Comment on "Climate sensitivity to black carbon aerosol from fossil fuel combustion," by D.L. Roberts and A. Jones

By Mark Z. Jacobson

Dept. of Civil & Environmental Engineering, Stanford University

Roberts and Jones (2004) (RJ04) used the HadSM4 climate model to suggest that the climate sensitivity of black carbon may be weaker than that of carbon dioxide, a result they found was opposite from that of Jacobson (2002) (J02). However, the omission of numerous physical processes and feedbacks in RJ04 and two other models they compared with, and the fact that neither gas, aerosol, nor radiative predictions from these models has been evaluated against paired-in-time-and-space data on any scale, appear to diminish the likelihood that their climate sensitivity of black carbon was accurate, as demonstrated by Johnson (2005). Further, the acute differences in model processes treated renders the comparison of their results with those of J02 one of apples and oranges.

RJ04 state, "…since the result (of J02) could be highly model dependent, it is important to investigate whether it is also obtained in other climate models." While true in theory, a model comparison is useful only if the models are relatively similar or if model differences are clearly described. The model of RJ04 appears to have lacked over 100 physical processes and numerical techniques that were present in J02. Such processes are listed at www.stanford.edu/group/efmh/GATOR/index.html. Table 1 here lists thirty of the physical processes missing in RJ04 related to aerosol particles and clouds. Whereas, RJ04 acknowledged the omission of some processes (e.g., indirect effects) or showed the simplicity of others (e.g., empirical treatment of aerosol scavenging and particle aging), they did not acknowledge that J02 treated these and other processes more physically and

with discretized size and composition resolution with respect to both aerosol particles and clouds. For example, they did not acknowledge that J02 treated subgrid-scale cloud thermodynamics and discrete size-resolved aerosol and hydrometeor microphysics, whereas they assumed no more than a single cloud in a grid column and had no discrete size resolution of either aerosol particles or clouds. It is physically not possible for their climate sensitivity to be correct, except by pure chance, since the addition of each additional physical process and size resolution will change their results. Although uncertainty exists in J02 as well, such as with overall grid resolution, the feedbacks of aerosol particles are treated physically to a significant extent given the resolution, so the climate response can only be more complete than that of RJ04.

More important, neither the gas, aerosol, nor radiative modules of RJ04 have ever been evaluated on any scale against paired-in-time-and-space data. Those of J02 have, including on the urban scale [*Jacobson*, 1997], the nested global-urban scale [*Jacobson*, 2001], and the nested global-regional scale [*Jacobson et al.*, 2004 supp. info.]. In addition, the aerosol treatments of RJ04 have not been shown to replicate analytical or exact solutions. Those of J02 have been developed and evaluated rigorously in numerous papers over 15 years against analytical and exact numerical solutions. Further, the stronger climate response of BC relative to CO_2 has been replicated in *Jacobson* [2004].

In sum, RJ04 have left readers with the impression that the models they intercompared should be given equal weight, regardless of the physics treated or the model evaluation. However, given that aerosol climate response depends entirely on interactions between size- and composition- resolved aerosols and the environment around them (e.g., clouds, radiation, surfaces, gases), the lack of climate-response mechanism in RJ04 and similar models prevents such a comparison.

Nothwithstanding the above, RJ04 implied that their results might be more reliable than J02 because two other models gave a climate sensitivity in the same direction as their own: "It may be premature to conclude on the basis of these experiments alone that λ_{BC} is much smaller than λ_C, though it is noteworthy that the results of *Penner et al.* [2003] and *Wang* [2003] seem to point in the same direction." However, those models ignored substantially similar physical processes as did RJ04, and neither the gas, aerosol, nor radiative modules of either of these studies has been evaluated against paired-in-time-and-space data either. More important, in an independent study, *Johnson* [2005] recently showed that the specific cloud module used in both *Penner et al.* [2003] and *Wang* [2004] underpredicted the semidirect radiative effect by a factor of five in comparison with a large-eddy simulation result. This finding alone, if correct, supports the contention that the models tested underestimate the climate sensitivity of black carbon relative to carbon dioxide. Given that the cloud representation is only one of many processes that is simplified in those models, one can only conclude that it is unlikely that these models and that of RJ04 were able to provide an accurate climate sensitivity of black carbon. Whereas the accuracy of the black carbon climate sensitivity from J02 can be and has been improved [e.g., *Jacobson,* 2004] and can be improved further, a comparison of results of RJ04 and other similar models with those of J02 was one of apples and oranges.

