Supporting Information for

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

Katherine Hayden1, Shao-Meng Li1,2*, Paul Makar1, John Liggio1, Samar G. Moussa1, Ayodeji Akingunola1, Robert McLaren3, Ralf M. Staebler1, Andrea Darlington1, Jason O’Brien1, Junhua Zhang1, Mengistu Wolde4, Leiming Zhang1

1Air Quality Research Division, Environment and Climate Change Canada, Toronto, Ontario, Canada, M3H 5T4
2College of Environmental Science and Engineering, Peking University, Beijing, 100871 China
3Center for Atmospheric Chemistry, York University, 4700 Keele Street, Toronto, Ontario, Canada
4National Research Council Canada, Flight Research Laboratory, Ottawa, Canada K1A 0R6

*corresponding authors shaomeng.li@pku.edu.cn; katherine.hayden@canada.ca

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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 footprint areas under the plumes for TOS and TON are also provided.

|       | Cumulative deposition (%) | e-folding transport distance \( (d_{1/e}) \) (km) | Lifetime \( (\tau = \frac{d_{1/e}}{u}) \) (hrs) | Footprint \( (km^2) \) |
|-------|----------------------------|-----------------------------------------------|-----------------------------------------------|------------------|
| TOS   | 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 \( (km^2) \) | 3500                        | 5700                                         | 4200                                         |                  |
| TON   | 7                          | 19                                           | 20 (SP)                                      | 7 19 20          |
| Measurements | 31±11                       | 49±11                                        | 62±14                                        | 360±14 190±7 62±1290±30 7.6 5.6 1.9 9.0 |
| Model | 3                          | 19                                           | 4                                            | 4300 650 2000 2400 91 23 63 78 |
| Footprint \( (km^2) \) | 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  | 1.06     |
|        |              |          | (SP)     | (SP)     |
|        |              |          | 4.2±1.3  | 0.94     |
|        |              |          | (NP)     | (NP)     |
|        | 3.2±0.5     | 0.52     | 2.8±0.8  | 0.77     |
|        |              |          | (SP)     | (SP)     |
|        |              |          | 0.18±0.05| 0.85     |
|        |              |          | (NP)     | (NP)     |
| mean   | 3.4±0.6     | 0.58     | 4.7±0.14 | 0.92     |
|        |              |          | (SP)     | (SP)     |
|        |              |          | 2.2±0.7  | 0.90     |
|        |              |          | (NP)     | (NP)     |
Table S3. Prescribed values used in the Monte-Carlo simulations with five different deposition algorithms.

| Component                                      | Input Range | Units   | Algorithm         | Reference                      |
|------------------------------------------------|-------------|---------|-------------------|--------------------------------|
| Friction velocity (U*)                         | 0.2 to 0.6  | unitless| All 5 algorithms  | Oski-ōtin ground site observations |
| Obukhov Length (L)                             | -200 to -350| m       | All 5 algorithms  | Oski-ōtin ground site observations |
| Reference Height (Z)                           | 40 to 45    | m       | All 5 algorithms  | Estimate of AOSR                |
| Roughness Length (z0)                          | 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-ōtin 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 H2O (rs_min) | 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/m²    | 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-MACH | Zhang et al., 2003 |
| Parameter                                           | Value                  | Unit(s) | Reference                          | Notes                                                                 |
|-----------------------------------------------------|------------------------|---------|------------------------------------|----------------------------------------------------------------------|
| 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_{cut})                     | 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](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\textsubscript{2} assimilation rate (A_n)     | 1e^{-6} to 4e^{-6}     | mol C/m\textsuperscript{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                                                      |
| Description                                                                 | Value       | Unit        | Algorithm            | Source                        |
|----------------------------------------------------------------------------|-------------|-------------|----------------------|-------------------------------|
| Atmospheric pressure (P)                                                   | 101300      | Pa          | NOAH-GEM             | Aircraft observations         |
| CO₂ partial pressure at the leaf surface (Cₛ)                             | 23 to 37    | Pa          | NOAH-GEM             | Niyogi et al., 2009           |
| Ambient T at height Z (Tₐ)                                                | 20 to 25    | °C          | ZHANG, C5DRY, GEM-MACH | Aircraft observations         |
| Tₘᵢₙ                                                                        | -5 to 0     | °C          | ZHANG, C5DRY, GEM-MACH | Makar et al., 2018            |
| Tₘᵞ                                                                          | 40 to 45    | °C          | ZHANG, C5DRY, GEM-MACH | Makar et al., 2018            |
| Tₒᵖₜ                                                                       | 15 to 30    | °C          | ZHANG, C5DRY, GEM-MACH | Makar et al., 2018            |
| Molecular diffusivity of SO₂ (Dₛ)                                         | 0.1085      | cm²/s       | All 5 algorithms     | Massman et al., 1998          |
| Molecular diffusivity of water (Dₜₐₜₒ)                                    | 0.2178      | cm²/s       | All 5 algorithms     | Massman et al., 1998          |
Figure S1. Emissions-normalized deposition fluxes of (a) TOS and (b) TON derived from the aircraft-based measurements (solid symbols and lines) and the GEM-MACH model (open 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 $R_{\text{cut}}$, $R_c$, (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 SO\(_2\) 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 SO\(_2\) and NO\(_x\) respectively, determined the boundaries of the screens for the SO\(_2\) 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 SO\(_2\), pSO\(_4\) 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 Meteor., 83, 147-170, https://doi.org/10.1016/S0168-1923(96)02335-0, 1997.

