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A methodology and implementation of satellite data assimilation for improved modeling of global properties of tropospheric aerosols

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Tropospheric aerosols are recognized as an important, although highly uncertain atmospheric constituent affecting the global climate. The ability of small aerosol particles to effectively scatter and absorb solar light makes atmospheric aerosol one of key factors determining Earth's radiative budget. There is a diversity of research disciplines and methods for atmospheric aerosol characterization. For example, aerosol remote sensing and global chemical transport modeling rapidly progressed during last few decades. However, understanding of aerosol properties is far from satisfactory thus aerosol remains one of the most uncertain atmospheric components. The difficulties in monitoring natural and anthropogenic aerosols are caused by high spatial- and temporal variability of all properties including aerosol loading, chemical composition, size and shape of aerosol particles. Integrating remote sensing observations and transport model forecasts appears promising for future improvements of aerosol knowledge. We present a technique for constraining aerosol transport models by satellite observations of aerosol. The tracers transport models calculate four-dimensional (time, horizontal and vertical) dependent distribution of aerosol mass from prescribed emissions. These calculations rely on known or generated meteorological fields and account for atmospheric processes, such as advection, diffusion, convection, deposition, atmospheric chemistry, sedimentation, etc. The aerosol mass can be used for

modeling satellite observation by converting the aerosol mass into optical properties such as optical thickness, phase function, absorption, etc. Such conversions rely on the assumptions of aerosol particle size, shape, complex refractive index, humidification, etc. that are linked to chemical composition of each aerosol type. Using these properties in simulations of atmospheric radiaitve transfer of solar radiation through the atmosphere, one can model radiation observed by satellites. The constraining of transport model is implemented via statistically optimized fitting of satellite data and adjusting aerosol emissions employed in transport model. Optimization accounts for the different accuracy levels of satellite data, a priori and ancillary information. The developed numerical scheme is based on principles of statistical estimation and implemented as a generalized multi-term least-square-type formulation that complementarily unites advantages of a variety of practical inversion approaches, such as Phillips-Tikhonov-Twomey constrained inversion, Kalman filters, gradient iterative search, etc. Conventional matrix techniques in this application are problematic because of very high dimensionality of vectors that need to be used in matrix techniques for describing the four-dimensional global aerosol distribution. Therefore, the strategy adopted attempts to reduce computational requirements of the inversion to that closer to the computational requirements of forward modeling aerosol transport. This is usually implemented by numerical time integration via sequential computing of chemical transport during each time step and with separate treatment of isolated processes. Similar approaches can be employed in inverse modeling by means of developing so-called “adjoint” transport operators. A practical version of the retrieval algorithm was developed, tested and applied to the retrieval of location and strength of aerosol emission from a combination of MODIS and AERONET observations. The method uses an adjoint operation to the aerosol transport of GOCART (Goddard Chemistry Aerosol Radiation and Transport) model that allows performing the inversion within the original space (2 x 2.5 degrees) and time (20-60 min) resolutions.