Supplementary Material

Wind reduction by aerosol particles

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Introduction
This Supplementary Material describes the model used for this study in more detail (Section 1), discusses the setup of simulations for the study (Section 2), shows paired-in-time-and-space comparisons of baseline model predictions with data (Section 3), and discusses baseline and additional difference plots from the simulations (Section 4).

1. Description of the Model
The model used for this study was GATOR-GCMOM, a parallelized and one-way-nested global-through-urban scale Gas, Aerosol, Transport, Radiation, General Circulation, Mesoscale, and Ocean Model (S1-S12). The model treated time-dependent gas, aerosol, cloud, radiative, dynamical, ocean, and transport processes. Aerosol processes were treated among a single aerosol size distribution with multiple components. Cloud processes were treated among three hydrometeor size distributions (liquid, ice, graupel), each containing aerosol inclusions. Size-resolved aerosols, clouds, and their chemical inclusions were transported in 3-D. All processes described were solved in all grid cells in the stratosphere and troposphere.

1.A. Atmospheric Dynamical and Transport Processes
On the global scale, the model solved the momentum equation under the hydrostatic assumption and the thermodynamic energy equation with a potential-enstrophy, mass, and energy-conserving scheme (S13). In nested regional domains, the solution scheme conserved enstrophy, mass, and kinetic energy (S14). Dynamical schemes on all domains used spherical and sigma-pressure coordinates in the horizontal and vertical, respectively. Transport of gases (including water vapor), aerosol particles, and hydrometeor particles was solved with a conservative, monotonic method (S15) using modeled online winds and vertical diffusion coefficients.
1.B. Gas processes
Gas processes included emission, photochemistry, advection, turbulence, cloud convection of gases, nucleation, washout, dry deposition, and condensation onto and dissolution into aerosol particles, clouds, and precipitation. Gases affected solar and thermal-IR radiation, aerosol formation, and cloud evolution, all of which fed back to meteorology. Gas photochemistry was solved with SMVGear II (SI6). The chemical mechanism included 126 gases and 283 reactions relevant to urban, free tropospheric, and stratospheric chemistry.

1.C. Aerosol Processes
For the present application, aerosol processes were treated in a single size distribution consisting of 17 size bins ranging from 0.002 to 50 µm in diameter, and multiple aerosol components per bin. The model is generalized so that any number of discrete, interacting aerosol size distributions can be treated and used for cloud development (SI7). The aerosol size bin structure used was the moving-center structure, whereby bin edges were fixed but bin centers moved in diameter space due to change in particle size (SI). Parameters treated prognostically in each size bin included particle number concentration and individual component mole concentration. Single-particle volume was calculated assuming particles contained a solution and nonsolution component, as in (S18), which also describes most numerical techniques used for solving aerosol physical and chemical processes.

Size-dependent aerosol processes included emission, homogeneous nucleation, condensation, dissolution, aerosol-aerosol coagulation, aerosol-cloud/ice/graupel coagulation, equilibrium hydration of liquid water, internal-particle chemical equilibrium, irreversible aqueous chemistry, evaporation of cloud drops to aerosol-particles, transport, sedimentation, dry deposition, rainout, and washout. Aerosol particles affected solar and thermal-IR radiation, cloud evolution, gas concentration, and surface albedo, all of which fed back to meteorology.

Sulfuric acid-water binary homogeneous nucleation rates were calculated as in (SI9); sulfuric acid-ammonia-water ternary homogeneous nucleation rates were calculated as in (S20). Homogeneous nucleation and condensation of sulfuric acid were solved simultaneously between the gas phase and all size bins with a mass-conserving, noniterative, and unconditionally stable scheme (SI8) that also solved condensation of organic gases onto size-resolved aerosol particles. The model further treated nonequilibrium dissolutional growth of inorganics (e.g., NH₃, HNO₃, HCl) and soluble organics to all size bins with a mass-conserving nonequilibrium growth solver, PNG-EQUISOLV II (S21), where PNG is Predictor of Nonequilibrium Growth. EQUISOLV II is a chemical equilibrium solver that determines aerosol liquid water content, pH, and ion distributions following nonequilibrium growth (S22). Aerosol-aerosol coagulation was solved among all size bins and components and among total particles in each bin with a volume-conserving, noniterative algorithm (SI8).

