Droplet Number Prediction in the NCAR Community Atmosphere Model

Steven Ghan
Pacific Northwest National Laboratory

Why Predict Droplet Number?

- Droplet number is needed for indirect effects of aerosols.
- Droplet loss processes are much easier to represent in a prognostic framework.
- It can concentrate droplet nucleation near cloud base, where droplets naturally form.
- It can treat the competition between different aerosol types in a physically-based manner.

Predicting Droplet Number

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

N_k = droplet number mixing ratio in layer k

D_k = vertical diffusion to layer k

S_k = droplet nucleation source in layer k, parameterized in terms of aerosol properties and pdf(w)

A_k = droplet loss by autoconversion of droplets

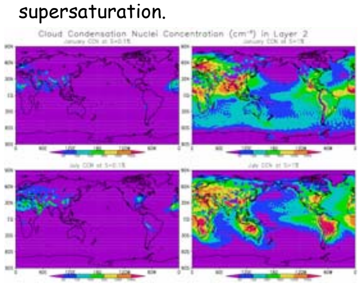
C_k = droplet loss by collection by precipitation

E_k = droplet loss by evaporation

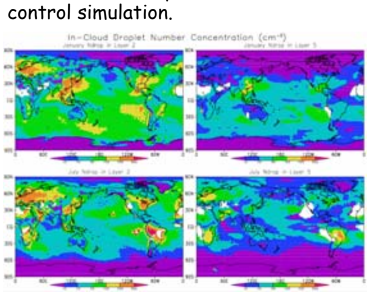
Experiment Design

- Applied to CAM3
- FV dycore, 2x2.5xL26 resolution
- Prescribe aerosol as an external mixture of lognormal modes
- Approximate pdf(w) by delta function at w=σ_w
- Diagnose σ_w from diffusivity, with lower bound 0.2 m/s
- Three 5-year simulations
  - Control
    - prescribed droplet effective radius =
      - 8 mm land
      - 14 mm ocean & sea ice
    - prescribed N_d =
      - 400 cm^{-3} warm continental clouds
      - 150 cm^{-3} cold and oceanic clouds
      - 75 cm^{-3} sea ice clouds
  - Predicted N_d with first indirect effect only
  - Predicted N_d with first and second indirect effects

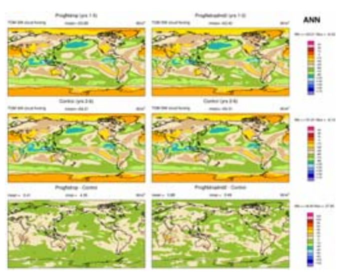
The distribution of CCN reflects the prescribed aerosol distribution. More CCN are activated at higher supersaturation.



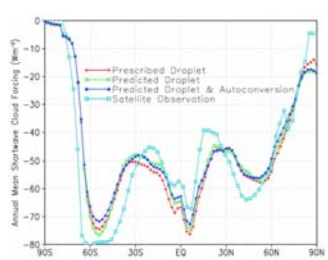
Simulated droplet number concentrations in clouds are highest in regions with high CCN concentrations, and are lower at higher altitudes because CCN concentrations are lower. Droplet number concentrations are somewhat lower than those prescribed in the control simulation.



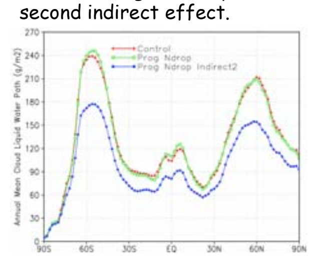
The shortwave cloud forcing is remarkably insensitive to the prediction of droplet number, both with and without the second indirect effect (which treats the influence of droplet number on precipitation).



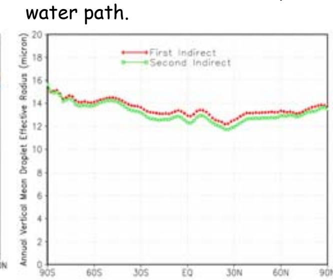
The shortwave cloud forcing simulated with predicted droplet number is closer to the control than to the observations.



The mean cloud liquid water path is reduced significantly with the second indirect effect.



The mean droplet effective radius decreases only slightly with the second indirect effect, so the insensitivity of the shortwave cloud forcing to the large reduction in mean liquid water path must be due to the tendency of liquid water path reductions to occur for clouds that are optically thick with albedos insensitive to the liquid water path.



Conclusions

•Predicting rather than prescribing droplet number changes droplet concentrations, but not the energy and water balances.

•Adding a treatment of the influence of droplet number on precipitation reduces the mean liquid water path, but produces little impact on the energy balance.

•This version of CAM can therefore be used to simulate cloud-aerosol interactions, estimate aerosol indirect effects, and simulate the climate impact of aerosol indirect effects with no need to retune the simulated climate.

•It is likely that this scheme will be adopted for CAM4.

The global and annual mean budgets of energy and water.

	Control	ProgN-Ctl	Ctl-Ind2
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 (gm^{-2})	124.7	0.61	-29.49
Precipitation (mm/day)	2.832	0.011	0.055