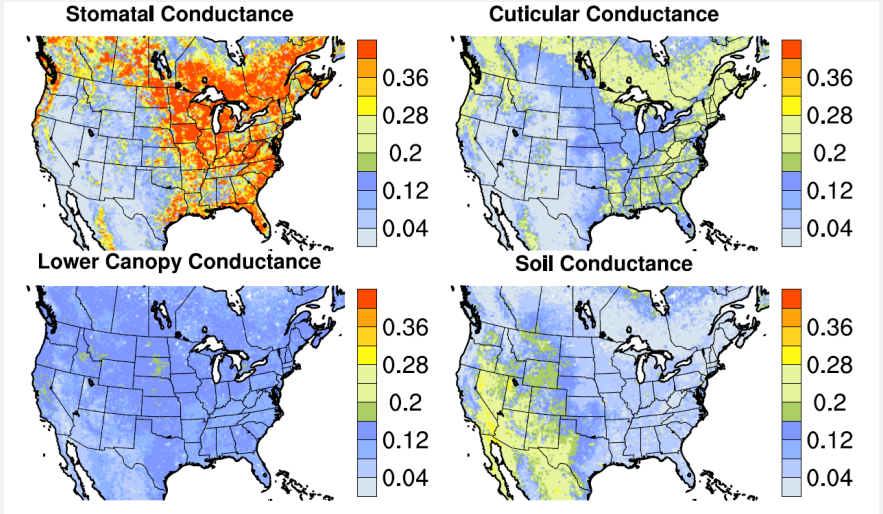
Example Analysis, Activity 1: Spatial and Temporal Variability of Grid-Scale O_3 ECOND, Model M2



Winter 2 pm (LST) Seasonal Average



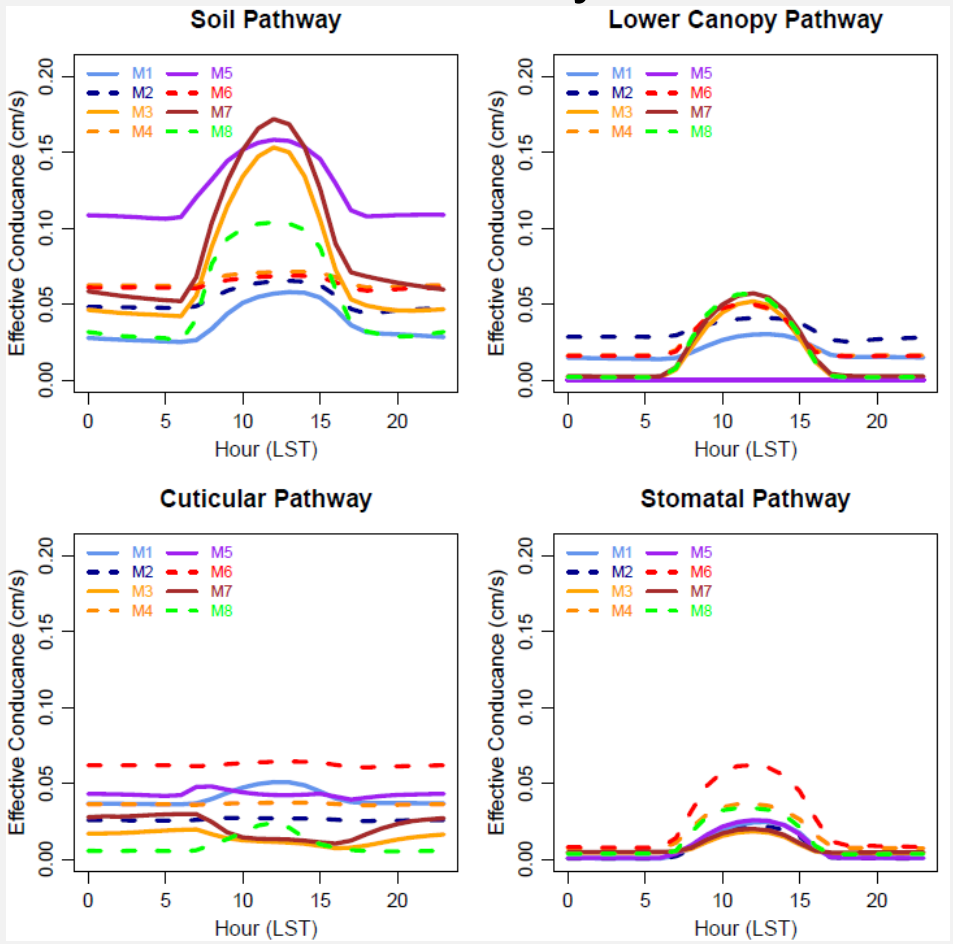
Summer 2 pm (LST) Seasonal Average



- The magnitudes of the four dry deposition pathways vary diurnally, seasonally, and spatially
- This variation is most pronounced for the stomatal pathway due to its dependence on solar radiation and leaf area