1.D. Gas-Aerosol-Cloud-Turbulence Interactions
On the regional scale, cloud thermodynamics and microphysics were calculated explicitly and clouds were transported in three dimensions. Water vapor and size- and composition-resolved aerosol particles were first transported using predicted horizontal and vertical velocities. When the partial pressure of water vapor exceeded the saturation vapor pressure over liquid water or ice on an aerosol particle or pre-existing hydrometeor-particle surface, water vapor condensed or deposited. The saturation vapor pressure was affected by the Kelvin effect and Raoult’s law, both of which were calculated from aerosol and hydrometeor composition. Thus, changes in, for example, surface tension due to organics and inorganics affected the activation properties of aerosol particles. The
numerical solution for hydrometeor growth accounted for water vapor condensation and deposition onto all activated size-resolved aerosol particles and pre-existing size-resolved hydrometeor simultaneously, as in (S7). The numerical scheme was unconditionally stable, noniterative, positive-definite, and mole conserving.

Following the condensation/deposition calculation, liquid drops and ice crystals were partitioned from a single size-resolved aerosol distribution into separate liquid and ice hydrometeor size distributions, where each discrete size bin contained all the chemical components of the underlying CCN aerosol particles. A third discretized hydrometeor distribution, graupel, was also tracked. This distribution formed upon heterocoagulation of the liquid water and ice hydrometeor distributions, contact freezing of aerosol particles with the liquid distribution, heterogeneous-homogeneous freezing of the liquid distribution, and evaporative freezing of the liquid distribution.

Following partitioning, the size-resolved cloud-aerosol processes treated each time step included hydrometeor-hydrometeor coagulation (liquid-liquid, liquid-ice, liquid-graupel, ice-ice, ice-graupel, and graupel-graupel), aerosol-hydrometeor coagulation, large liquid drop breakup, settling to the layer below (or precipitation from the lowest layer to the surface), evaporative cooling during drop settling, evaporative freezing (freezing during drop cooling), heterogeneous-homogeneous freezing, contact freezing, melting, evaporation, sublimation release of aerosol cores upon evaporation/sublimation, coagulation of hydrometeors with interstitial aerosols, irreversible aqueous chemistry, gas washout, and lightning generation from size-resolved coagulation among ice hydrometeors. The kernel for all cloud coagulation interactions and aerosol-cloud coagulation interactions included a coalescence efficiency and collision kernels for Brownian motion, Brownian diffusion enhancement, turbulent inertial motion, turbulent shear, settling, thermophoresis, diffusiophoresis, and charge. Numerical techniques used for these processes are given in (S17).

During the microphysical calculations, changes in energy due to condensation, evaporation, deposition, sublimation, freezing, and melting were included as diabatic heating terms in the thermodynamic energy equation; energy was conserved due to cloud formation and decay. Similarly, total water (water vapor, size-resolved aerosol water, size-resolved cloud water, soil water, and ocean water) was conserved.

Following the cloud- and aerosol microphysical calculations each time step, size-resolved aerosol particles and hydrometeors particles (if they existed) in each grid cell were transported by horizontal and vertical winds and turbulence. Thus, three-dimensional size-resolved clouds (stratus, cumulus, cumulonimbus, cirrus, etc.) formed, moved, and dissipated in the model.

Aerosol particles of different size were removed by size-resolved clouds and precipitation through two mechanisms: nucleation scavenging and aerosol-hydrometeor coagulation. Both processes were size-resolved with respect to both aerosol particles and hydrometeor particles.

On the global scale, cloud thermodynamics was calculated with stratus and cumulus parameterizations whereas cloud microphysics was calculated explicitly, as described in (S17). The stratus cloud scheme was from (S23) and was coupled with the calculation of turbulence (order 2.5). The stratus scheme predicted cloud fraction and cloud water content in each layer given turbulence terms and vertical gradients in potential temperature and moisture. Turbulence parameters affected clouds, momentum, energy, and tracers, particularly in the boundary layer, which was resolved. Cumulus clouds were predicted with a modified Arakawa-Šchubert algorithm (S24). In each
column, nearly 500 subgrid cumulus clouds could form (and 1-10 typically formed), each defined by a unique cloud base and top (when 23 layers existed below the tropopause, 22 bases and 22 tops are possible). For each subgrid cloud, water and energy transport were solved with a mass-flux convection scheme; gas and size-resolved aerosol component transport were solved with a positive-definite, stable convective plume transport scheme. For each subgrid cloud, the model also generated adjustments to large-scale potential temperature, momentum, and water vapor.

