Process-Modeling Study of Ship Tracks and Marine Cloud Brightening

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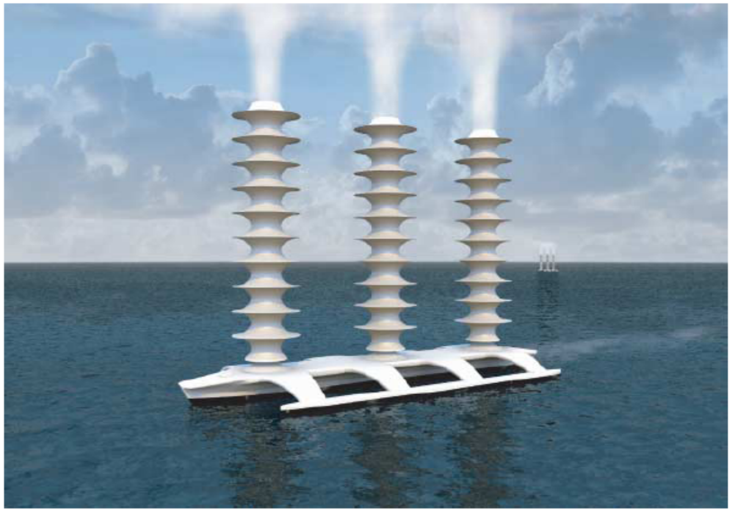
Outline

- Introduction
- Simulation of shiptrack in open and closed cells
  (Wang and Feingold, 2009b)
- Marine cloud brightening by sea-salt injection
  (Wang, Rasch, Feingold, 2011; Wang et al., in preparation)
- Summary and issues for discussion

Introduction

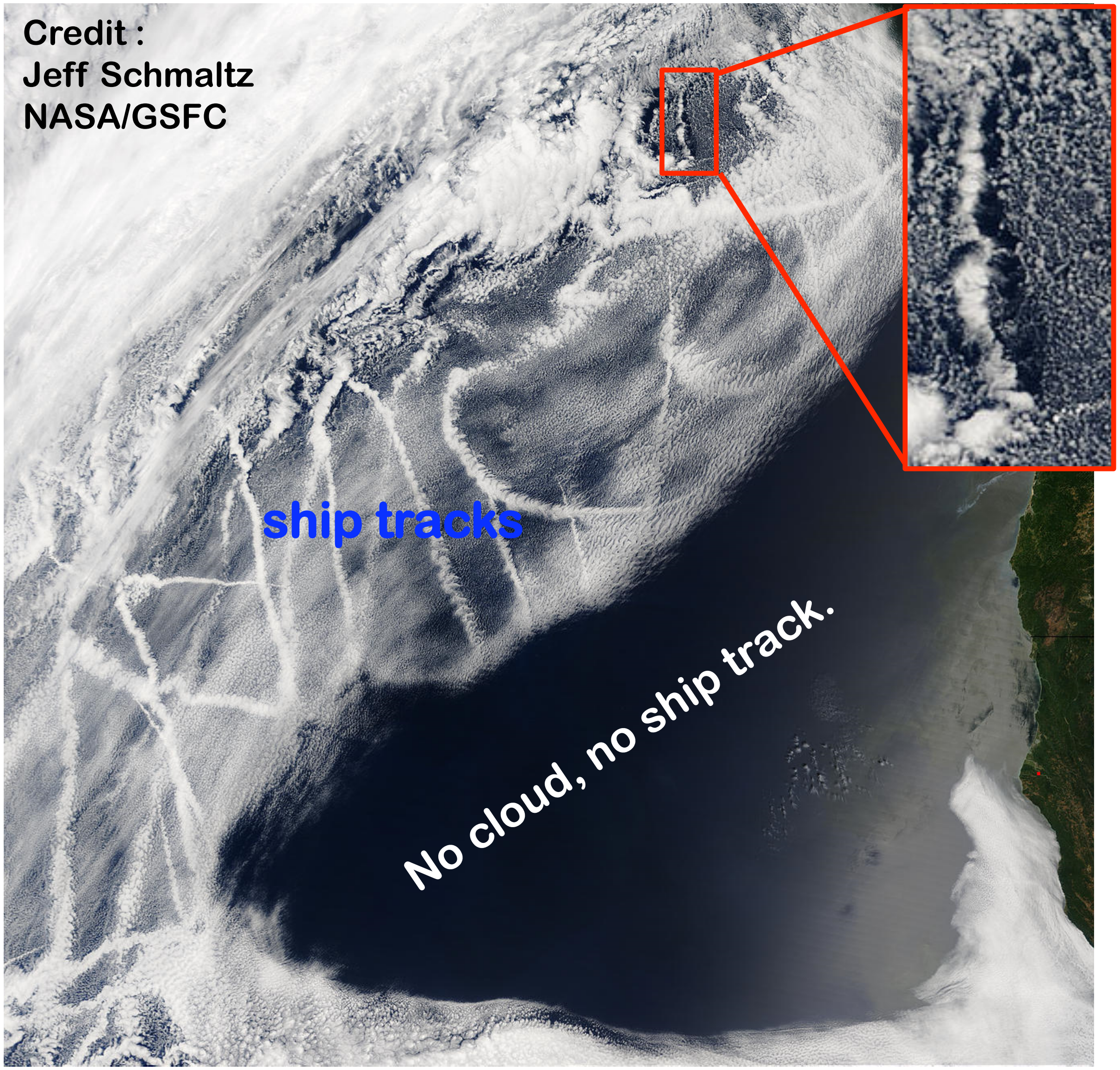
- Geoengineering: deliberate manipulation of the Earth's climate to counteract the effect of global warming by GHGs
  - Solar radiation management
    - Marine cloud albedo enhancement
      - Seawater spray
      - Ocean sulfur cycle enhancement
    - Stratospheric aerosols
    - Cool roof
    - space shade
    - Cirrus cloud seeding
  - GHG removal
  - Limiting arctic sea ice loss
  - Ocean heat transport

