Supporting Information for

New Methodology Shows Short Atmospheric Lifetimes of Oxidized Sulfur and Nitrogen due to Dry Deposition

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Section 1. Supporting Tables S1 to S3.

Table S1. Measurement and model-derived estimates of cumulative deposition (%), transport distance (km) and lifetimes (hrs) of TOS and TON for F7, F19 and F20. Geographic foot print areas under the plumes for TOS and TON are also provided.

	Cumulative deposition (%)				e-folding transport distance ($d_{1/e}$) (km)				Lifetime ($\tau= d_{1/e}/u$) (hrs)			
TOS	7	19	20		7	19	20		7	19	20	
Measurements	22±4	74±5	45±3		1230±290	71±1	210±4		26	2.2	6.5	
Model	7	21	8		4300	500	2800		large	16	91	
Footprint (km²)	3500	5700	4200									
TON	7	19	20 (SP)	20 (NP)	7	19	20 (SP)	20 (NP)	7	19	20	
Measurements	31±11	49±11	62±14	34±6	360±14	190±7	62±1	290±30	7.6	5.6	1.9	9.0
Model	3	19	4	2	4300	650	2000	2400	91	23	63	78
Footprint (km²)	3500	5700	4200	3100								

Table S2. Equivalent dry deposition velocities V_d (cm s^{-1}) determined from the aircraft measurements (AC) and the model. SO_2 and TON mixing ratios were taken from the average of the lowest ~40m (interpolated values) across the plume width for two sets of screens. SP=south plume, NP=north plume for F20.

Flight	SO_2		TON	
	AC	model	AC	model
7	0.9 ± 0.6	0.76	2.3 ± 0.7	1.32
	1.5 ± 0.3	0.67	3.2 ± 1.0	1.55
mean	1.2 ± 0.5	0.72	2.8 ± 0.8	1.44
19	2.3 ± 0.5	0.52	1.9 ± 0.6	1.10
	2.8 ± 0.5	0.67	1.3 ± 0.4	1.35
	2.3 ± 0.4	0.70	1.5 ± 0.5	1.40
mean	2.4 ± 0.4	0.63	1.6 ± 0.5	1.28
20	3.5 ± 0.6	0.63	6.7 ± 2.0 (SP)	1.06 (SP)
			4.2 ± 1.3 (NP)	0.94 (NP)
	3.2 ± 0.5	0.52	2.8 ± 0.8 (SP)	0.77 (SP)
			0.18 ± 0.05 (NP)	0.85 (NP)
mean	3.4 ± 0.6	0.58	$4.7 \pm 0.1.4$ (SP)	0.92 (SP)
			2.2 ± 0.7 (NP)	0.90 (NP)

36 **Table S3.** Prescribed values used in the Monte-Carlo simulations with five different deposition
37 algorithms.

Component	Input Range	Units	Algorithm	Reference
Friction velocity (U^*)	0.2 to 0.6	unitless	All 5 algorithms	Oski-ôtin ground site observations
Obukhov Length (L)	-200 to -350	m	All 5 algorithms	Oski-ôtin ground site observations
Reference Height (Z)	40 to 45	m	All 5 algorithms	Estimate of AOSR
Roughness Length (z_0)	0.6 to 1	unitless	All 5 algorithms	Grassi et al., 2013
Schmidt Number (S_c)	0.8 to 2	unitless	All 5 algorithms	Oski-ôtin ground site observations
Leaf Area Index (LAI)	2 to 5	unitless	All 5 algorithms	Makar et al., 2018; Brook et al., 1999
Minimum Leaf stomatal resistance for H_2O (r_{smin})	100 to 250	s/m	ZHANG, C5DRY, WESLEY, GEM_MACH	Zhang et al., 2003
Canopy Height (h_c)	6 to 18	m	C5DRY	Estimate of AOSR
Ground resistance (R_g)	100 to 250	s/m	All 5 algorithms	Wesley et al., 1989
Solar Radiation (SolarRG)	450	W/m^2	ZHANG, C5DRY, WESLEY, GEM-MACH	Oski Otin ground site observations
Mesophyll resistance (R_m)	0.03 to 0.05	s/m	ZHANG, C5DRY, NOAH-GEM	Makar et al., 2018
In canopy aerodynamic	20 to 60	s/m	ZHANG, WESLEY, GEM-	Zhang et al., 2003