Following cumulus-parameterization convection on the global scale, the bulk water predicted in each layer from the cumulus and stratus parameterizations were evaporated/sublimated, then regrown (simultaneously for liquid and ice) onto the size-resolved aerosol distributions transported vertically to that layer. Because aerosol particles were transported vertically with cloud water in all cases, aerosol activation was consistent with that in a rising plume. The remainder of the microphysical calculation, including all interaction of aerosol particles with clouds, was the same as on the regional scale. The main difference between the global and regional calculations was that, on the global scale, all remaining cloud water was evaporated at the end of a time step and clouds were allowed to reform during the next step; on the regional scale, clouds that formed were tracked continuously and allowed to evolve over time. In both cases, the first and second indirect effects were treated. In other words, aerosol particles affected cloud drop size and optical properties and precipitation rates.

In sum, on the global scale, cumulus and stratus parameterizations were used to determine subgrid clouds and cloud water, and cloud microphysics was calculated as a time-dependent process following an equilibrium calculation of cloud thermodynamics. Clouds were not transported but were developed locally. On the regional scale, however, clouds evolved and developed in time following explicit thermodynamic and microphysical calculations and were transported in three dimensions.

1.E. Radiative Processes
Radiation processes included UV, visible, solar-IR, and thermal-IR interactions with gases, size/composition-resolved aerosols, and size/composition-resolved hydrometeor particles. Radiative transfer was solved with the scheme of (S25). Calculations were performed for over >600 wavelengths/probability intervals and affected photolysis and heating (S26). Gas absorption coefficients in the solar-IR and thermal-IR were calculated for H₂O, CO₂, CH₄, CO, O₃, O₂, N₂O, CH₂Cl, CFC₁₁, CF₂Cl₂, and CCl₄ from HITRAN data (S26). Aerosol-particle optical properties were calculated assuming that black carbon (BC) (if present in a size bin) comprised a particle's core and all other material coated the core. Shell real and imaginary refractive indices for a given particle size and wavelength were obtained by calculating the solution-phase refractive index, calculating refractive indices of non-solution, non-BC species, and volume averaging solution and nonsolution refractive indices. Core and shell refractive indices were used in a core-shell Mie-theory calculation (S27). Cloud liquid, ice, and graupel optical properties for each hydrometeor size and radiation wavelength were also determined from Mie calculations that accounted for absorbing inclusions. For such a calculation, nonspherical ice crystals were assumed to be a collection of spheres of the same total volume to area ratio and total volume (S28). The surface albedos of snow, sea ice, and water (ocean and lake) were wavelength-dependent and predicted by (rather than specified in) the model (S12). Column calculations treated shading by structures (e.g., buildings) and topography.

1.F. Subgrid Surfaces and Oceans
The model treated ground temperatures over subgrid surfaces (up to 12 soil classes and roads over soil, roofs over air, and water in each cell). It also treated vegetation over soil, snow over bare soil, snow over vegetation over soil, sea-ice over water, and snow over
sea-ice over water (S5). For all surfaces except sea ice and water, surface and subsurface temperatures and liquid water were found with a time-dependent 10-layer module. Ocean mixed-layer velocities, energy transport, and mass transport were calculated with a gridded 2-D potential-entrophy, energy, and mass-conserving shallow-water equation module, forced by wind stress (S29), based on the shallow-water scheme of (S13). The actual depth at each location was a prognostic variable, but because the module conserved volume exactly, the average mixing depth over the global ocean was constant (80 m). For lake water, a fixed 80 m mixing depth was assumed. Water (ocean and lake) temperatures were also affected by sensible, latent, and radiative fluxes. Nine additional layers existed below each ocean mixed-layer grid cell to treat energy diffusion from the mixed layer to the deep ocean and ocean chemistry. Dissolution of gases to the surface ocean, diffusion to the deep ocean, and ocean chemistry in the surface and deep oceans were calculated with OPD-EQUISOLV O (S30), where OPD solves nonequilibrium transport between the ocean and atmosphere and EQUISOLV O solves chemical equilibrium in the ocean. Both schemes are mass conserving and unconditionally stable.