About the seawater spray method



- Latham (1990, 2002) proposed injecting submicron sea-salt particles to increase marine Sc cloud albedo to offset the +3.7 Wm^{-2} forcing from $2xCO_2$
- Salter et al. (2008) proposed a wind-driven sprayer that can produce sea-salt to increase CDNC by 200 cm^{-3}
- The idea was evaluated by a few global/box modeling studies (e.g., Bower et al. 2006; Latham et al. 2008; Jones et al. 2009; Rasch et al. 2009; Korhonen et al. 2010; Bala et al. 2010)
- Process modeling is needed to understand the transport of injected particles and interactions with clouds

Motivation



Ship exhaust modifies marine Scu cloud albedo.

Unpredictable

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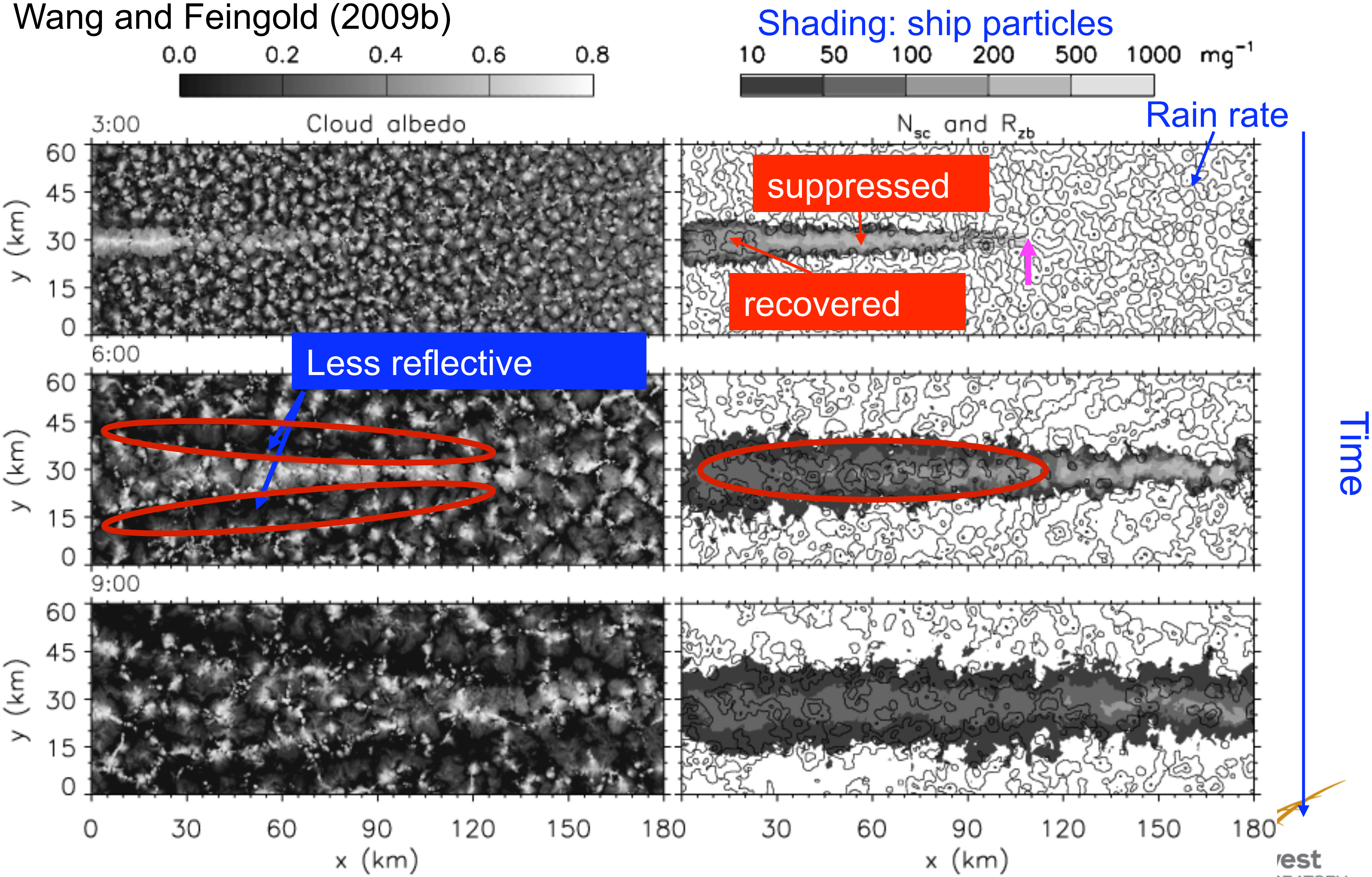
Process Modeling

- the Weather Research and Forecasting (WRF) model
  - $\Delta x = \Delta y = 300$ m; $\Delta z \sim 30$ m; $\Delta t = 3$ s
  - Domain size: 60 x 120 (180) x 1.5 km^3
  - Simulation time: 30 hours (one diurnal cycle)
  - Two-moment (bin-emulating) microphysics