resistance reference (R_{ac0})			MACH, NOAH-GEM	
Cuticle resistance (R_{cut})	500 to 1000	s/m	C5DRY	Based on calculations of R_{cut} from the other deposition algorithms
Dry cuticle reference ($R_{cut,d0}$)	2000	s/m	ZHANG, WESLEY, NOAH-GEM	Zhang et al., 2002
Dry cuticle reference (R_{cuti})	1000	s/m	GEM-MACH	Makar et al., 2018
Surface Temperature (T_s)	20 to 25	°C	ZHANG, C5DRY, WESLEY, GEM-MACH	Aircraft observations
Relative Humidity (RH)	55 to 70	%	ZHANG, C5DRY, GEM-MACH, NOAH-GEM	Aircraft observations
Solar Zenith Angle (Theta)	65 to 75	unitless	ZHANG, C5DRY	https://www.esrl.noaa.gov/gmd/grad/antuv/SolarCalc.jsp
Slope gas exchange data (m)	9 to 10	unitless	NOAH-GEM	Zhang et al., 2002
Intercept gas exchange data (b)	0.01 to 0.04	unitless	NOAH-GEM	Zhang et al., 2002
Net CO ₂ assimilation rate (A_n)	$1e^{-6}$ to $4e^{-6}$	mol C/m ² /s	NOAH-GEM	Baldocchi et al., 1997
RH fraction at the leaf surface (h_s)	0.5 to 1	unitless	NOAH-GEM	Estimated range

Atmospheric pressure (P)	101300	Pa	NOAH-GEM	Aircraft observations
CO ₂ partial pressure at the leaf surface (C _s)	23 to 37	Pa	NOAH-GEM	Niyogi et al., 2009
Ambient T at height Z (T _a)	20 to 25	°C	ZHANG, C5DRY, GEM-MACH	Aircraft observations
T _{min}	-5 to 0	°C	ZHANG, C5DRY, GEM-MACH	Makar et al., 2018
T _{max}	40 to 45	°C	ZHANG, C5DRY, GEM-MACH	Makar et al., 2018
T _{opt}	15 to 30	°C	ZHANG, C5DRY, GEM-MACH	Makar et al., 2018
Molecular diffusivity of SO ₂ (D _c)	0.1085	cm ² /s	All 5 algorithms	Massman et al., 1998
Molecular diffusivity of water (D _{H2O})	0.2178	cm ² /s	All 5 algorithms	Massman et al., 1998

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42 **Figure S1.** Emissions-normalized deposition fluxes of (a) **TOS** and (b) **TON** derived from the
43 aircraft-based measurements (solid symbols and lines) and the GEM-MACH model (open
44 symbols and dashed lines).

Figure S2. Probability distributions of a) R_a , b) R_b , and c) R_c (s/m) for SO_2 derived from Monte Carlo simulations using 5 different deposition algorithms.

Figure S3 R_{cut} , R_c , (s/m) and V_d (cm/s) for SO_2 as a function of pH as derived from Monte Carlo simulations with the GEM-MACH deposition algorithm.

Figure S4. A strong diurnal cycle was seen in the V_d for SO_2 as determined from the vertical gradient methodology at the Oski-ôtin site in the AOSR, with a full stability correction (S24). Essentially no uptake of SO_2 was found during the night. Such a diurnal cycle in the V_d mirrors the diurnal cycle of eddy diffusivity observed at this site.

Section S3. Ground-based SO₂ fluxes. SO₂ fluxes were estimated using an eddy covariance/vertical gradient method with data collected on a 32m tower at the Oski-ôtin air quality station (57.1837 ° N, 111.6395 ° W) in Fort McKay, centrally located in the AOSR. The observation method was similar to that reported previously (Wu et al., 2018); ultrasonic anemometers (model CSAT-3, Campbell Scientific, USA) were collocated with inlets of ½” Teflon tubing at 32m, 18m and 8m above ground, drawing sampled air to gas analyzers at the base of the tower (Thermo Environmental 43i TCL). Data presented here were collected between June 6-8, 2018. Eddy diffusivities were calculated from the difference in wind speed at 32m and 8m combined with the momentum flux determined through eddy covariance at 18m, and stability-corrected following Högström et al. 1996. The determined dry deposition velocities for SO₂ are shown in Figure S4. Only daytime data (between 19 and 1 UTC) unaffected by structural disturbances (e.g. flow through the tower) were included in the comparison with the aircraft results aligning with the typical flight times. Resulting deposition velocities for SO₂ had a median of 4.1 cm s⁻¹ and a trimmed mean of 4.9 cm s⁻¹ (standard error 1.2 cm s⁻¹).