2. Description of Simulations
The model was run in nested mode from the global to local scale for February and August, 1999. Three one-way nested domains were used: a global domain (4°-SN x 5°-WE resolution), a California domain (0.2°x0.15° ≈ 21.5 km x 14.0 km with the southwest corner grid cell centered at 30.0 °N and -126.0° W and 60 SN cells x 75 WE cells), and a South Coast Air Basin (SCAB) domain (0.045 °x0.05 ° ≈ 4.7 km x 5 km with the southwest corner grid cell centered at 30.88 °N and -119.35° W and 46 SN cells x 70 WE cells). The global domain included 39 sigma-pressure layers between the surface and 0.425 hectaPascal (hPa). The nested regional domains included 26 layers between the surface and 103.5 hPa, matching the bottom 26 global-model layers exactly. Each domain included five layers in the bottom 1 km. The nesting time interval for passing meteorological and chemical variables was one hour.

The baseline emission inventory used was the U.S. National Emission Inventory for 1999, version 2 (S31). The inventory accounts for over 370,000 stack and fugitive sources, 250,000 area sources, and 1700 source classification code (SCC) categories of onroad and nonroad mobile sources. Pollutants emitted hourly included CO, CH₄, paraffins, olefins, formaldehyde, higher aldehydes, toluene, xylene, isoprene, monoterpenes), NO, NO₂, HONO, NH₃, SO₂, SO₃, H₂SO₄, particulate black carbon, particulate organic carbon, particulate sulfate, particulate nitrate, and other particulate matter. From the raw U.S. inventory, special inventories were prepared for each model domain. Particle mass emissions were spread over multimodal lognormal distribution (S10). Total annual anthropogenic emissions (metric tonnes per year) in the California domain from the inventory were as follows: CO (11,000,000), NO as NO₂ (1,495,000), ROG (2,210,000), CH₄ (682,000), SO₂ as SO₃ (126,100), NH₃ (217,700), POM<2.5 micrometer diameter (283,800), BC<2.5 (51,290), sulfate<2.5 (17,300), nitrate<2.5 (1,731), other<2.5 (454,500), POM<10 micrometer diameter (497,000), BC<10 (74,310), sulfate<10 (29,470), nitrate<10 (3891), other<10 (1,752,000). Although the inventory appears to capture most of the important sources and species, some shortcomings are apparent from the inventory. For example, most onroad particulate matter is categorized as “other,” whereas some of this, such as tire and brake particles, should be identified as BC or OM. Additional emission types treated in the model were biogenic (isoprene, monoterpenes, other volatile organics, and nitric oxide), wind-driven soil dust, sea spray, pollen, spores, and bacteria, NO₂ from lightning, DMS from the oceans, volcanic SO₂, many gases and particles from biomass burning, and CO₂, H₂, and H₂O from fossil-fuel combustion and biomass burning. Soil dust, sea spray, and lightning numerical treatments are provided in (S32), Sections 14.1.2, 14.1.1, and 18.8.11, respectively. Pollen and spores were emitted as a function of leaf-area index, turbulent kinetic energy (thus wind
shear), and season. Spore emissions were additionally a function of the relative humidity. Bacteria emissions over land were a function of turbulent kinetic energy, vegetation fraction, and season. Bacteria emissions over the ocean were a function of wind speed. All natural emissions are described in more detail elsewhere (S33).

The model was run for each February and August 1999 with and without emission of anthropogenic aerosol particle and precursor gases (AAPPG) in the California domain. AAPPG includes aerosol particles (anthropogenic black carbon (BC), primary organic carbon (POC), sulfate, nitrate, and other) and precursor gases (anthropogenic SO\(_2\), NO\(_x\), NH\(_3\), and speciated reactive organics gases, ROGs, including paraffins, olefins, formaldehyde, higher aldehydes, toluene, xylene), but not CO\(_2\), CH\(_4\), N\(_2\)O, or CFCs. The simulation in the global domain was the same (with emissions of AAPPG) for both the California baseline and California sensitivity simulations. This ensured that errors due to coarser resolution in the global domain did not influence results in the California domain. This smoothed results considerably but resulted in slightly higher aerosol loadings during the sensitivity tests than should occur in reality because it allowed model aerosols to enter the California domain from the global domain even when emissions were removed from the California domain and should have been removed from the global domain as well. As such the effects of AAPPG are probably slightly stronger than simulated in this study.