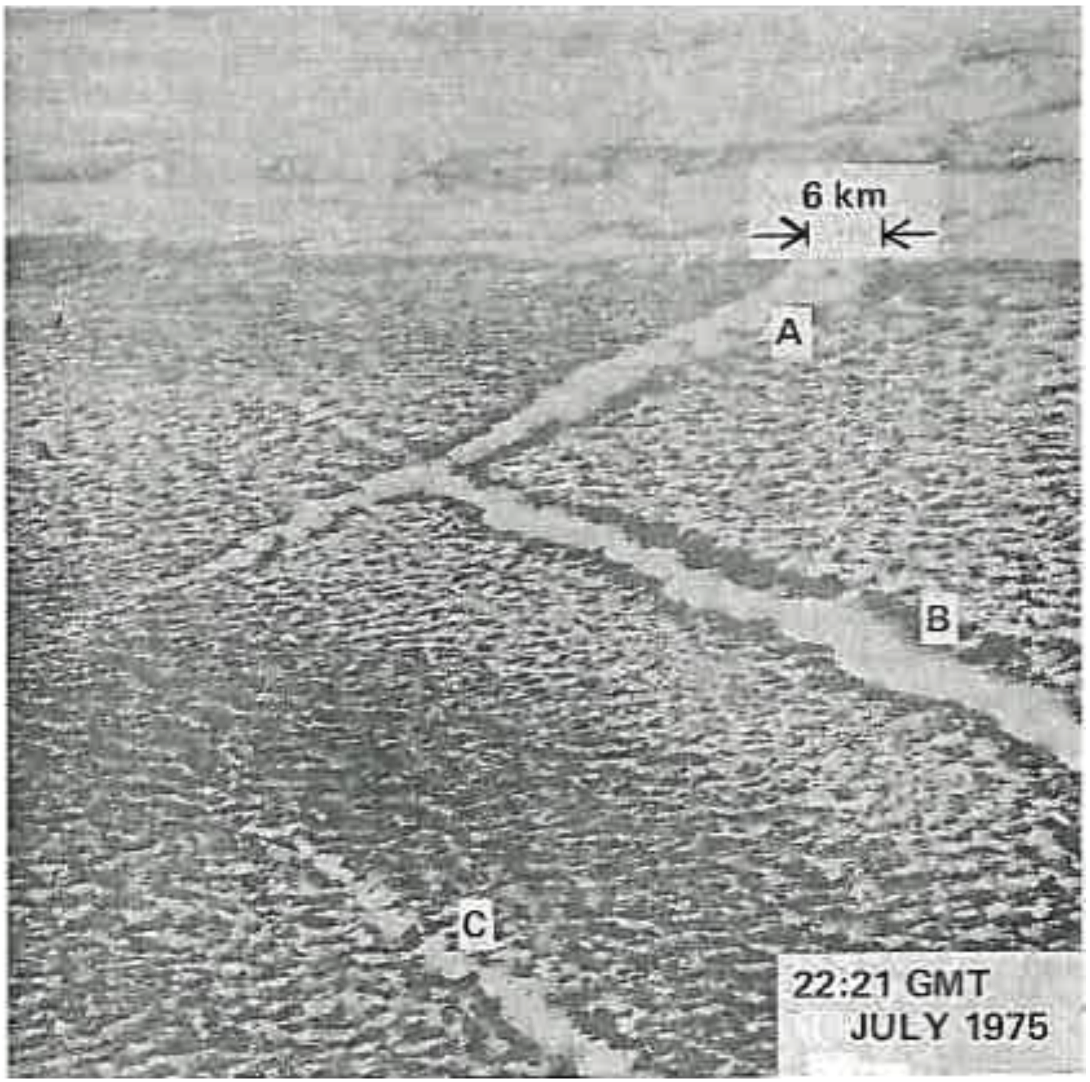
  (Wang et al. 2009; Wang and Feingold 2009a,b; Wang et al. 2010; Feingold et al. 2010)
- Initial conditions:
  - RF01 (Dry; Stevens et al. 2005) and RF02 (Wet; Ackerman et al. 2008) of DYCOMS-II
  - Prescribed surface heat fluxes and large-scale forcing
  - Diurnal variation of radiation (MCB)

Ship plume and ship track in open cells

Wang and Feingold (2009b)



Examples of ship track and “shadows”