Boy, M., Mogensen, D., Smolander, S., Zhou, L., Nieminen, T., Paasonen, P., Plass-Dülmer, C., Sipilä, M., Petäjä, T., Mauldin, L., Berresheim, H. and Kulmala, M.: Oxidation of SO\(_2\) 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.
Brock, C.A., Washenfelder, R.A., Trainer, M., Ryerson, T.B., Wilson, J.C., Reeves, J.M., Huey, L.G., Holloway, J.S., Parrish, D.D., Hübner, G., Fehsenfeld, F.C.; J. Geophys. Res. **107** (D12), 4155, 2002.

Brook, J.R., Zhang, L., Di-Giovanni, F. and Padro, J.: Description and evaluation of a model of deposition velocities for routine estimates of air pollutant dry deposition over North America. Part I: model development, Atmos. Environ., **33**, 5037-5051, https://ui.adsabs.harvard.edu/link_gateway/1999AtmEn..33.5053B/doi:10.1016/S1352-2310(99)00251-4, 1999.

Farmer, D.K., Matsunaga, A., Docherty, K.S., Surratt, J.D., Seinfeld, J.H., Ziemann, P.J. and Jimenez, J.L.: Response of an aerosol mass spectrometer to organonitrates and organosulfates and implications for atmospheric chemistry, PNAS, **107**, 6670-6675, https://doi.org/10.1073/pnas.0912340107, 2010.

Gordon, M., Makar, P.A., Staebler, R.M., Zhang, J., Akingunola, A., Gong, W. and Li, S.-M.: A comparison of plume rise algorithms to stack plume measurements in the Athabasca oil sands, Atmos. Phys. Chem., **18**, 14695-14714, https://doi.org/10.5194/acp-18-14695-2018, 2018.

Grassi, S., Junghans, S. and Raubal, M.: Estimating mean annual energy production of clustered wind turbines with GIS, Intern. Conf. on Appl. Energy, Paper ID: ICAE2013-492, 2013.

Högström, U.: Review of some basic characteristics of the atmospheric surface layer, Boundary-Layer Meteor., **78**, 215-246, doi:10.1007/bf00120937, 1996.

Huang, H.-L., Chao, W. and Jr-Min Lin, J.: Kinetics of a criegee intermediate that would survive high humidity and may oxidize atmospheric SO$_2$, PNAS, **112** (35) 10857-10862, https://doi.org/10.1073/pnas.1513149112, 2015.

Kleinman, L.I., Daum, P.H., Lee, Y.-N., Nunneermacker, L.J., Springston, S.R., Weinstein-Lloyd, J., Hyde, P., Doskey, P., Rudolph, J., Fast, J. and Berkowitz, C.: Photochemical age determinations in the Phoenix metropolitan area, *J. Geophys. Res.*, **108** (D3), 4096, https://doi.org/10.1029/2002JD002621, 2003.

Liggio, J., Li, S.-M., Hayden, K., Taha, Y. M., Stroud, C., Darlington, A., Drollette, B.D., Gordon, M., Lee, P., Liu, P., Leithead, A., Moussa, S.G., Wang, D., O’Brien, J., Mittermeier, R.L., Brook, J.R., Lu, G., Staebler, R.M., Han, Y., Tokarek, T.W., Osthooff, H.D., Makar, P.A., Zhang, J., Plata, D.L., Gentner, D.R.: Oil sands operations as a large source of secondary organic aerosols, Nature, **534**, 91, https://doi.org/10.1038/nature17646, 2016.

