Droplet Number Prediction in the National Center for Atmospheric Research Community Atmosphere Model

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Introduction

Droplet number prediction was first introduced in a climate model by Ghan et al. (1997a) to provide a physically based method of treating aerosol indirect effects. The droplet number balance was expressed

$$\frac{\partial N_k}{\partial t} = -(V \bullet \nabla N)_k + D_k + S_k - A_k - C_k - E_k$$

Where N is the droplet number mixing ratio in layer k, the second term is the resolved transport of droplet number, D represents vertical mixing to layer k, S is the droplet nucleation source, and A, C, and E are the droplet loss by autoconversion, collection, and evaporation respectively. The droplet nucleation source is parameterized in terms of the subgrid distribution of updraft velocity and the composition and size distribution of the aerosol.

The first application was to the National Center for Atmospheric Research (NCAR) Community Climate Model (CCM1). The climate simulated with prognostic droplet number was significantly different from the climate simulated by the standard CCM1 because other changes in cloud microphysics were also applied (Ghan et al. 1997b). That alone was enough reason to keep the scheme from being adopted by NCAR. In addition, the modifications to CCM1 doubled the run time, which guaranteed it would not be accepted.

The latest NCAR climate model, the Community Atmosphere Model (CAM3), still does not treat aerosol indirect effects. To provide a path forward, I have therefore applied prognostic droplet number (with an improved parameterization of droplet nucleation by Abdul-Razzak and Ghan [2000], and a treatment of the influence fractional cloud on the nucleation source by Ovtchinnikov and Ghan [2005]) to CAM3. The goal was to provide a physically consistent treatment of aerosol effects on warm clouds with little impact on the simulated climate or on the run time.

To connect the droplet nucleation to the aerosol, the aerosol size distribution and hygroscopity must be specified. This was done for each of the externally-mixed aerosol types whose spatial and temporal distributions are prescribed in CAM3.

To reduce the computational cost of the scheme, the subgrid distribution of updraft velocity was approximated by a delta function, so that the nucleation parameterization is applied to only a single updraft. The updraft velocity was diagnosed from the vertical diffusivity following Ghan et al. (1997a), with a lower bound (0.2 m/s) that was used as a tuning parameter to produce a realistic energy balance at the top of the atmosphere.

For physical consistency the droplet number was used to determine the cloud optical depth and the gravitational settling velocity of the cloud droplets. This provides a physically-based treatment of the first indirect effect. The droplet number was also optionally used in the treatment of autoconversion, thus providing a treatment of the second indirect effect.

Three five-year simulations were performed using the finite volume dynamical core and 2 x 2.5 horizontal resolution. The first simulation was with the standard CAM3, which prescribed droplet number for autoconversion and effective radius for cloud optical depth completely independently, and hence inconsistently. The second simulation was with prognostic droplet number but with the standard treatment of autoconversion. The third simulation was with prognostic droplet number used for autoconversion as well as cloud optical depth.

Figure 1 compares the spatial distribution of the annual mean shortwave cloud forcing for all first (control) and second (ProgNdrop) simulations. The differences between the simulations with droplet number and the control simulation are small everywhere. Figure 2 compares the distribution for the control and third (ProgNdropInd2) simulations. Differences are small even with the second indirect effect.