For each February and August 1999, another set of simulations was run to examine the effects of AAPPG in the SCAB. For this set of simulations, three nested domains (global, California, SCAB) were used. Again a baseline case (with AAPPG) and a sensitivity case (no AAPPG in the SCAB domain only) were run for each month. The simulations in the global domain and the California domain were the same (with emissions of AAPPG) for both the SCAB baseline and SCAB sensitivity simulations.

The model dynamics time steps were 300 s (global domain), 10 s (California domain), and 5 s (SCAB domain). The time interval for nesting between the domains was 1 hour. Variables passed at the horizontal boundaries included temperature, specific humidity, wind velocity, gas concentrations (including total water as water vapor), and size- and composition-resolved aerosol concentrations. Clouds themselves were treated with no-flux boundary conditions since total water as water vapor moved across boundaries and could generate new clouds; however, there is no reason why clouds could not be passed across the boundaries as well for future studies.

Initial meteorological fields were obtained from National Center for Environmental Prediction (NCEP) reanalysis fields for February 1 and August 1, 1999, at 12 GMT (S34). In the U.S., surface meteorological data from over 1650 stations (S35) were assimilated with the NCEP data at the time corresponding to initialization for each domain. Aerosol and gas fields in all domains were similarly initialized from background data. U.S. EPA ambient air quality data (S35) for O\(_3\), CO, NO\(_2\), SO\(_2\), PM\(_{2.5}\), and PM\(_{10}\) were then assimilated with background values at the initial time. No data assimilation, nudging, or model spinup was performed during any simulation.

3. Baseline Simulation Comparison With Data
Figure S1a-j compares model predictions with paired-in-time-and-space August 1999 data (S35) for gas, aerosol, radiative, and meteorological parameters in the California domain. Parameters compared include air pressure, UV radiation, solar radiation, temperature, relative humidity, wind speed, wind direction, non-methane organic carbon (NMOC), nitrogen dioxide, ozone, carbon monoxide, and particles smaller than 10 µm in diameter (PM\(_{10}\)). A paired-in-time-and-space comparison is one in which model predictions are compared with data values at the exact locations and times of the measurement. For several parameters, the model was able to simulate the data at exact
locations relatively well over all hours of a month, particularly considering the relatively coarse resolution of the California domain (21.5 km x 14 km).

4. California and SCAB Simulation Results
This section discusses sensitivity and baseline model results for the California- and SCAB-domain simulations beyond those discussed in the main text. Some of the figures in the main text are also repeated here for convenience.

A. California vertical profile differences
Figure S2 shows the monthly- and California-domain-averaged differences between the baseline case (with AAPPG) and the sensitivity case (without AAPPG) in the vertical profile of several parameters.

Figure S2a shows that AAPPG enhanced cloud scattering optical depths in February and August, with the greatest increases in the boundary layer and small increases above it. AAPPG also increased cloud liquid water content (CLWC) (Figure S2b) by decreasing precipitation. AAPPG increased lower-tropospheric cloud ice in February but caused relatively little change in August (Figure S2c) possibly due to warmer temperatures in August. Figure S2d shows that AAPPG decreased water vapor in the boundary layer in February and August, most likely due to the suppression of surface evaporation due to net surface cooling (Figure S2f) and slower wind speeds and a reduction in moisture flux from the ocean due to slower wind speeds.

The increase in cloud and aerosol optical depths due to AAPPG decreased the net day plus night averaged downward surface solar irradiance by about 7 W/m² in August and 4 W/m² in February (Figure S2e). Decreases in net downward solar irradiance above the boundary layer were due to increases in reflectivity caused by enhanced aerosol and cloud scattering (e.g., Figure S2a). Greater decreases in downward solar irradiance within the boundary layer were due primarily to aerosol particle absorption. Enhanced cloud and aerosol optical depth increased the net downward thermal-IR irradiance in February and August (Figure S2e). The net reduction in surface radiation (surface solar irradiance loss minus the thermal-IR gain) was greater in August than in February.