W. Porch et al. Apollo-Soyuz, July 1975

MODIS image

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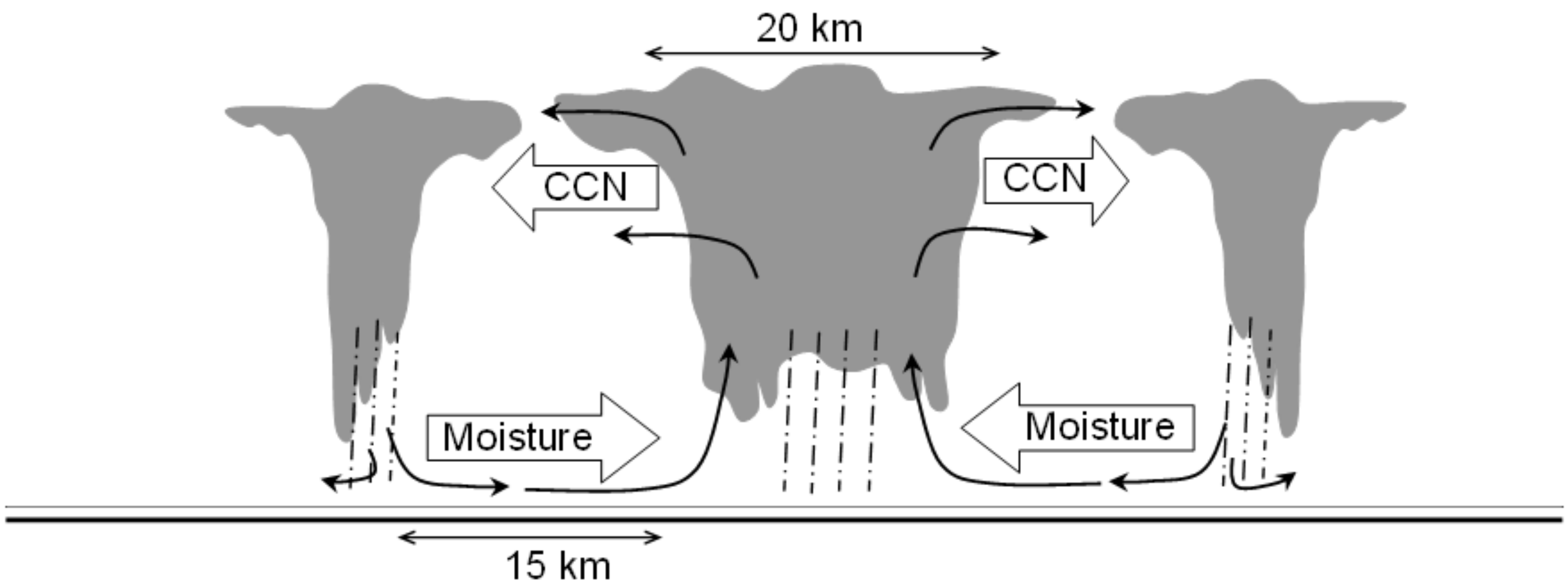
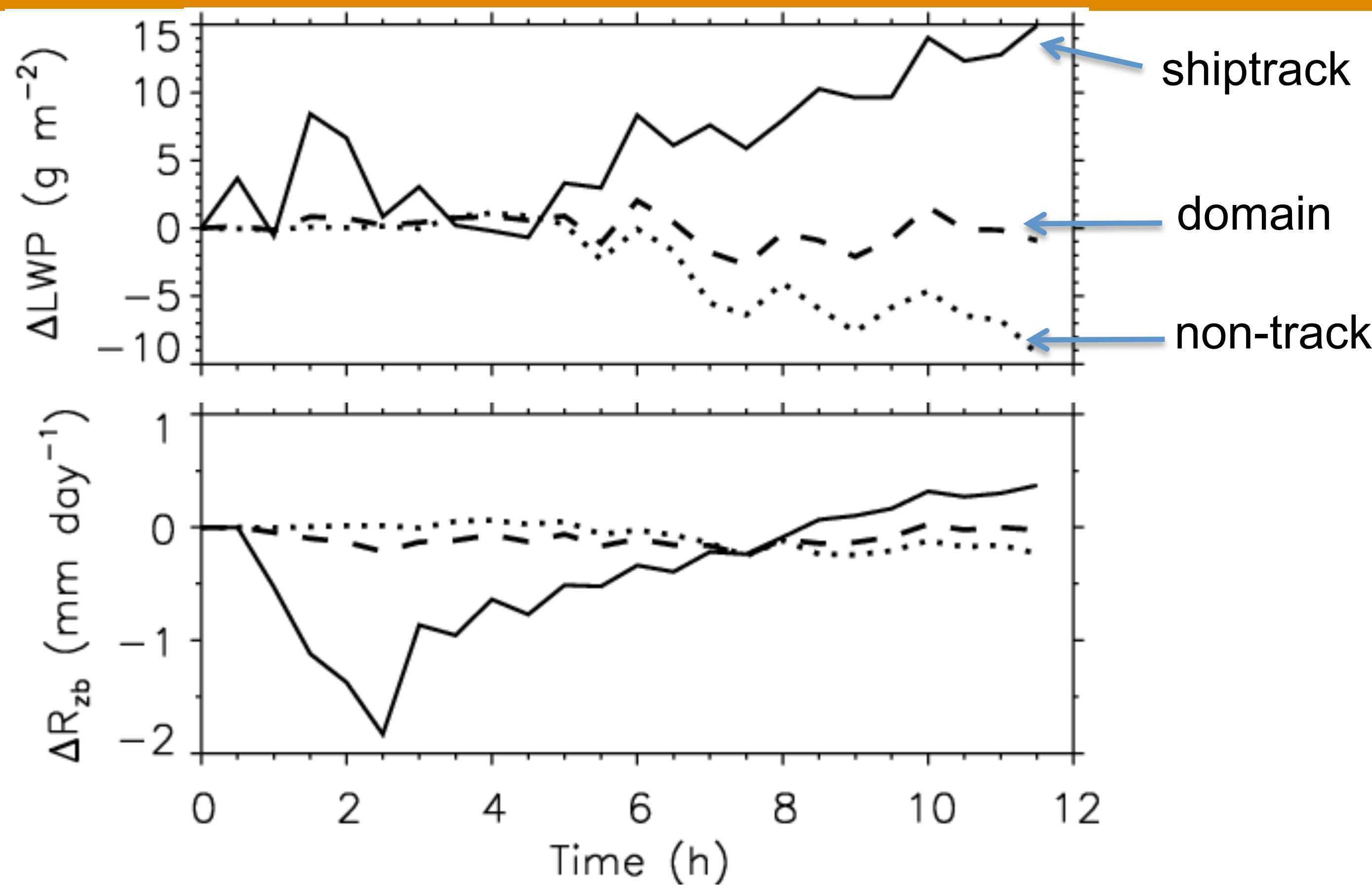
Conceptual diagram of the circulation

