The Study of Regional Climate and Chemical Processes with Single-Column Models

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Observations show that the diurnal cycle of surface air temperature changes as climate changes, with the diurnal range becoming smaller as the climate warms. We investigated the causes of this behavior using a single-column model (SCM). Our previous results investigated the roles of aerosol and greenhouse gas forcings, and water vapor and cloud feedbacks, but kept the horizontal boundaries fixed. Here, we focused on the Southern Great Plains (SGP) where a strong diurnal cycle of horizontal advection may also be important, especially if this low-level nocturnal jet changes as climate changes. We investigated the role of this jet in producing the current diurnal cycle of surface air temperature, and its relative importance in climate change. We compared the results to the northern Great Plains, where there is no large diurnal cycle of advection.

For most of this work, we used a single-column radiative convective model of the diurnal cycle developed by Stenchikov and Robock (1995). It accounts interactively for all the important physical processes. It is forced by the large-scale advective transport of latent and sensible heat, derived from observations or data assimilation.

The computation of the divergence of advective fluxes is not a simple numerical procedure because high levels of accuracy are needed. We used the National Aeronautics and Space Administration (NASA) Goddard Earth Observing System (GEOS-1) reanalysis, and verified the output with in situ data from the Atmospheric Radiation Measurement (ARM) site in Oklahoma. The boundary conditions were calculated from the divergence of latent, sensible, and potential energy fluxes. The integrated effect of this flux was tested against the observed radiative imbalance at the top of the atmosphere. Numerical experiments with different advection revealed the important role of horizontal energy transport for the diurnal cycle and helped to quantify the role of circulation effects in climate change over the Great Plains.

In the scope of this work, we also developed an SCM based on GEOS-2 GCM physical parameterizations. It includes radiative transport accounting for the effects of greenhouse gases and aerosol, turbulent mixing in the planetary boundary layer (PBL), energy exchange with the underlying surface, moist and dry convection, cloud formation, and the hydrological cycle. We performed calculations of transient and energy balance regimes for different seasons. We forced the model by the diurnally varying advective transport of latent and sensible heat obtained from the GEOS-1 Data Assimilation System (DAS) output.

Boundary conditions at the ground can be specified explicitly in accordance with the specific experiment. We did calculations so far using an unequally spaced GEOS-1 20-layer vertical grid. We studied model sensitivity to advective boundary conditions, and concentrations of greenhouse gases and aerosols. We used a modification of the GEOS-2 radiative transport code, which accounts for the aerosol effects in solar and infrared wave bands. Specifically, we looked at the effect of different types of tropospheric aerosols (sulfate, carbonaceous, organic, and dust) on turbulent mixing in the boundary layer and convective ventilation of the PBL. We extended the stretched grid approach to study air pollution and chemical composition of the atmosphere.

We have designed a Single-Column Chemical Transport Model (SCCTM) using SMVGEAR II, a sparse-matrix, vectorized Gear-type first order ordinary differential equation solver (Jacobson 1995). The Jacobson chemical model includes over 350 kinetic chemical reactions, 45 photolytic reactions, and 131 chemical species. We used parameterizations from GEOS-2 to describe moist convective mixing and turbulent diffusion, making the parameterizations in SCCTM consistent with our GEOS-2 SCM. SCCTM is driven by the assimilated data from the GEOS-1 DAS.

We performed column calculations for a highly polluted urban region, the Baltimore-Washington area, during a July 1995 high ozone episode, and compared our model results with observations. With the large amount of emissions in this region, the model reaches steady state quickly regardless of the initial conditions used in the sensitivity studies. We found a strong sensitivity of the chemical processes to the turbulent mixing parameters.

References

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