AAPPG decreased ground temperatures in February and August, decreased near-surface air temperatures in February and increased middle/upper boundary layer air temperatures in August (Figure S2f). In all cases, aerosol particles stabilized the boundary layer, decreasing the mixing depth. Decreases in ground temperatures were due primarily to a net reduction in downward solar plus thermal-IR irradiance in both months. Increases in boundary layer temperatures were due to absorption of solar radiation by absorbing components of aerosol particles (namely organics in the UV spectrum and black carbon throughout the solar spectrum). Absorption was greater in August than in February due to the greater solar irradiance, higher BC concentrations, and lower cloud cover in August.

SCAB surface differences
Figure 1 of the main text shows spatial difference plots for the SCAB simulations. In other work (S7), the development of the model used here and the effects of aerosols on clouds, precipitation, temperatures, and air pollution in the SCAB are discussed. Here, the discussion focuses on the effects of aerosols on wind speeds, and the feedback of wind speeds to precipitation, which is not discussed in that work.

Fig. 1a (of the main text) shows the location of enhanced aerosol optical depth in February and August 1999 due to AAPPG. The enhancement in aerosols triggered an increase in cloud optical depths (Fig. 1b). The additional aerosol particles and aerosol-enhanced clouds reduced surface solar radiation, decreasing surface temperatures (Fig.
The resulting increase in stability reduced turbulent kinetic energy (Fig. 1d), reducing the vertical flux of horizontal momentum, slowing down winds near the surface (Fig. 1e). The reduction in wind speed reduced the uplift rate of wind-driven soil dust (Fig. 1f) and wind-driven sea spray, in which sodium is a major component (Fig. 1g). The reduction in ground temperature and slower surface winds reduced evaporation from soil. The slower surface winds also reduced advection of moisture from the ocean. Both factors decreased near-surface water vapor (Fig. 1h). The reduction in water vapor, together with the enhancement of cloud lifetime, illustrated by the enhancement of cloud optical depth (Fig. 1b) and cloud fraction (Fig. 1i) due to AAPPG reduced precipitation (Fig. 1j)

B. California surface differences

Figure S3 shows spatial difference plots for the California simulation. Figures S3.a-S3.g show differences in aerosol column loadings due to AAPPG. The BC column abundance increased more in August than in February (Fig. S3a). The major emission sources of BC were in the South Coast Air Basin, Central Valley, and San Francisco Bay Area. The column abundance of BC was lower in winter than in summer because, as BC particles aged, they became coated with hygroscopic material (e.g., hygroscopic organic matter, sulfate, nitrate, ammonium), and such particles were readily removed by precipitation. The two mechanisms of wet removal in the model were rainout (size-resolved nucleation scavenging) and washout (size-resolved aerosol-hydrometeor coagulation). The removal of BC by precipitation was greatest in the Central Valley, particularly in the Northern Central Valley, in February, because BC concentrations were modestly high there and precipitation rates were higher there than in more southern locations.

Figure S3b shows the difference in particle primary organic matter (POM) column abundance due to AAPPG. POM includes lubricating oil components in diesel and gasoline vehicle exhaust as well as primary organics from non-vehicle sources. The spatial distribution of POM roughly followed that of BC. The magnitude of POM concentration (and emission) was greater than that of BC because the number of POM sources exceeded those of BC.

Figure S3c shows the difference in particle secondary organic matter (SOM) column abundance due to AAPPG. Secondary organic matter formed in the model primarily by condensation of low-vapor pressure organic gases onto size resolved aerosol particles. Condensing gases included byproducts of toluene, xylene, and isoprene oxidation. The enhancement of SOM was much greater in August than in February due to the enhanced oxidation rate of organic gases resulting from greater OH in August and the lower removal rate of SOM by precipitation in August than in February. Because SOM formed in the atmosphere, it was spatially distributed over a broader region than was POM.