Wang and Feingold (2009b)



- **Drizzle is first suppressed by the influx of aerosols, and breakup of clouds is delayed.**
- **When drizzle recovers due to moisture convergence and CCN dilution, clouds break up and form open cells.**

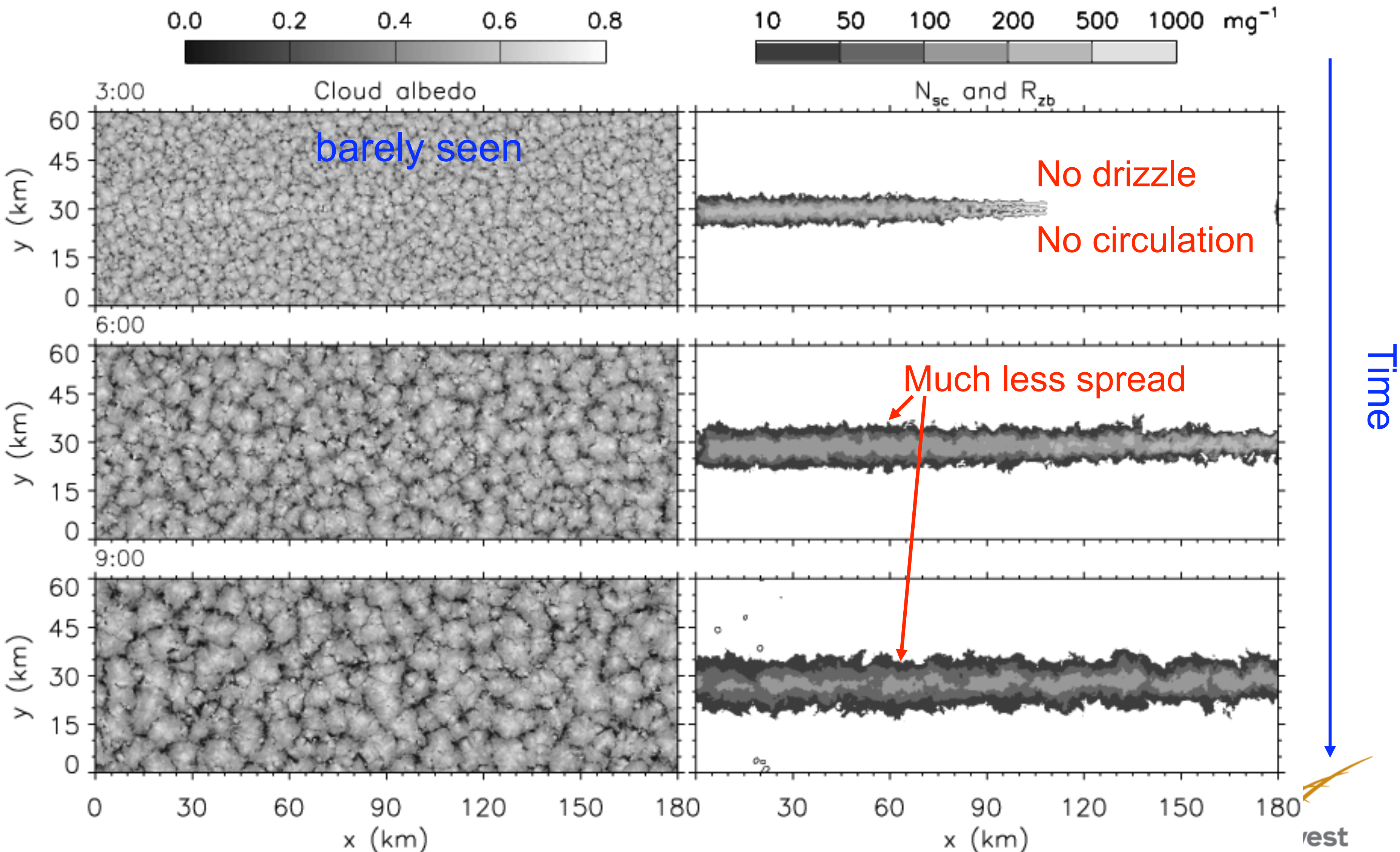
Change in LWP and rain rate with time



Wang and Feingold, 2009b

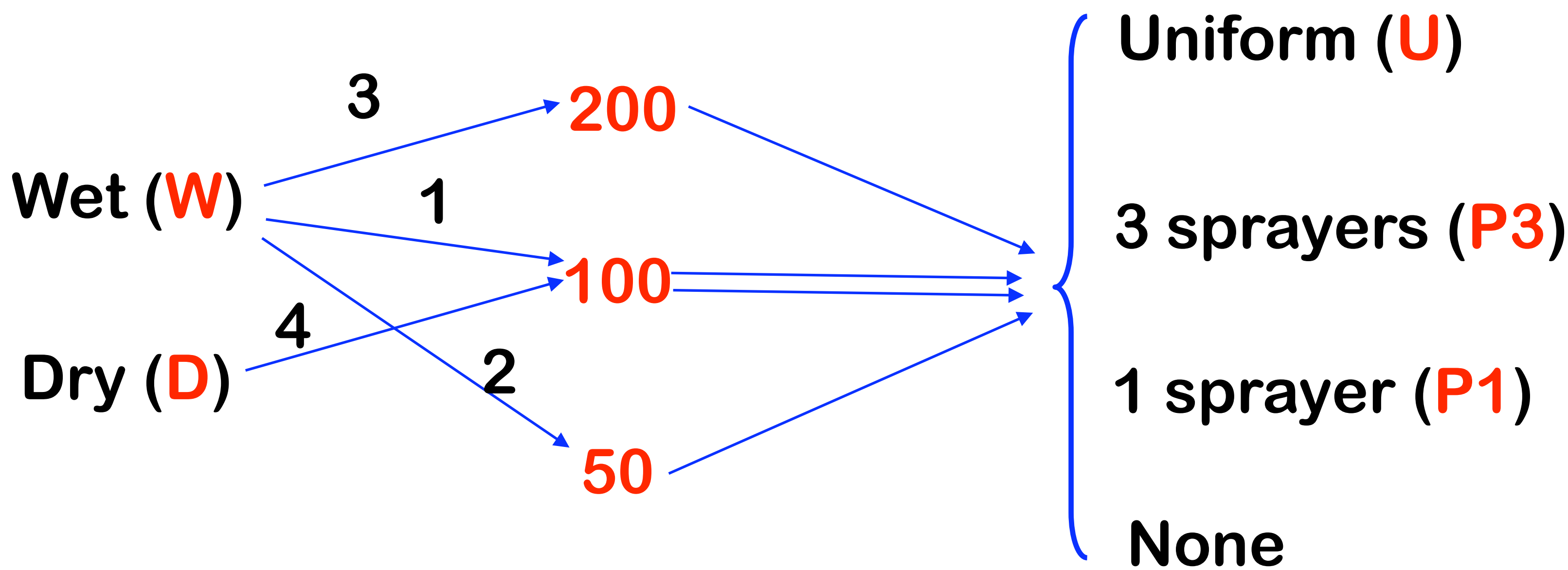
Ship plume and ship track in closed cells