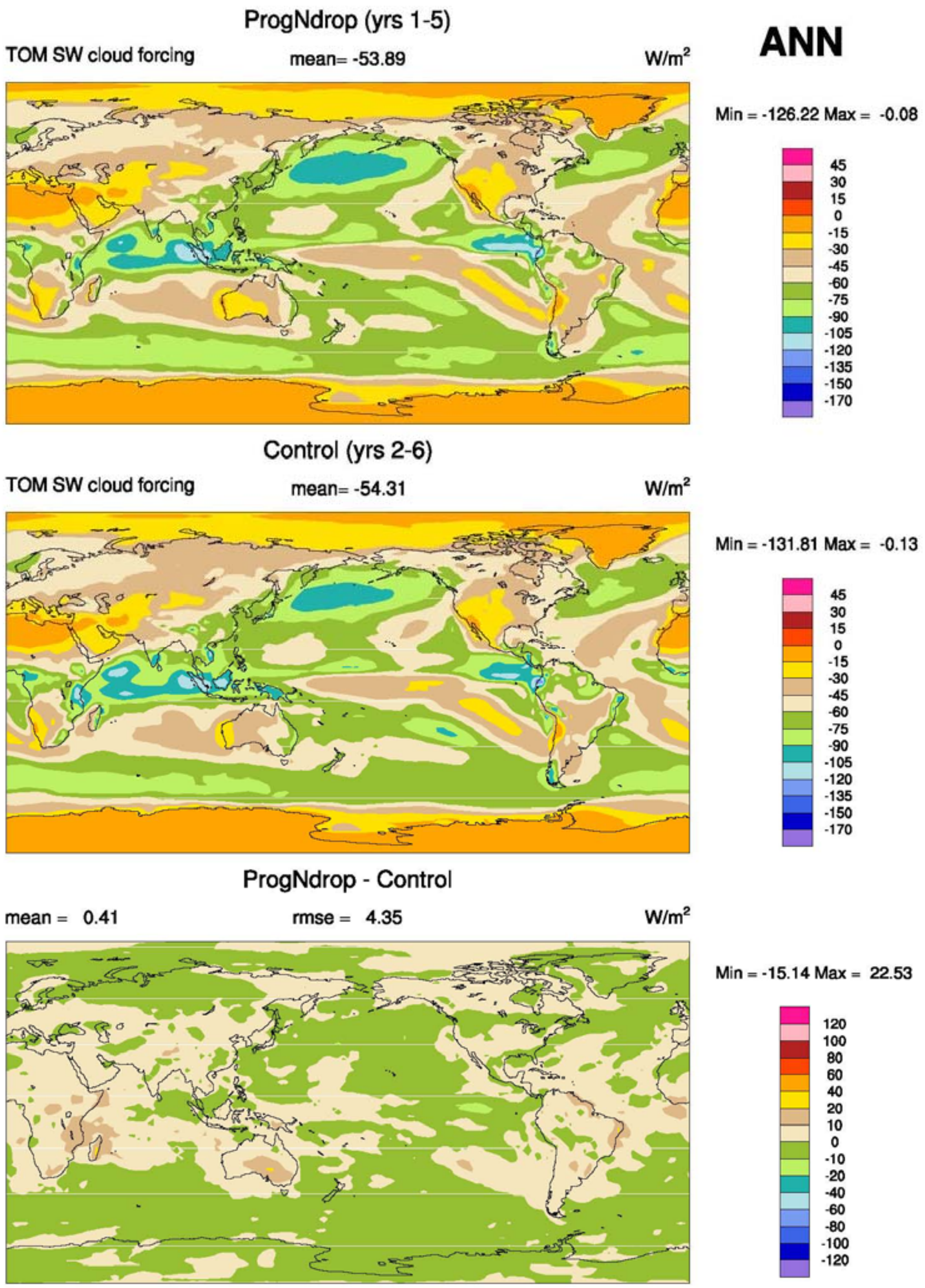

Figure 1. Comparison of the spatial distribution of the annual mean shortwave cloud forcing for all first (control) and second (ProgNdrop) simulations.