Figure S3d shows the difference in particle sulfate due to AAPPG. Although more sulfate was removed by precipitation in the model in February than in August, more sulfate was also produced by aqueous oxidation within aerosol particles, fog drops, and cloud drops in February than in August. When fog drop and cloud drops evaporated, for example, they released their aerosol cores, which contained more sulfate due to aqueous oxidation.

Figure S3e shows that the difference in particle nitrate due to AAPPG was greater in August than in February. Nitrate was directly emitted and formed in the model by gas-to-particle conversion of nitric acid.
Other aerosol particle components treated included ammonium, sodium, chloride, soil dust, pollen, spores, and liquid water. Figure S3f shows the difference in the column abundance of the total aerosol liquid water content (ALWC) due to AAPPG. Aerosol liquid water in the model hydrated to electrolytes such as sulfate, nitrate, ammonium, sodium, chloride, etc., and other solutes (e.g., oxalic acid, malonic acid) in aerosol particle solutions. Hydration occurred in the model for relative humidities (RHs) between 0% and 100% although RHs between 99.5% and 100% were treated assuming an RH of 99.5%. Although electrolyte concentrations were lower in February than in August, ALWCs were similar in many locations in February and August because of the higher RH in February than August and the superlinear effect of RH on hydration. Figure S3g shows the change in total aerosol column mass due to AAPPG. The change represents the summation of the changes among all aerosol components discussed.

Figures S3h and S3i show the baseline aerosol optical depth and the aerosol optical depth difference due to AAPPG, respectively. AAPPG had a greater effect on aerosol optical depth in August than in February due to the greater removal of aerosol particles in February by precipitation.

Figures S3j and S3k show the baseline (with AAPPG) cloud optical depth and the cloud optical depth difference due to AAPPG, respectively. Most cloud optical depth increases occurred over the Central Valley and other locations near where aerosol optical depths increased. Cloud optical depths increased over a greater area in February than in August because clouds were more prevalent in February. Figure S3l shows that AAPPG increased cloud fraction.

Figure S3m shows that AAPPG decreased the net down minus up surface solar irradiance in locations of enhanced aerosol and cloud optical depth, including in the Central Valley, the SCAB, and some areas offshore. Figure S3n shows that AAPPG increased net down minus up surface thermal-IR irradiance. Thermal-IR irradiances increased primarily in locations where cloud and aerosol optical depths increased. Clouds and aerosols enhance net downward thermal-IR irradiance by trapping the Earth’s emitted thermal-IR irradiance and reemitting some of it back toward the ground. Figure S3o shows that AAPPG decreased downward UV fluxes to the surface. The figure is averaged over day and night, so it does not give an indication of peak reductions. UV reductions were affected by gases, aerosol particles, and hydrometeor particles.

Figure S3p shows that AAPPG decreased near-surface air temperatures in the Central Valley, in the SCAB, and along the coast, particularly near the SCAB. The decreases in near-surface air temperatures were due to a reduction in net downward solar plus thermal-IR radiation due to enhanced aerosol and cloud optical depths due to AAPPG. However, absorption of sunlight by black carbon (BC) and some organic carbon (OC) (in the UV spectrum) warmed the middle boundary layer (e.g., Figure S2f) where these particle components were present, particularly in August. The warmer air molecules, which generally have long lifetimes, were transported to the large-scale environment, where they mixed vertically, warming the ground slightly in some locations outside the valley.

Figure S3q shows that AAPPG increased the near-surface relative humidity in the Central Valley. The relative humidity increases with increasing water vapor and decreasing air temperature. Figures S3r and S3p show, though, that AAPPG decreased both near-surface water vapor and near-surface temperature in the valley. Because the relative humidity increased, the decrease in temperature had a greater effect than the decrease in water, causing the relative humidity to increase.
Figure S3 shows the baseline modeled precipitation fields in February and August. A comparison of modeled February field with measured February 1999 precipitation in California (Figure S3.t) suggests that regions of modeled high and low precipitation followed the corresponding measurements well. For example, the peak observed precipitation rate in California was at the northwest corner of the state, which is where the model predicted substantial precipitation. Measured high precipitation levels along the northern coast and Sierra-Nevada range in February were similarly modeled. The model also picked up the relatively low measured precipitation rate in the southern part of the state if February and the low precipitation throughout the state in August. Magnitudes of peak measured precipitation were lower than were measured values in February. Modeled precipitation in the Central Valley in August was primarily fog depositing to the ground. Figure S3u shows that AAPPG decreased precipitation on the upslope side of the Sierra Nevada mountains in February and in the Central Valley (due mostly to reduction in fog deposits) in August. The reduction in precipitation contributed to a general increase in cloud liquid water (Figure S3v), particularly in the Central Valley.