Section S4. SO₂ chemical losses

The most significant oxidant that reacts in the gas phase with SO₂ is the hydroxyl radical, OH, to produce H₂SO₄. Previous aircraft studies have shown that, in the absence of clouds, SO₂ oxidation by OH is the main pathway for SO₂ loss in industrial plumes in summertime (Brock et al., 2002; Miyakawa et al., 2007). The transformation flights were all conducted during midday under clear sky conditions, hence the contribution of cloud aqueous chemistry towards pSO₄ production during the study flights is minimal. The potential loss of SO₂ to reactions with alkenes to form organosulfates (Shang et al., 2016) and with criegee biradicals to form H₂SO₄ (Boy et al., 2013; Mauldin et al., 2012; Huang et al., 2015) would not be accounted for in the mass balance of the S mass in SO₂ presented above but would be <1% of the SO₂ conversion. Regardless, since sulfates are detected as pSO₄ by the AMS (Farmer et al., 2010), any SO₂ chemical loss other than by the reaction with OH would still be captured in the mass balance of TOS.

OH concentrations were estimated using ratios of selected volatile organic compounds (VOCs) that react almost exclusively with OH (during the daytime) and a methodology as described previously (Kleinman et al., 2003). Lagrangian transport times were determined from the aircraft-based wind speed measurements and the transit time of air between successive screens (Liggio et al., 2016). It is possible that there will be cross plume gradients in SO₂ and VOC concentrations given their different sources from each facility. However, the VOC canisters were not instantaneous, but were ~ 30 s long, representing a spatial grab of ~ 2-3 km at the speed of the aircraft. These VOC's represent the average VOC concentration from numerous sources on site, and their spatial footprint overlaps significantly with the SO₂ source footprint in these facilities. The uncertainties ranged from 17 to 58%, which attempts to account for uncertainties associated with the selection of the reference hydrocarbon concentrations, the slope determination, transport times, and reaction rate constants. OH concentrations derived using the ratio of toluene to benzene and plume box modeling for F19 (Liggio et al., 2016) were consistent within the uncertainties.

Since the AMS measures only particle mass (PM) < 1 µm in diameter, the mass of SO₄ formed through OH oxidation was scaled to account for all particle sizes that H₂SO₄ vapor could potentially condense on. The scaling factor was determined using the surface area ratio of PM₁/PM₂₀ from the aircraft particle measurements. PM₁ measurements were from the UHSAS and PM₂₀ were from the FSSP300. As the ratio did not vary significantly, one single value was used between each set of screens; in F19 the ratio between screens ranged from 0.6 to 0.8, in F20 the ratio ranged from 0.8 to 0.9, and in F7 the ratio ranged from 0.7 to 0.9.

Section S5. Modelled dry deposition fluxes and dry deposition velocities

Dry deposition fluxes estimated are compared with those predicted from an air quality model, Global Environmental Multiscale – Modelling Air-quality and Chemistry (GEM-MACH). GEM-MACH is a comprehensive on-line chemical reaction transport model (Moran et al., 2010) that has recently been used to estimate acidic deposition downwind of the AOSR (Makar et al., 2018) using a 2.5 km grid cell resolution. A detailed description of GEM-MACH appears elsewhere (Makar et al., 2018; Akingunola et al., 2018; Gordon et al., 2018). The model includes parameterizations for gas-phase chemistry, aqueous chemistry and cloud processing of

gases and aerosols, inorganic heterogeneous chemistry, secondary organic aerosol formation, and aerosol microphysics. The model version used here employs a 12-bin sectional approach to resolve particle size distribution, and eight aerosol species (sulfate, nitrate, ammonium, secondary organic aerosol, primary organic aerosol, black carbon, sea-salt, and crustal material), and incorporates aerosol direct and indirect feedbacks with the meteorological code's radiative transfer (Makar et al., 2015a; Makar et al., 2015b). Gas phase deposition of N and S compounds is determined through a commonly used resistance methodology with deposition velocities calculated using inferential methods (Makar et al., 2018). The deposition fluxes are incorporated into the vertical diffusion operator as a flux boundary condition. Further details on the formulation of GEM-MACH are provided elsewhere (Makar et al., 2018 and references therein).

