Reply

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Shine (2005) contends that the temperature trend results of Minnis et al. (2004, hereafter MAPP) are overestimated by an order of magnitude because MAPP implicitly assumed that the average Northern Hemisphere temperature response to a change in cirrus cloud cover applies at the regional level. The basis for this argument is that the results of Rind et al. (2000, hereafter RSP) indicate that the net equilibrium increase in temperature due to increased cirrus clouds is diffused over a wide area and shows only a minimal geographical relationship to the original forcing. This is a legitimate criticism of the MAPP temperature change estimate because it takes the RSP regional results at face value. However, it is argued here that the Shine (2005) and MAPP estimates represent the minimum and maximum regional responses, respectively, to the increased cloudiness given the current state of general circulation modeling. The following discussion reinforces the recommendations of MAPP that the problem of contrail–climate interactions should be modeled more realistically to minimize the uncertainty in the system's temperature response.

General circulation model (GCM) simulations of past temperature change using recognized forcings such as changes in greenhouse gases, ozone, and stratospheric aerosols produce favorable temperature correlations on the global, but not the regional (e.g., Hansen et al. 1997) or zonal (e.g., Douglass et al. 2004), scales. Indeed, Hansen et al. (1997), using the same model as RSP, state that the poor correlations "imply severe limitations on regional climate predictability at middle latitudes." Hansen et al. (1997) assign much of that poor correlation to chaotic behavior but recognize that the model is not perfect and that all forcings are not input into the system. Thus, taking the regional response at face value carries considerable uncertainty, as does MAPP's scaling of the hemispherical response for a limited area.

While the RSP model is the most realistic modeling effort to date for estimating contrail temperature impacts—it was chosen by MAPP for that reason—it suffers numerous shortcomings for simulating the regional climate effects of the 25-yr changes in cirrus cloud cover reported by MAPP. First, it is not ideal for studying an ongoing, highly variable process because it provides an equilibrium solution based on stable results from years 31–50 of 50-yr runs. Given that air traffic and, presumably, contrail–cirrus coverage has been incrementally increasing each year, the actual system will not be in equilibrium. Instantaneous temperature responses would be superimposed on the feedback responses of the system. Furthermore, RSP do not mimic the actual observed cloud cover changes in their model.

The instantaneous response can be estimated from the results of Meerkötter et al. (1999), who determined that the troposphere below flight level warms at a rate of ~0.3°C day^{-1} for a midlatitude atmosphere entirely blanketed by a contrail–cirrus cloud with an optical depth of 0.52. A thin surface layer cools at ~0.8°C day^{-1} when no clouds occur below the contrail and at ~0.2°C day^{-1} when thick low clouds are present. Most of the warming occurs between 8 and 10 km just below the cloud at 11 km. The thin layer containing the cloud warms by up to 17°C day^{-1} while the stratosphere above cools slightly. Overall, warming dominates at an average rate of ~0.25°C day^{-1}. Accounting for the diurnal variation of heating, Meerkötter et al. (1999) concluded that the minimum and maximum surface temperatures would be increased and decreased, respectively, resulting in a reduced diurnal temperature range,

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a phenomenon that has been attributed to instantaneous contrail effects (e.g., Travis et al. 2002) and results in observable changes in the surface temperature.

Over the long term, the upper-tropospheric heating would be significant. Scaling the computed 0.25°C day^{-1} atmospheric heating rate by the average contrail optical depth of 0.26 for contrails over North America (Palikonda et al. 2005) and the decadal fractional cirrus coverage increase of 0.01 (MAPP) yields a tropospheric heating rate of 0.00125°C day^{-1} or 4.6°C decade^{-1}. Applying a simple radiation relaxation rate of 0.1 day^{-1} (K. Shine 2005, personal communication) would decrease the value to 0.46°C decade^{-1}, which is close to the average atmospheric heating rates of 0.32°C decade^{-1} estimated by MAPP and 0.29°C decade^{-1} observed by Angell (1999). This approach is probably too simple because the occurrence of contrails and the atmospheric structure in which they form are not uniform. An estimate of the true relaxation rate would require more sophisticated modeling.

Strauss et al. (1997) attempted a more explicit estimate of the regional response using a radiative convective model with parameterized advection effects, but with no other feedbacks. Their results for Germany using cirrus–contrail optical depths between 0.18 and 0.28 yield a temperature change of ~1°C for a 10% cirrus–contrail coverage at that midlatitude location. This value is roughly one-half to one-third of that estimated by MAPP, not an order of magnitude less, and it includes no feedbacks and is confined to a smaller region. However, a radiative convective model also reaches equilibrium and does not include all of the factors required for realistically simulating contrail effects.

Given the uncertainty in the GCM regional forecast, the differences between the RSP-specified and real contrail regional forcings, and the potential differences between an equilibrium and real, constantly changing process, it is likely that both the MAPP and Shine (2005) estimates of the regional response are within the uncertainty of the RSP results for representing the regional response. The MAPP estimate of the temperature response, which was explicitly assumed to be valid for a regional forcing, should be considered as the upper bound of the response of the surface and tropospheric temperatures because it assumes that the average equilibrium thermal response applies in proportion to the change in cloud cover in a nonequilibrium process. The equilibrium response, which is considerably diffused from the location of the forcing as noted by Shine (2005), should be considered as the minimum response for the nonequilibrium condition. The MAPP results agree well in magnitude and seasonality with the observations. Is that agreement serendipitous? The answer to that question cannot be obtained with back-of-the-envelope calculations. As suggested by MAPP, a more realistic modeling effort is needed to more accurately assess the climate response of anthropogenic cirrus initiation. The mounting evidence for increased cirrus coverage due to air traffic (e.g., Zerefos et al. 2003; MAPP; Stordal et al. 2004) makes the development of such models even more imperative.

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