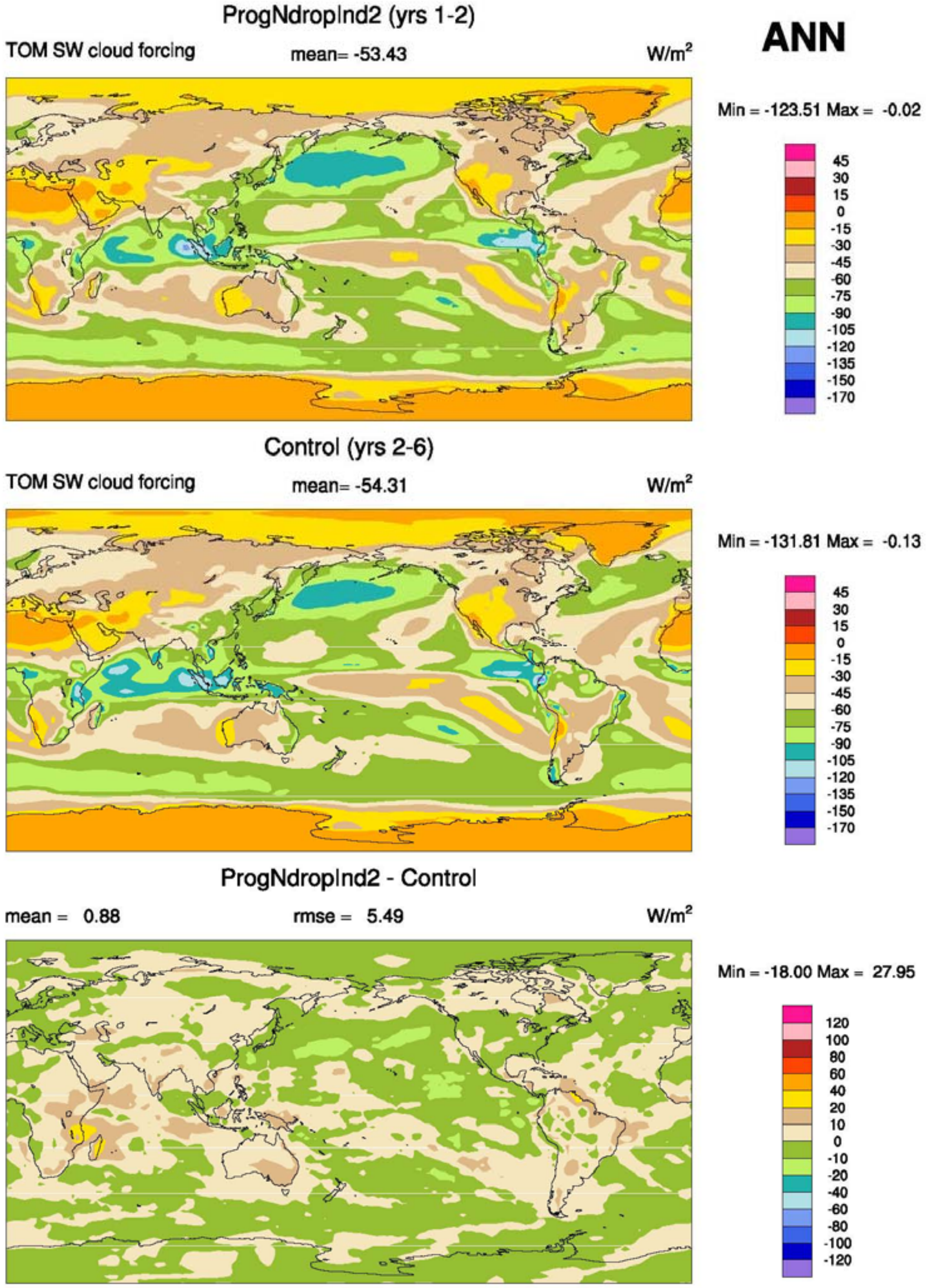

Figure 2. Comparison of the distribution for the control and third (ProgNdropInd2) simulations.

Table 1 summarizes the global mean differences for several fields. Global mean differences are less than 1 W m^{-2} for all components of the energy balance, but the cloud liquid water path is significantly reduced when the second indirect effect is treated. Evidently, the cloud optical depth is sufficiently high when autoconversion is triggered that the cloud albedo is insensitive to the reduction in liquid water path.

Table 1. Summary of global mean differences.

	Control	**ProgNdrop-Ctl**	**ProgNdropInd2-Ctl**
Net at top of model (Wm^{-2})	0.57	0.16	0.90
Shortwave cloud forcing	-54.3	0.41	0.88
Longwave cloud forcing	30.3	-0.01	0.38
Net shortwave at top	234.3	0.37	0.86
Net longwave at top	233.8	0.21	-0.04
Net shortwave at surf	159.7	0.31	1.04
Net longwave at surface	58.4	-0.09	-1.13
Liquid water path (g m^{-2})	124.7	0.61	-29.49
Precipitation (mm/day)	2.832	0.011	0.055

The insensitivity of the energy and water budget to addition of prognostic droplet number suggests that prognostic droplet can be used for coupled climate change simulations will little additional tuning. This provides a viable framework for treatment of the aerosol indirect effect (both first and second). Further work with fully interactive aerosol is needed to more fully explore the implications of this scheme for the aerosol indirect effect.

References

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