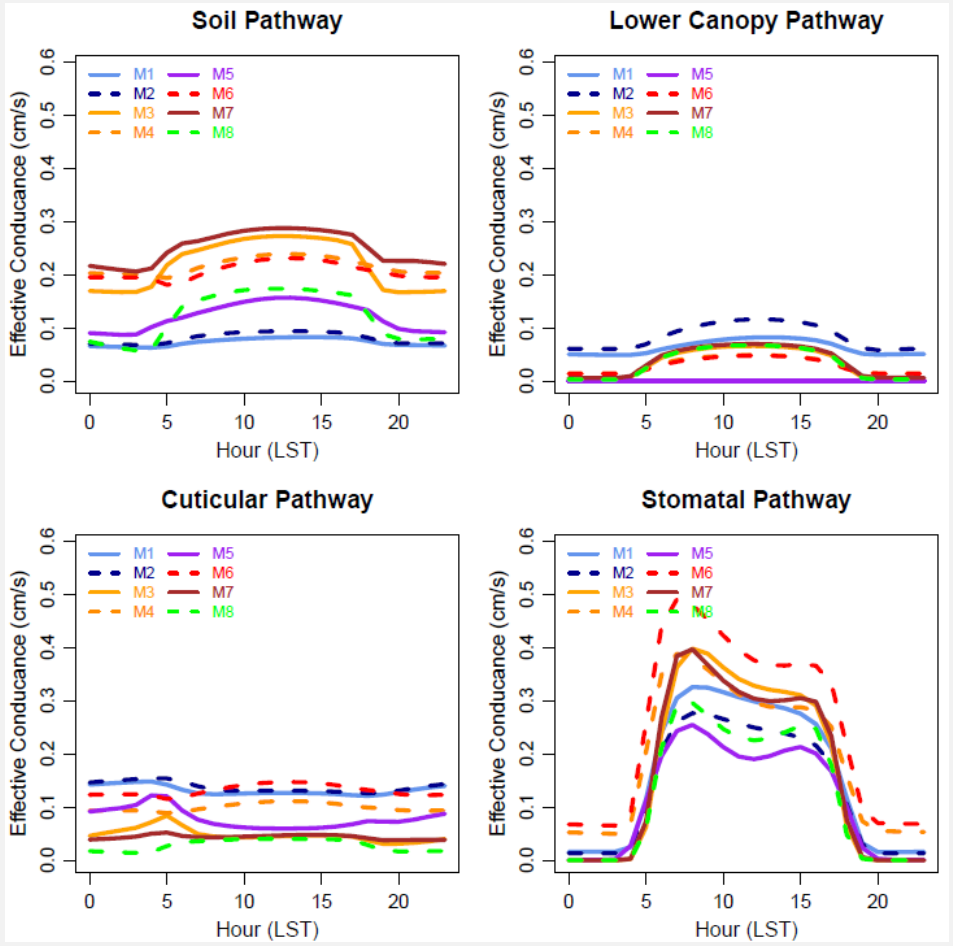
Example: Gridscale O_3 ECOND Diurnal Cycles 8 Models, North America, Domain Average

