Mechanisms for Indirect Effects from Aerosol Pollution on Glaciated Clouds

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1. Abstract

A state-of-the-art, quasi-double moment bulk micro-physics scheme coupled to WRF model was developed and validated by simulating continental and maritime tropical cases of deep convection. The results show that the scheme simulates cloud systems with high accuracy. Sensitivity tests are performed to investigate mechanisms of aerosol indirect effects on glaciated clouds caused by anthropogenic aerosol pollution.

Overview

- Clouds regulate the Earth's energy budget, but how they will respond in future to changes in aerosol chemistry and loading remains conjectural.
- The IPCC report concluded that clouds remain the greatest source of uncertainty in climate prediction (Solomon *et al.* 2007).
- This research focuses on cold-cloud indirect effects; the *albedo* effect for mixed-phase and ice only clouds, the *riming, thermodynamic* and the *glaciation* effects (Lohmann and Feicter, 2005).

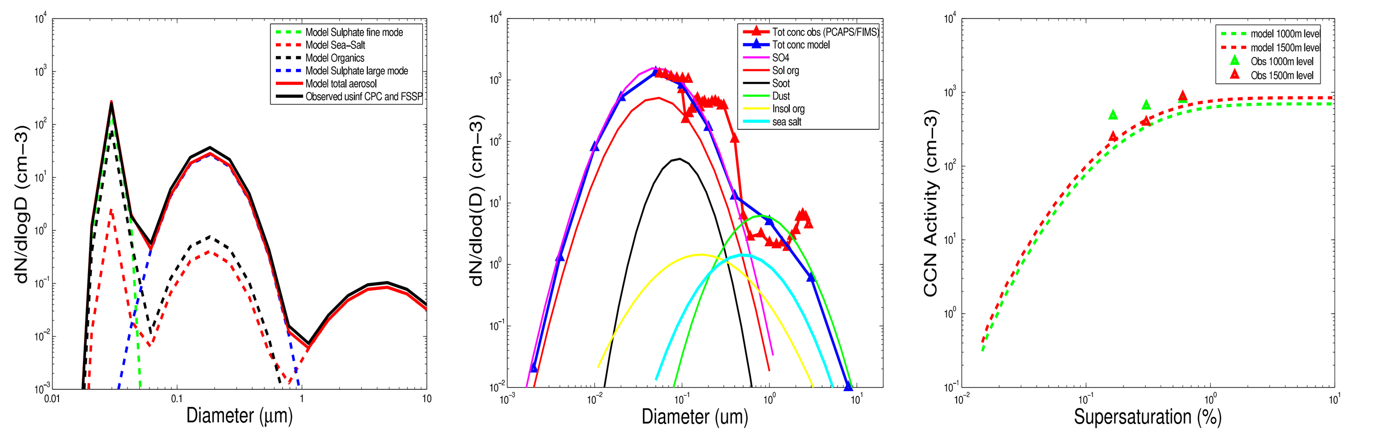

Fig. 1 *The multi-modal aerosol size distributions for the various aerosol species applied in the model initialisation for TWPICE (left) and CLASIC (centre) and the CCN activity spectrum for CLASIC.*

2. Model Description

Overview of the Model

- Bulk micro-physics model originally developed by Phillips *et al*, (2007) and recently modified to conform to Phillips *et al*, (2012), it is coupled to the Weather Research and Forecasting (WRF) model.
- Two-dimensional and non-hydrostatic with periodic boundary conditions and uses σ coordinates.
- Vertical and horizontal resolutions are approximately 500m and 2km, respectively with 10s integration time-steps.

The Micro-physics scheme

- This is a Cloud-System Resolving Model (CSRM), with two-moment prognostic variables for non-precipitating hydrometeors and one-moment treatment for precipitation.
- The scheme has a semi-prognostic aerosol component currently accommodating six aerosol species.
- Droplet nucleation by all aerosols takes place at the cloud base using Ming *et al*, (2006) and in-cloud nucleation utilises the scheme of Petters and Kreidenweis, (2007).
- Uses empirical parameterisation for heterogeneous ice nucleation developed by Phillips *et al.* (2008); It treats all four modes of ice initiation.
- Autoconversion, HM multiplication, sublimation and evaporation are also treated.

3. Simulated Cases and Validations

- Two tropical campaigns of deep convection were chosen for this study; the Tropical Warm Pool International Cloud Experiment (TWP-ICE), Darwin, Australia in 2006, was a 4-week maritime case (May et al., 2008) and,
- The Cloud and LAnd-Surface Interaction Campaign (CLASIC) was a 3-week continental case over the U.S Department of Energy's (D0E) (ARM-SGP) research site in Oklahoma, U.S.A. in 2007 (Miller, 2007).
- The choice of these two contrasting scenarios makes the study more comprehensive and adaptable to both maritime and continental situations.