The model plume boundaries were determined separately for NO_x and SO₂ plumes, using the assumption that the plume edge corresponds to background concentrations, as was the case for the observed plumes. Model and observed screens did not necessarily spatially coincide due to differences between the modelled and observed wind fields (Tables 1, 2). However, the same strategy was used to set up downwind model screen locations as in the observations (specifically, determining the plume center at one hour's advection time downwind from the sources, placing the first screen perpendicular to this direction and centred on the plume centreline, calculating a one-hour forward trajectory for the second screen and repeating the process for the second and subsequent screens). The intersection of the screen lines with the 0.1 maximum concentration contours for SO₂ and NO_x respectively, determined the boundaries of the screens for the SO₂ and NO_x plumes. Boundaries were also adjusted to correspond with the 0.2 and 0.3 maximum concentration contours which resulted in small differences (<5%) in the derived deposition fluxes. In F7, the modelled and actual plume locations were very similar; however, in F19 and F20, the modelled plumes were not exactly in the same geographical location as the observations because of differences in advection direction (Tables 1, 2).

The spatially averaged dry deposition velocities for SO₂, pSO₄ and TON are compared with those obtained using inferential methods from GEM-MACH. The measurement and model results for all three flights are listed in Table S2.

Section S6. References

- Akingunola, A., Makar, P.A., Zhang, J., Darlington, A., Li, S.-M., Gordon, M., Moran, M.D. and Zheng, Q.: A chemical transport model study of plume-rise and particle size distribution for the Athabasca oil sands, *Atmos. Chem. Phys.*, **18**, 8667-8688, 2018.
- Baldocchi, D.D., Vogel, C.A. and Hall, B.: Seasonal variation of carbon dioxide exchange rates above and below a boreal jack pine forest, *Agri. and Forest Meteorol.*, **83**, 147-170, [https://doi.org/10.1016/S0168-1923\(96\)02335-0](https://doi.org/10.1016/S0168-1923(96)02335-0), 1997.
- Boy, M., Mogensen, D., Smolander, S., Zhou, L., Nieminen, T., Paasonen, P., Plass-Dümler, C., Sipilä, M., Petäjä, T., Mauldin, L., Berresheim, H. and Kulmala, M.: Oxidation of SO₂ by stabilized criegee intermediate (sCI) radicals as a crucial source for atmospheric sulfuric acid concentrations, *Atmos. Chem. Phys.*, **13**, 3865-3879, doi:10.5194/acp-13-3865-2013, 2013.