January



Note different y-axis range for January vs. July

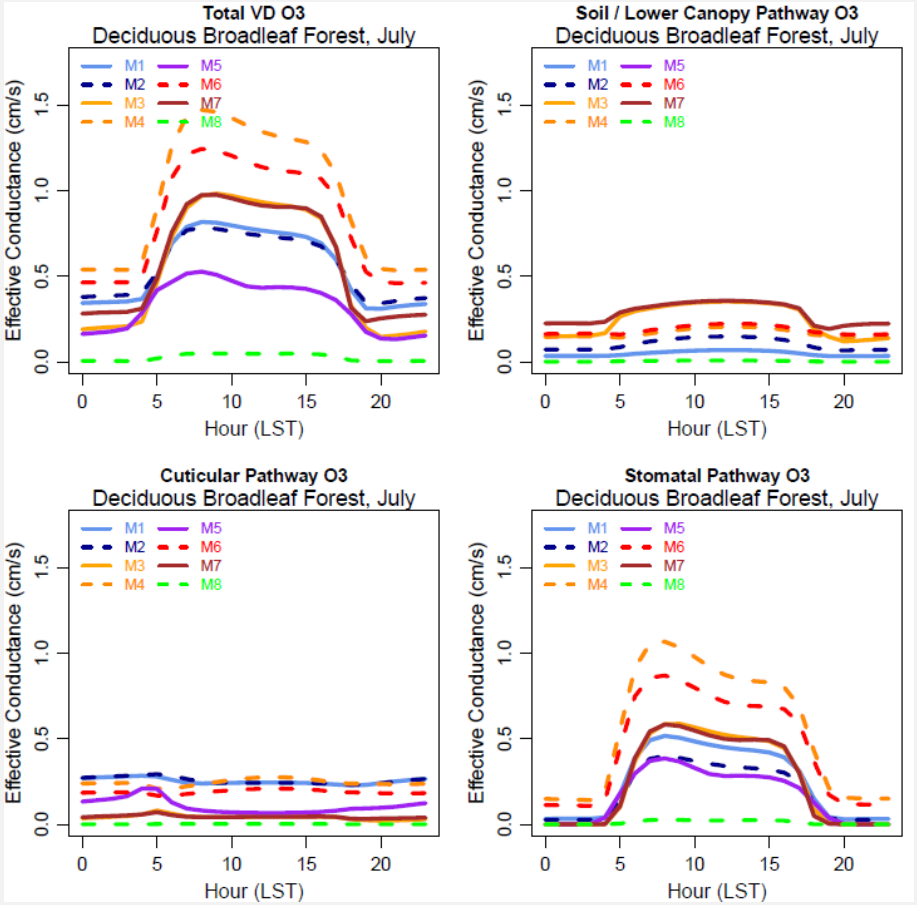
July



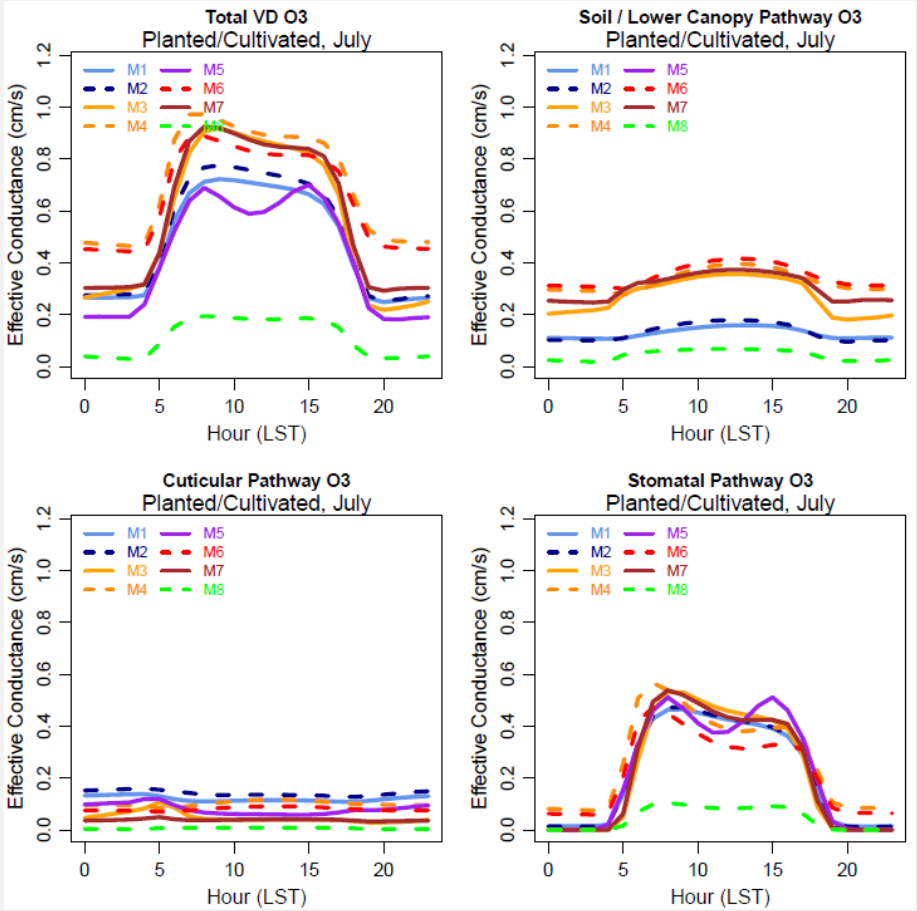
The soil and stomatal pathways tend to dominate for all models, but significant differences in their magnitude exist between models