REFERENCES

Jacobson, M. Z. (1997) Development and application of a new air pollution modeling system. Part III: Aerosol-phase simulations, *Atmos. Environ., 31A,* 587 – 608.

Jacobson, M. Z. (2001) GATOR-GCMM: 2. A study of day- and nighttime ozone layers aloft, ozone in national parks, and weather during the SARMAP Field Campaign, *J. Geophys. Res., 106,* 5403-5420.

Jacobson, M.Z. (2002), Control of fossil-fuel particulate black carbon and organic matter, possibly the most effective method of slowing global warming. *J. Geophys. Res.*, 107, 4410, doi:10.1029/2001JD001376.

Jacobson, M.Z. (2004), The climate response of fossil-fuel and biofuel soot, accounting for soot's feedback to snow and sea ice albedo and emissivity, *J. Geophys. Res., 109*, D21201, doi:10.1029/2004JD004945.

Jacobson, M. Z., J. H. Seinfeld, G. R. Carmichael, and D.G. Streets (2004). The effect on photochemical smog of converting the U.S. fleet of gasoline vehicles to modern diesel vehicles, *Geophys. Res. Lett., 31*, L02116, doi:10.1029/2003GL018448.

Johnson, B.T. (2005), The semidirect effect: Comparisons of a single-column model with large eddy simulation for marine stratocumulus, *J. Clim., 18*, 119-130.

Penner, J.E., S.Y. Zhang, and C.C. Chuang (2003), Soot and smoke aerosol may not warm climate, *J. Geophys. Res., 108* (D21), 4657, doi:10.1029/2003JD003409.

Roberts, D.L., and A. Jones (2004), Climate sensitivity to black carbon aerosol from fossil fuel combustion, *J. Geophys. Res*., 109, D16202, doi:10.1029/2004JD004676.

Wang, C. (2004), A modeling study on the climate impacts of black carbon aerosols, *J. Geophys. Res.*, 109, D03106, doi:10.1029/2003JD004084.

Table 1. Identification of thirty aerosol and cloud physical processes treated in J02 not treated in RJ04.

	J02	RJ04
Discretized size-resolved (S.R.) aerosol particles	Yes	No
S.R. prognostic equations for aerosol number and component mole concentrations	Yes	No
S.R. aerosol nucleation	Yes	No
S.R. aerosol condensation/evaporation	Yes	No
S.R. aerosol dissolution/evaporation	Yes	No
S.R. aerosol solid formation/dissociation with solute activity coefficients	Yes	No
S.R. aerosol ion dissociation/association with solute activity coefficients	Yes	No
S.R. aerosol hydration from electrolyte composition, relative humidity, temperature	Yes	No
S.R. aerosol-aerosol coagulation of total particles and particle components	Yes	No
S.R. aerosol dry deposition, sedimentation	Yes	No
S.R. aerosol rainout, washout by interaction with S.R. hydrometeor particles	Yes	No
Gas washout by size-resolved precipitation	Yes	No
Subgrid clouds with multiple cloud bases and tops	Yes	No
Convection of gases, S.R aerosol particles and their components in subgrid clouds	Yes	No
S.R. prognostic hydrometeor liquid, ice, graupel and their aerosol component cores	Yes	No
S.R. water condensation/evaporation onto aerosols to form liquid hydrometeors	Yes	No
S.R. water deposition/sublimation onto aerosols to form ice crystals	Yes	No
S.R. hydrometeor liq.-liq. liq.-ice, liq.-gr. (graupel) ice-ice, ice-gr., gr.-gr. coagulation	Yes	No
S.R. aerosol-liq., aerosol-ice, aerosol-graupel coagulation	Yes	No
S.R. hydrometeor freezing/melting	Yes	No
S.R. homogeneous/heterogeneous freezing, contact freezing, evaporative freezing	Yes	No
S.R. aerosol, cloud, and precipitation aqueous chemistry	Yes	No
S.R. subcloud evaporation to aerosol cores	Yes	No
S.R. liquid drop breakup	Yes	No
Lightning due to S.R. rebound charging in clouds	Yes	No
S.R. tracking of composition-resolved aerosol cores in cloud liq., ice, graupel hydrometeors	Yes	No
S.R. aerosol solution and nonsolution components for optical calculations	Yes	No
S.R. black carbon cores in aerosols for optical calculations	Yes	No
S.R. hydrometeor liquid, ice, graupel for optical calculations	Yes	No
S.R. aerosols and hydrometeors affects on spectral photolysis, solar, thermal-IR heating	Yes	No