Makar, P.A., Gong, W., Milbrandt, J., Hogrefe, C., Zhang, Y., Curci, G., Zabkar, R., Im, U., Balzarini, A., Baró, R., Bianconi, R., Cheung, P., Forkel, R., Gravel, S., Hirtl, M., Honzak, L., Hou, A., Jiménez-Guerrero, P., Langer, M., Moran, M.D., Pabla, B., Pérez, J.L., Pirovano, G., San José, R., Tuccella, P., Werhahn, J., Zhang, J. and Galmarini, S.: Feedbacks between air pollution and weather, Part 1: Effects on weather, Atmos. Environ., **115**, 442-469, https://doi.org/10.1016/j.atmosenv.2014.12.003, 2015a.
Makar, P.A., Gong, W., Hogrefe, C., Zhang, Y., Curci, G., Zabkar, R., Milbrandt, J., Im, U., Balzarini, A., Baró, R., Bianconi, R., Cheung, P., Forkel, R., Gravel, S., Hirtl, M., Honzak, L., Hou, A., Jiménez-Guerrero, P., Langer, J., Moran, M.D., Pabla, B., Pérez J.L., Pirovano, G., San José, R., Tuccella, P., Werhahn, J., Zhang, J. and Galmarini, S.: Feedbacks between air pollution and weather, Part 2: Effects on chemistry, Atmos. Environ., 115, 499-526, https://doi.org/10.1016/j.atmosenv.2014.10.021, 2015b.

Makar, P.A., Staebler, R.M., Akingunola, A., Zhang, J., McLinden, C., Kharol, S.K., Pabla, B., Cheung, P. and Zheng, Q.: The effects of forest canopy shading and turbulence on boundary layer ozone, Nature Com., 8, 15243, https://doi.org/10.1038/ncomms15243, 2017.

Makar, P.A., Akingunola, A., Aherne, J., Cole, A.S., Aklilu, Y., Zhang, J., Wong, I., Hayden, K., Li, S.-M., Kirk, J., Scott, K., Moran, M.D., Robichaud, A., Cathcart, H., Baratzedah, P., Pabla, B., Cheung, P., Zheng, Q. and Jeffries, D.S.: Estimates of exceedances of critical loads for acidifying deposition in Alberta and Saskatchewan, Atmos. Chem. Phys., 18, 9897-9927, https://doi.org/10.5194/acp-18-9897-2018, 2018.

Massman, W.J.: A review of the molecular diffusivities of H2O, CO2, CH4, CO, O3, SO2, NH3, N2O, NO, and NO2 in air, O2 and N2 near STP, Atmos. Environ., 32 (6), 1111-1127, https://doi.org/10.1016/s1352-2310(97)00391-9, 1998.

Mauldin III, R.L., Berndt, T., Sipilä, M., Paasonen, P., Petäjä, T., Kim, S., Kurté, T., Stratmann, F., Kerminen, V.-M. and Kulmala, M.: A new atmospherically relevant oxidant of sulphur dioxide, Nature, 488, 193-197, https://doi.org/10.1038/nature11278, 2012.

Miyakawa, T., Takegawa, N. and Kondo Y.: Removal of sulfur dioxide and formation of sulfate aerosol in Tokyo, J. Geophys. Res., 112, D13209, doi:10.1029/2006JD007896, 2007.

Moran, M.D., Ménard, S., Pavlovic, R., Anselmo, D., Antonopoulos, S., Makar, P.A., Gong, W., Gravel, S., Stroud, C., Zhang, J., Zheng, Q., Robichaud, A., Landry, H., Beaulieu, P.A., Gilbert, S., Chen, J. and Kallaur, A.: Recent Advances in Canada’s national operational AQ forecasting system, In: Steyn DG, Rao ST (Eds) Air Pollution Modelling and Its Application, Springer, Dordrecht, 289, 2010.

Niyogi, D., Alapaty, K., Raman, S. and Chen, F.: Development and evaluation of a coupled photosynthesis-based gas exchange evapotranspiration model (GEM) for mesoscale weather forecasting applications, J. Appl. Meteor. and Climatol., 48, 349-368, https://doi.org/10.1175/2008JAMC1662.1, 2009.

Shang, J., Passanantis, M., Dupart, Y., Ciurarus, R., Tinel, L., Rossignol, S., Perrier, S., Zhu, T. and George, C.: SO2 uptake on oleic acid : a new formation pathway of organosulfur compounds in the atmosphere, Environ. Sci. Technol. Lett. 3, 67-72, https://doi.org/10.1021/acs.estlett.6b00006, 2016.

Wesley, M.L.: Parameterization of surface resistances to gaseous dry deposition in regional-scale numerical models, Atmos. Environ., 23, 1293-1304,
Wu, Z. Schwede, D.B., Vet, R., Walker, J.T., Shaw, M., Staebler, R. and Zhang, L.: Evaluation and intercomparison of five North American dry deposition algorithms at a mixed forest site, J. Adv. Modelling Earth Systems, 10, 1571-1586, 2018.

Zhang, L., Brook, J.R. and Vet, R.: A revised parameterization for gaseous dry deposition in air-quality models, Atmos. Chem. Phys. 3, 2067-2082, https://doi.org/10.5194/acp-3-2067-2003, 2003.

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