Example: LU Specific O_3 V_d and ECOND Diurnal Cycles, July, 8 Models, North America

Deciduous Broadleaf Forest



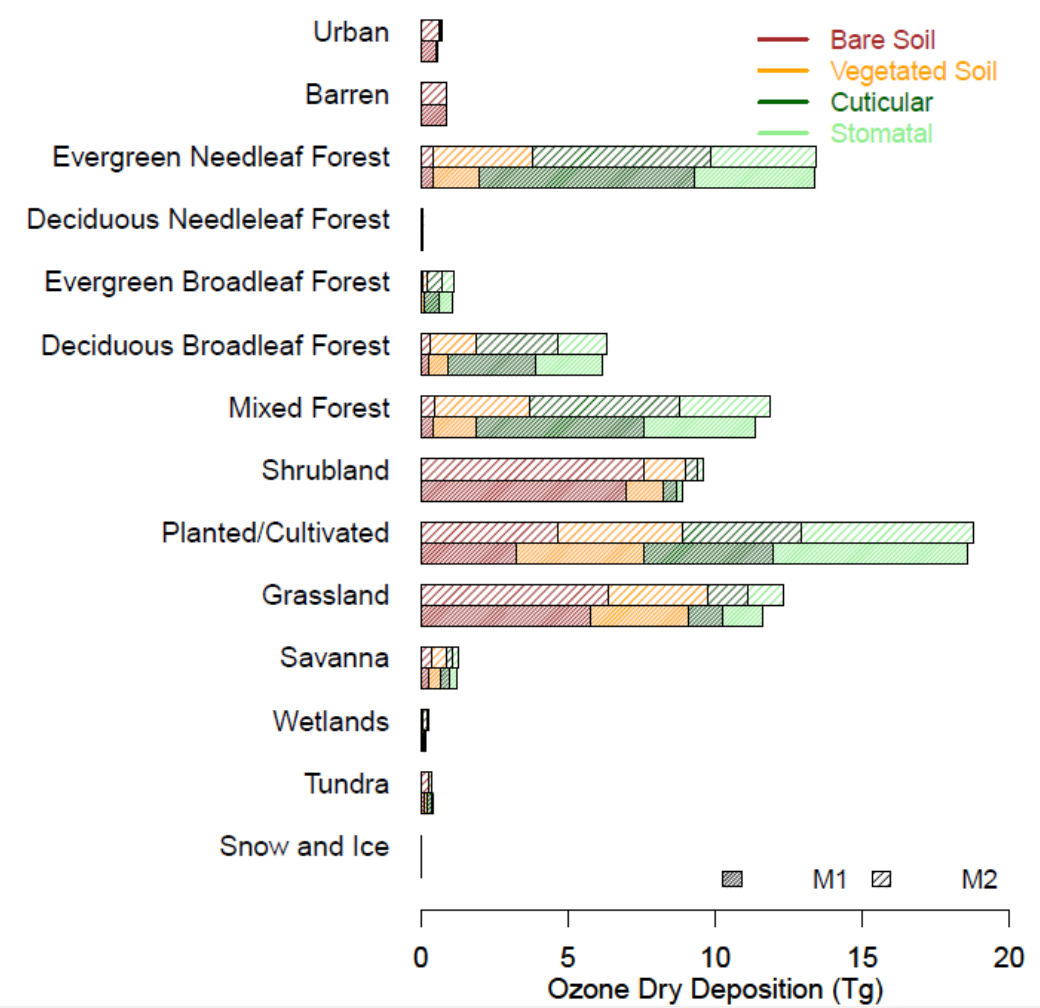
Planted / Cultivated



- Information collected through Activity 1 allows analysis of process-linked dry deposition diagnostics across space, LU categories, hours and seasons
- Initial results indicate that the pathways driving differences in modeled V_d differ across LU categories

Example: Annual Total LU-Specific O_3 DDEP by Pathway (Effective Fluxes) for M1 and M2

Annual Domain-Total O_3 DDEP by Pathway and LU (excl. Water)