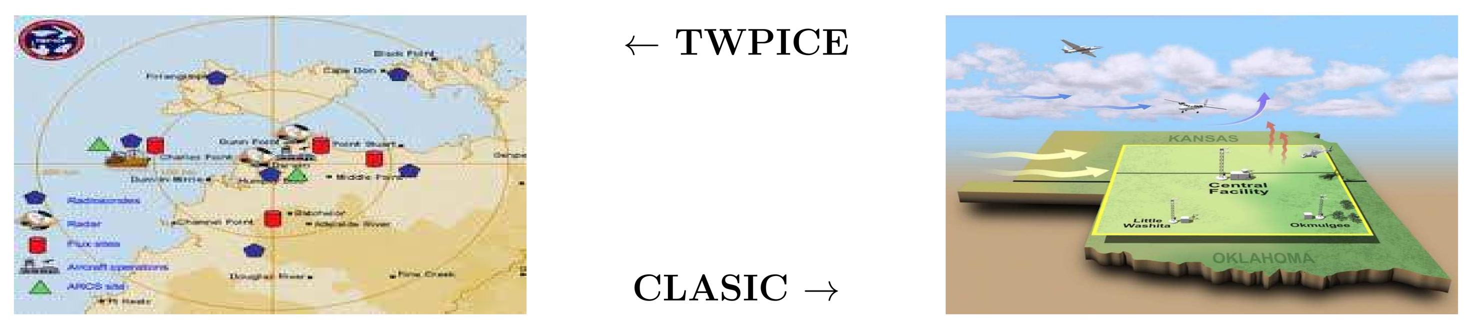

Fig. 2 *Maps of the two simulated cases, on the left is TWPICE, Darwin, Australia, 2006, and on the right is the CLASIC, Oklahoma, USA, 2007 field campaigns*

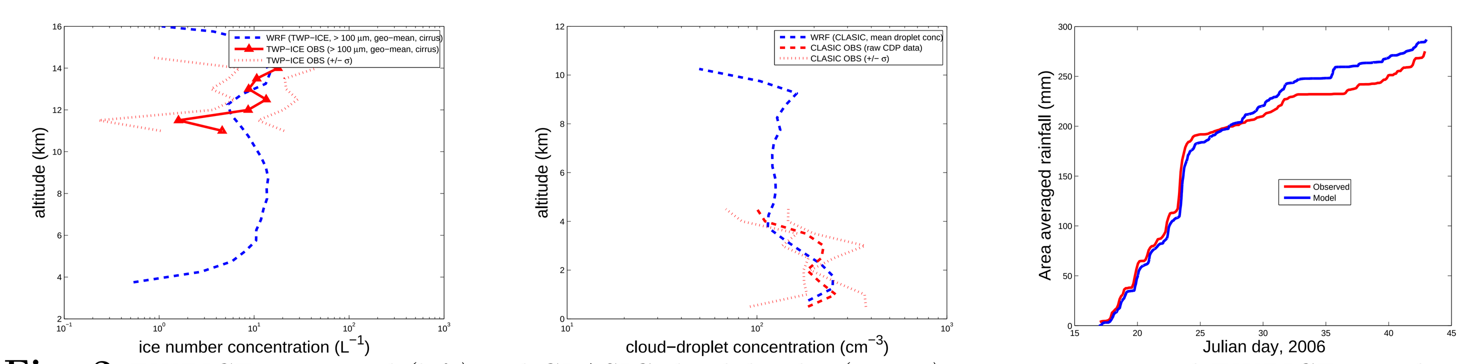

Fig. 2 *TWPICE ice crystal (left) and CLASIC cloud droplet (centre) concentrations and TWPICE cumulative precipitation (right). Red curves represent observed fields while blue shows model results.*

Radiation Statistics

Radiation fluxes (Wm^{-2}) % bias	SW TOA ↑	SW SFC ↓	LW TOA ↑	LW SFC ↓
TWPICE	24.61	1.62	5.93	-8.83
CLASIC	-2.53	16.06	-6.96	-4.20

Table 1 *Shows the radiation statistics for both TWPICE and CLASIC given as percentage errors; all have less than 25% of error.*

2. Description of Sensitivity tests

- **Hypothesis (1): Anthropogenic soluble aerosols modify cold-clouds through homogeneous freezing.**
- **Test (A)**; Fix the effective radius of ice crystals in the second diagnostic call to the radiation scheme.
- **Test (B)**; Fix the droplet size in warm cloud processes, (i.e radiation scheme, auto-conversion and sedimentation processes) to determine the cold-cloud indirect effect.
- **Test (C)**; Fix the droplet size in the riming routine to determine the riming indirect effect.
- **Test (D)**; Switch off all temperature adjustments arising homogeneous freezing of cloud droplets and melting of ice in order to determine the thermodynamic indirect effect.
- **Test (E)**; Reduce the large scale horizontal wind components, by a ratio of air pressure to surface pressure (Zeng *et al*, 2008), to determine the effect of wind shear on radiation.