- 159 Brock, C.A., Washenfelter, R.A., Trainer, M., Ryerson, T.B., Wilson, J.C., Reeves, J.M.,
160 Huey, L.G., Holloway, J.S., Parrish, D.D., Hübler, G., Fehsenfeld, F.C., *J. Geophys.*
161 *Res.* **107** (D12), 4155, 2002.
- 162 Brook, J.R., Zhang, L., Di-Giovanni, F. and Padro, J.: Description and evaluation of a model
163 of deposition velocities for routine estimates of air pollutant dry deposition over North
164 America. Part I: model development, *Atmos. Environ.*, **33**, 5037-5051,
165 [https://ui.adsabs.harvard.edu/link_gateway/1999AtmEn..33.5053B/doi:10.1016/S1352-](https://ui.adsabs.harvard.edu/link_gateway/1999AtmEn..33.5053B/doi:10.1016/S1352-2310(99)00251-4)
166 [2310\(99\)00251-4](https://ui.adsabs.harvard.edu/link_gateway/1999AtmEn..33.5053B/doi:10.1016/S1352-2310(99)00251-4), 1999.
- 167 Farmer, D.K., Matsunaga, A., Docherty, K.S., Surratt, J.D., Seinfeld, J.H., Ziemann, P.J. and
168 Jimenez, J.L.: Response of an aerosol mass spectrometer to organonitrates and
169 organosulfates and implications for atmospheric chemistry, *PNAS*, **107**, 6670-6675,
170 <https://doi.org/10.1073/pnas.0912340107>, 2010.
- 171 Gordon, M., Makar, P.A., Staebler, R.M., Zhang, J., Akingunola, A., Gong, W. and Li, S.-M.:
172 A comparison of plume rise algorithms to stack plume measurements in the Athabasca
173 oil sands, *Atmos. Phys. Chem.*, **18**, 14695-14714, [https://doi.org/10.5194/acp-18-](https://doi.org/10.5194/acp-18-14695-2018)
174 [14695-2018](https://doi.org/10.5194/acp-18-14695-2018), 2018.
- 175 Grassi, S., Junghans, S. and Raubal, M.: Estimating mean annual energy production of
176 clustered wind turbines with GIS, *Intern. Conf. on Appl. Energy*, Paper ID: ICAE2013-
177 492, 2013.
- 178 Högström, U.: Review of some basic characteristics of the atmospheric surface layer,
179 *Boundary-Layer Meteo.*, **78**, 215-246, doi:10.1007/bf00120937, 1996.
- 180 Huang, H.-L., Chao, W. and Jr-Min Lin, J.: Kinetics of a criegee intermediate that would
181 survive high humidity and may oxidize atmospheric SO₂, *PNAS*, **112** (35), 10857-
182 10862, <https://doi.org/10.1073/pnas.1513149112>, 2015.
- 183 Kleinman, L.I., Daum, P.H., Lee, Y.-N., Nunneermacker, L.J., Springston, S.R., Weinstein-
184 Lloyd, J., Hyde, P., Doskey, P., Rudolph, J., Fast, J. and Berkowitz, C.: Photochemical
185 age determinations in the Phoenix metropolitan area, *J. Geophys. Res.*, **108** (D3), 4096,
186 <https://doi.org/10.1029/2002JD002621>, 2003.
- 187 Liggitto, J., Li, S.-M., Hayden, K., Taha, Y. M., Stroud, C., Darlington, A., Drollette, B.D.,
188 Gordon, M., Lee, P., Liu, P., Leithead, A., Moussa, S.G., Wang, D., O'Brien, J.,
189 Mittermeier, R.L., Brook, J.R., Lu, G., Staebler, R.M., Han, Y., Tokarek, T.W.,
190 Osthoff, H.D., Makar, P.A., Zhang, J., Plata, D.L., Gentner, D.R.: Oil sands operations
191 as a large source of secondary organic aerosols, *Nature*, **534**, 91,
192 <https://doi.org/10.1038/nature17646>, 2016.
- 193 Makar, P.A., Gong, W., Milbrandt, J., Hogrefe, C., Zhang, Y., Curci, G., Zabkar, R., Im, U.,
194 Balzarini, A., Baró, R., Bianconi, R., Cheung, P., Forkel, R., Gravel, S., Hirtl, M.,
195 Honzak, L., Hou, A., Jiménez-Guerrero, P., Langer, M., Moran, M.D., Pabla, B., Pérez,
196 J.L., Pirovano, G., San José, R., Tuccella, P., Werhahn, J., Zhang, J. and Galmarini, S.:
197 Feedbacks between air pollution and weather, Part 1: Effects on weather, *Atmos.*
198 *Environ.*, **115**, 442-469, <https://doi.org/10.1016/j.atmosenv.2014.12.003>, 2015a.