- Generally greater contribution to DDEP from stomatal and cuticular pathways and lower contribution from lower canopy and soil pathways in M1 compared to M2
- While the examples shown here are for O_3, Activity 1 analyses will also include SO_2 and various reactive nitrogen species
- Comparing pathway and LU-specific V_d and DDEP across models provides diagnostic insights into model behavior
- Such comparisons performed as part of AQMEII4 are expected to be useful for informing the use of model output for ecosystem impact assessments such as critical load analyses

Hogrefe et al., in preparation

Activity 2: Single Point Model Intercomparison

Activity 2 Co-leads: O. Clifton, D. Schwede, C. Holmes, and C. Hogrefe

- Extract dry deposition schemes from chemical transport models as standalone single point models
- Compare & evaluate modeled dry deposition at **long-term** ozone flux measurement sites
- Collected long-term site environmental & meteorological measurements to drive single point models
- Single point models are computationally inexpensive – can perform large # simulations

Inputs: observed LAI, meteorology, soil & canopy characteristics, etc.

Standalone dry dep scheme

observed ozone flux

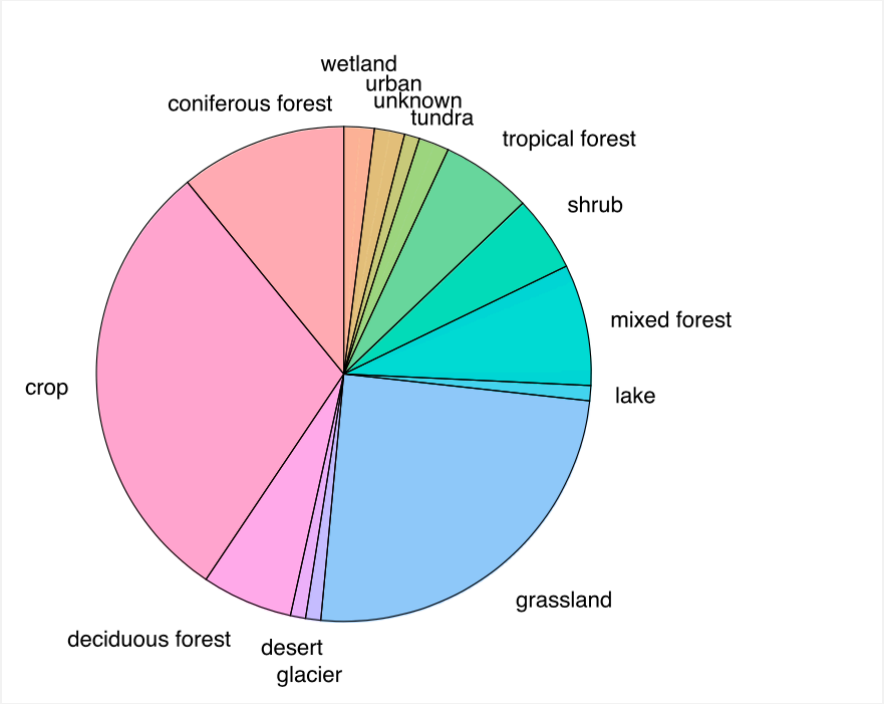
Regional Models

Global and impact assessment models

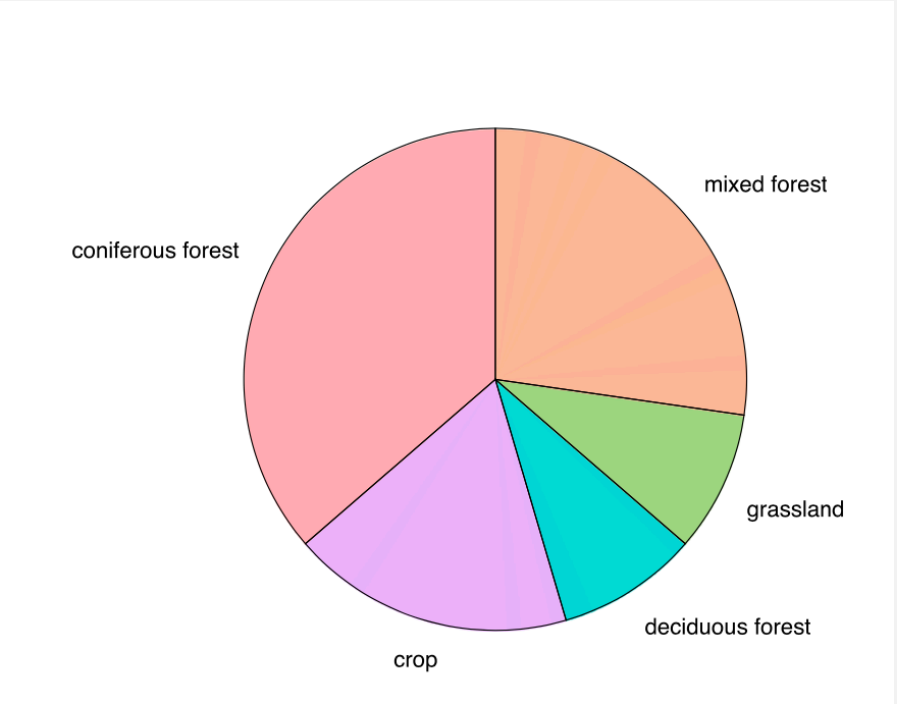
Group	Scheme(s)
ECCC	Wesely, Zhang
U.S. EPA	M3DRY, M3DRY-psn, STAGE
UPM	Wesely (as in WRF-Chem)
ECMWF	Wesely (as in IFS), two configurations
Wageningen University	MLC-CHEM (multilayer canopy model)
Florida State University	Wesely (as in GEOS-Chem)
Chinese University of Hong Kong	TEMIR Wesely and Zhang, with three stomatal options each
Stockholm Environment Institute at York	DO_3SE

Availability of Ozone Dry Deposition Measurements