5. Results

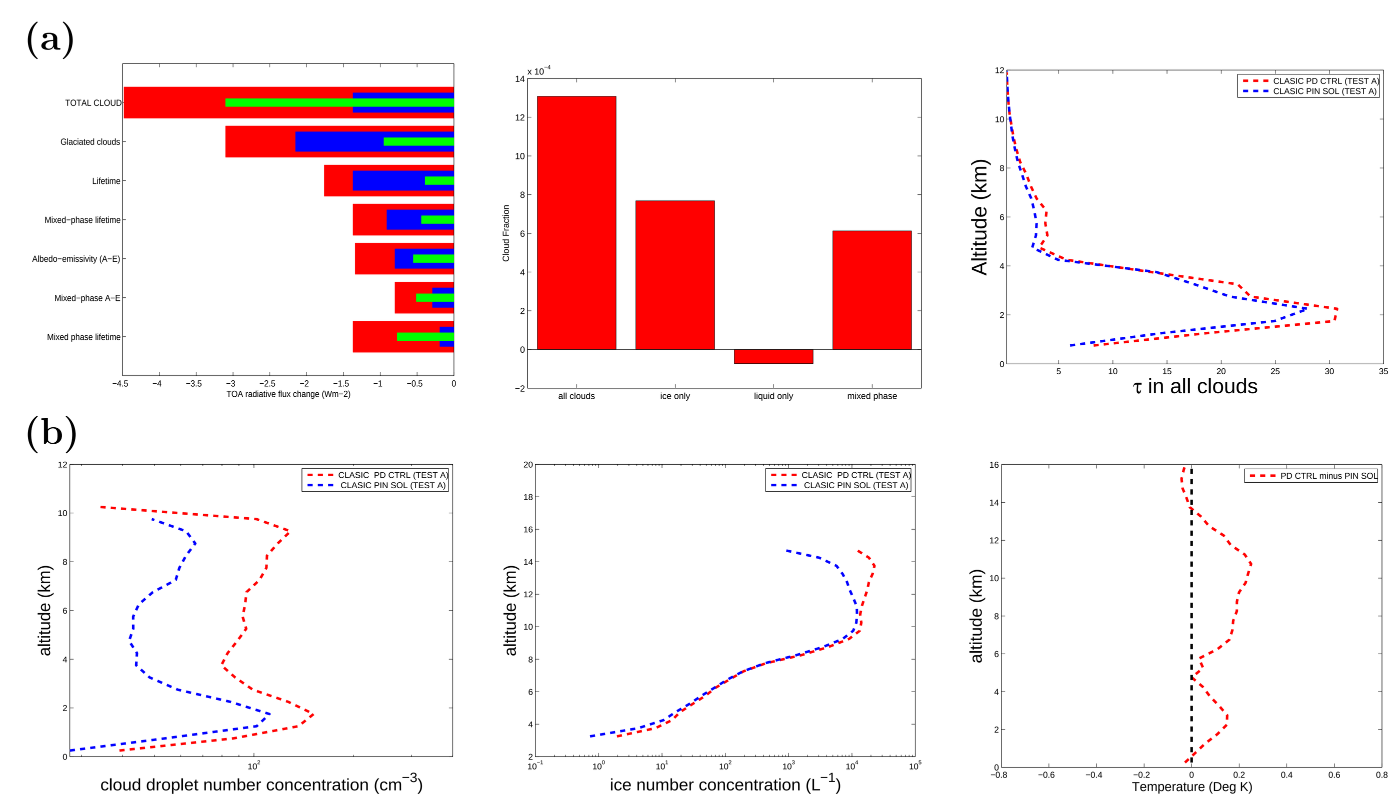

Fig. 3 (**a.**) *1.) Net radiative forcing (left) 1) Total cloud = AIE from all, water, glaciated clouds. 2) Glaciated clouds = AIE from glaciated, mixed-phase, ice-only clouds. 3) Lifetime = Lifetime AIE from glaciated, mixed phase, ice only clouds. 4) Mixed−phase lifetime = Mixed phase Lifetime AIE from mixed phase, water, ice components of mixed phase clouds. 5) Albedo−emissivity (A−E) = Albedo−emissivity (A−E) AIE from glaciated, mixed phase, ice only clouds. 6) Mixed−phase A−E = Mixed phase A−E AIE from mixed phase, water, ice components of mixed-phase clouds. 7) Other lifetime AIE = mixed phase lifetime AIE, Riming AIE, Thermodynamic AIE components of mixed-phase clouds and cloud fraction (centre) statistics and cloud optical depth (right).* (**b**) *Micro-physical species; cloud droplet (left) and crystal (center) concentrations CLASIC (left) conditionally averaged over cloud regions, while temperature change (right) is unconditionally averaged across the whole domain. Red curves represent the presenent-day control run while blue shows a pre-industrial soluble aerosol concentration run. All are for the CLASIC case.*

- The net all-clouds and glaciated-clouds radiative forcing is generally negative implying a cooling effect of the climate system.

6. Conclusions and Future Work

- Anthropogenic soluble aerosol pollution enhances cloud albedo predominantly in the short-wave radiative flux. It also boosts cloud ice concentrations through homogeneous freezing.
- Preliminary results show a weak cold-cloud indirect effect relative to warm clouds, which is in agreement with literature.

Future Work

- Investigate the effect of anthropogenic insoluble aerosols (e.g. black carbon from biomas burning) indirect on radiation and the glaciation indirect effect.
- Identify important mechanisms giving rise to the above radiation statistics.

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