- 199 Makar, P.A., Gong, W., Hogrefe, C., Zhang, Y., Curci, G., Zabkar, R., Milbrandt, J., Im, U.,
200 Balzarini, A., Baró, R., Bianconi, R., Cheung, P., Forkel, R., Gravel, S., Hirtl, M.,
201 Honzak, L., Hou, A., Jiménez-Guerrero, P., Langer, J., Moran, M.D., Pabla, B., Pérez,
202 J.L., Pirovano, G., San José, R., Tuccella, P., Werhahn, J., Zhang, J. and Galmarini, S.:
203 Feedbacks between air pollution and weather, Part 2: Effects on chemistry, *Atmos.*
204 *Environ.*, **115**, 499-526, <https://doi.org/10.1016/j.atmosenv.2014.10.021>, 2015b.
- 205 Makar, P.A., Staebler, R.M., Akingunola, A., Zhang, J., McLinden, C., Kharol, S.K., Pabla,
206 B., Cheung, P. and Zheng, Q.: The effects of forest canopy shading and turbulence on
207 boundary layer ozone, *Nature Com.*, **8**, 15243, <https://doi.org/10.1038/ncomms15243>,
208 2017.
- 209 Makar, P.A., Akingunola, A., Aherne, J., Cole, A.S., Aklilu, Y., Zhang, J., Wong, I., Hayden, K.,
210 Li, S.-M., Kirk, J., Scott, K., Moran, M.D., Robichaud, A., Cathcart, H., Baratzedah, P.,
211 Pabla, B., Cheung, P., Zheng, Q. and Jeffries, D.S.: Estimates of exceedances of critical
212 loads for acidifying deposition in Alberta and Saskatchewan, *Atmos. Chem. Phys.*, **18**,
213 9897-9927, <https://doi.org/10.5194/acp-18-9897-2018>, 2018.
- 214 Massman, W.J.: A review of the molecular diffusivities of H₂O, CO₂, CH₄, CO, O₃, SO₂, NH₃,
215 N₂O, NO, and NO₂ in air, O₂ and N₂ near STP, *Atmos. Environ.*, **32** (6), 1111-1127,
216 [https://doi.org/10.1016/s1352-2310\(97\)00391-9](https://doi.org/10.1016/s1352-2310(97)00391-9), 1998.
- 217 Mauldin III, R.L., Berndt, T., Sipilä, M., Paasonen, P., Petäjä, T., Kim, S., Kurté, T.,
218 Stratmann, F., Kerminen, V.-M. and Kulmala, M.: A new atmospherically relevant
219 oxidant of sulphur dioxide, *Nature*, **488**, 193-197, <https://doi.org/10.1038/nature11278>,
220 2012.
- 221 Miyakawa, T., Takegawa, N. and Kondo Y.: Removal of sulfur dioxide and formation of
222 sulfate aerosol in Tokyo, *J. Geophys. Res.*, **112**, D13209, doi:10.1029/2006JD007896,
223 2007.
- 224 Moran, M.D., Ménard, S., Pavlovic, R., Anselmo, D., Antonopoulos, S., Makar, P.A., Gong,
225 W., Gravel, S., Stroud, C., Zhang, J., Zheng, Q., Robichaud, A., Landry, H., Beaulieu,
226 P.A., Gilbert, S., Chen, J. and Kallaur, A.: Recent Advances in Canada's national
227 operational AQ forecasting system, In: Steyn DG, Rao ST (Eds) *Air Pollution*
228 *Modelling and Its Application*, Springer, Dordrecht, 289, 2010.
- 229 Niyogi, D., Alapaty, K., Raman, S. and Chen, F.: Development and evaluation of a coupled
230 photosynthesis-based gas exchange evapotranspiration model (GEM) for mesoscale
231 weather forecasting applications, *J. Appl. Meteor. and Climatol.*, **48**, 349-368,
232 <https://doi.org/10.1175/2008JAMC1662.1>, 2009.
- 233 Shang, J., Passanantis, M., Dupart, Y., Ciurarus, R., Tinel, L., Rossignol, S., Perrier, S., Zhu,
234 T. and George, C.: SO₂ uptake on oleic acid : a new formation pathway of organosulfur
235 compounds in the atmosphere, *Environ. Sci. Technol. Lett.* **3**, 67-72,
236 <https://doi.org/10.1021/acs.estlett.6b00006>, 2016.
- 237 Wesley, M.L.: Parameterization of surface resistances to gaseous dry deposition in regional-
238 scale numerical models, *Atmos. Environ.*, **23**, 1293-1304,

239 [https://ui.adsabs.harvard.edu/link_gateway/1989AtmEn..23.1293W/doi:10.1016/0004-](https://ui.adsabs.harvard.edu/link_gateway/1989AtmEn..23.1293W/doi:10.1016/0004-6981(89)90153-4)
 240 [6981\(89\)90153-4](https://ui.adsabs.harvard.edu/link_gateway/1989AtmEn..23.1293W/doi:10.1016/0004-6981(89)90153-4), 1989.

241 Wu, Z. Schwede, D.B., Vet, R., Walker, J.T., Shaw, M., Staebler, R. and Zhang, L.:
 242 Evaluation and intercomparison of five North American dry deposition algorithms at a
 243 mixed forest site, J. Adv. Modelling Earth Systems, **10**, 1571-1586, , 2018. Zhang, L.,
 244 Brook, J.R. and Vet, R.: A revised parameterization for gaseous dry deposition in air-
 245 quality models, Atmos. Chem. Phys. **3**, 2067-2082, [https://doi.org/10.5194/acp-3-](https://doi.org/10.5194/acp-3-2067-2003)
 246 [2067-2003](https://doi.org/10.5194/acp-3-2067-2003), 2003.

247 Zhang, L., Moran, M.D., Makar, P.A., Brook, J.R. and Gong, S.: Modelling gaseous dry
 248 deposition in AURAMS: a unified regional air-quality modelling system, Atmos.
 249 Environ., **36**, 537-560, [https://doi.org/10.1016/S1352-2310\(01\)00447-2](https://doi.org/10.1016/S1352-2310(01)00447-2), 2002.