Short-Term Datasets



Long-Term Datasets



Information based on peer reviewed literature & personal communication

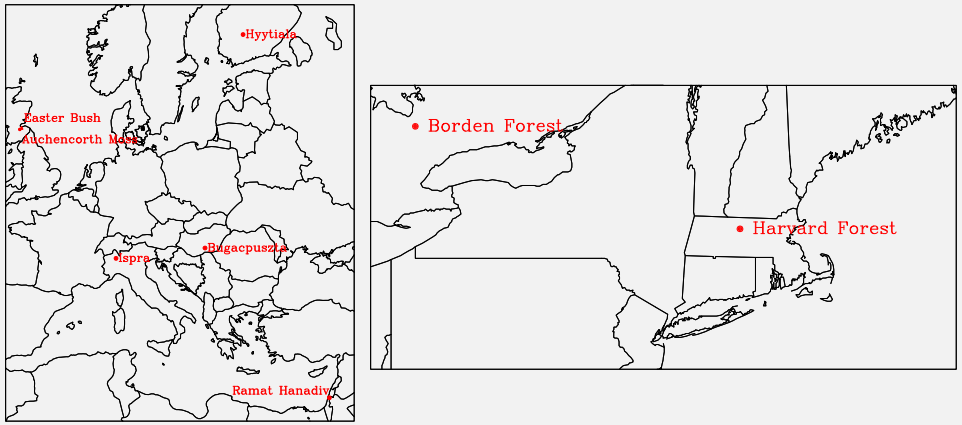
- Abundant short-term information (103 sites)
- Relatively few long-term datasets (11 sites with > 5 years; none with >15 years)

Clifton *et al. Reviews of Geophysics* [2020]

Activity 2: Single Point Models Driven by Identical Meteorological and Environmental Conditions

Goals

- Quantify the performance of a variety of dry deposition schemes under identical conditions, minimizing input uncertainty
- Understand how the different deposition pathways contribute to the model spread
- Probe the sensitivity of schemes to environmental factors and the variability in the environmental sensitivities across schemes
- Understand the differences in dry deposition simulated in the regional models in Activity 1



Site	Location Setting
Auchencorth Moss, UK	Peat bog
Borden Forest, Canada	Temperate mixed forest
Bugacpuszta, Hungary	Grass
Easter Bush, UK	Grass
Ispra, Italy	Deciduous broadleaf forest
Harvard Forest, US	Temperate mixed forest
Hyytiälä, Finland	Evergreen needleleaf forest
Ramat Hanadiv, Israel	Shrub

Clifton et al., in preparation

Summary and Next Steps

- AQMEII4 applies detailed dry deposition diagnostics (pathway and LU-specific V_d and DDEP, component resistances) to a range of air quality models and their deposition schemes
- These diagnostics are expected to provide insights into model behavior and are likely also useful for impacts assessments
- The activity is designed around complementary point intercomparisons and grid model intercomparisons
- Comparisons and analyses to take place over the coming year
  - Special issue in ACP open for submissions through August 2023