Figures S3w and S3x show the baseline and difference in 60-170 m wind speeds in February and August. AAPPG slowed down the winds by up to about 0.4 m/s in the Central Valley, as described in the main text.

C. Hourly wind speed differences
Figure S4 shows the hour-by-hour differences in wind speed for 12 days at several specific locations during February and August when AAPPG were and were not included. The figures indicate the average of the hourly percent differences were up to 8%. Decreases in wind speed occurred primarily during the day.

D. Sensitivity of Results to Turbulence Parameterization
A sensitivity test was run to test whether the results found here were sensitive to the original order 2.5 turbulence parameterization used (S23). The test was run with a second turbulence parameterization (S36), which combined a Blackadar formulation for stable and marginally unstable regimes with a convective plume scheme for strongly unstable regimes. Figure S5 shows the difference in the vertical profile of August wind speeds in California due to AAPPG from the simulations. A comparison of Fig. S5 with Fig. S2g indicates that both turbulence parameterizations reduced near-surface wind speeds and increased upper-boundary-layer wind speeds in August in a similar manner, suggesting that that conclusions found here regarding the reduction of near-surface wind speeds by AAPPG did not depend on the specific turbulence parameterization used.

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10. References


S34. National Centers for Environmental Prediction (NCEP), 2.5 degree global final analyses, distributed by the Data Support Section, National Center for Atmospheric Research, 2003.


S1. Air pressure

S1. UV flux

S1. Solar flux

S1. Temperature / relative humidity

S1. Near-surface wind speed/direction
S1. NMOC

S1. Nitrogen dioxide

S1. Ozone
**Figure S1.** Comparison of August 199 hourly model predictions (solid lines) from the California domain with paired-in-time-and-space data (dashed lines) from (S35) for air pressure, UV radiation, solar radiation, temperature (left panels) and relative humidity (right panels), wind speed and direction, non-methane organic carbon (NMOC), nitrogen dioxide, ozone, carbon monoxide, and particles smaller than 10 µm in diameter (PM$_{10}$). Model results were interpolated with bilinear interpolation from four surrounding grid cell centers to the exact location of the measurement (given in each figure). The time resolution of data and model values was 1 hour.
Figure S2. Modeled differences in the monthly-averaged and California-grid-averaged vertical profiles of several parameters for February and August 1999. The optical depths in Fig. S2a are layer optical depths, not cumulative between the layer and the top of the atmosphere. The bottom value in Fig. S2f is ground temperature.
Figure S3

S3.a.

S3.b.

S3.c.
S3.t. Measured February and August 1999 precipitation (mm/day).

S3.u.
Figure S3. Modeled differences between the baseline case and the sensitivity case (no AAPPG), averaged over all hours of February (left column) and August (right column) 1999 in the California domain. Some baseline simulation results are shown as well. All maps not specified otherwise are near-surface maps. The numbers in parenthesis are the average parameter value over all land points in the figure. Figure S3.t shows precipitation data (prepared by Gina Lopez and Guido Franco of the California Energy Commission using data from the Western Regional Climate Center.) for comparison with Fig. S3s.
**Figure S4.** Modeled hourly wind speed when AAPPG were present (solid line) and absent (dashed line) and the difference between the two cases (isolated solid line) for 12 days in February or August 1999 in California. A zero-change line is showed to compare the difference with. The “mean of hourly % differences” is $100\% \times \sum_{i=1}^{N} \frac{(W_i - O_i)}{NW_i}$, where $W_i$ is the hourly value with AAPPG, $O_i$ is the hourly value without AAPPG, and $N$ is the number of hourly values.

**Figure S5.** Modeled difference, due to AAPPG, in the August- and California-grid-averaged vertical profile of wind speed when the turbulence scheme described in Section 4.D. was used. Compare the result with that from the original turbulence scheme (Fig. S2g).