Wang and Feingold (2009b)



Experiments for cloud brightening

Sounding	Background CCN, mg^{-1}	Injection method



1. Weakly precipitating case
2. Strongly precipitating case
3. Non-precipitating wet case
4. Non-precipitating dry case

Injection rate (Salter et al. 2008): $1.45 \times 10^6\ m^{-2}\ s^{-1}$

~ 6 mg^{-1} per hour

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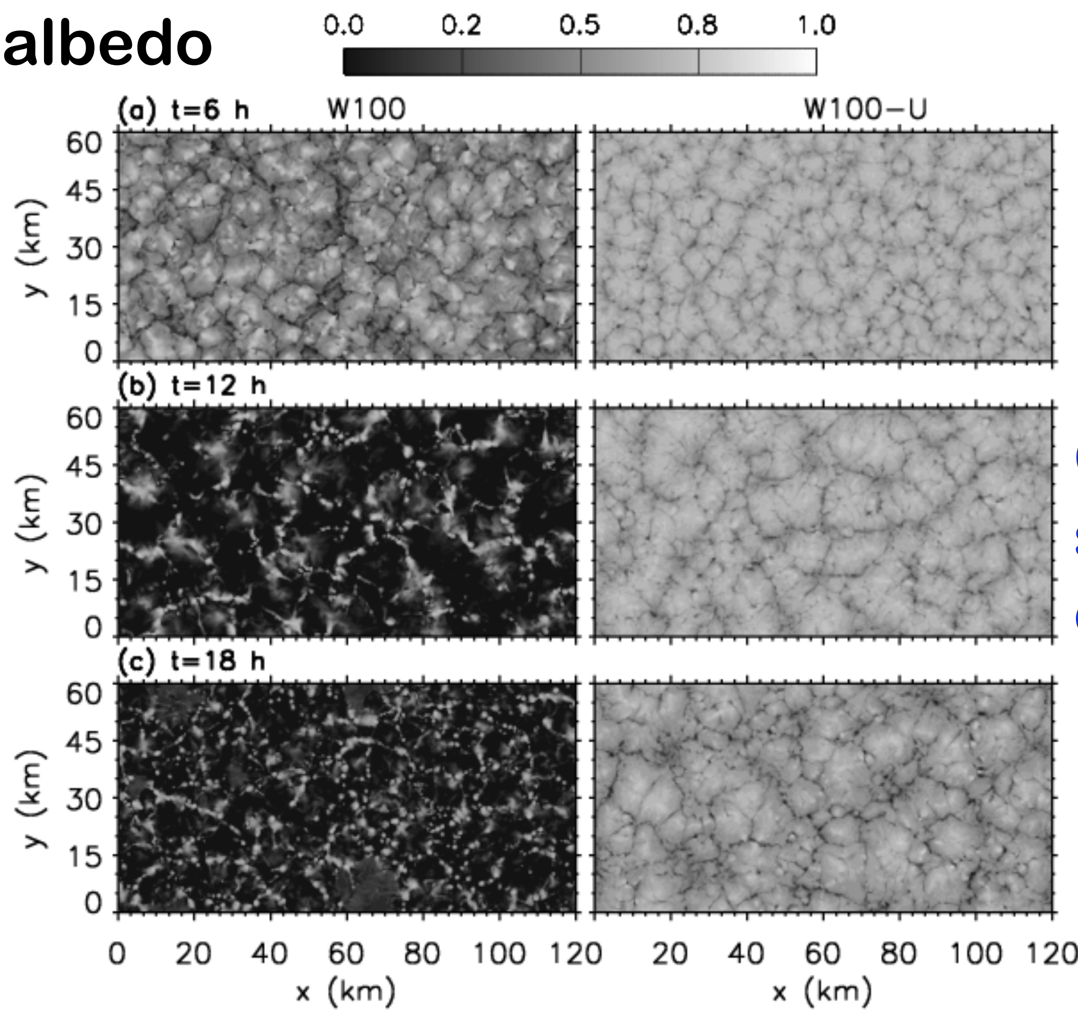
Results: weakly precipitating case (W100)

Most effective

Cloud albedo



Cloud cellular structure changes

Baseline, W100

Uniform injection

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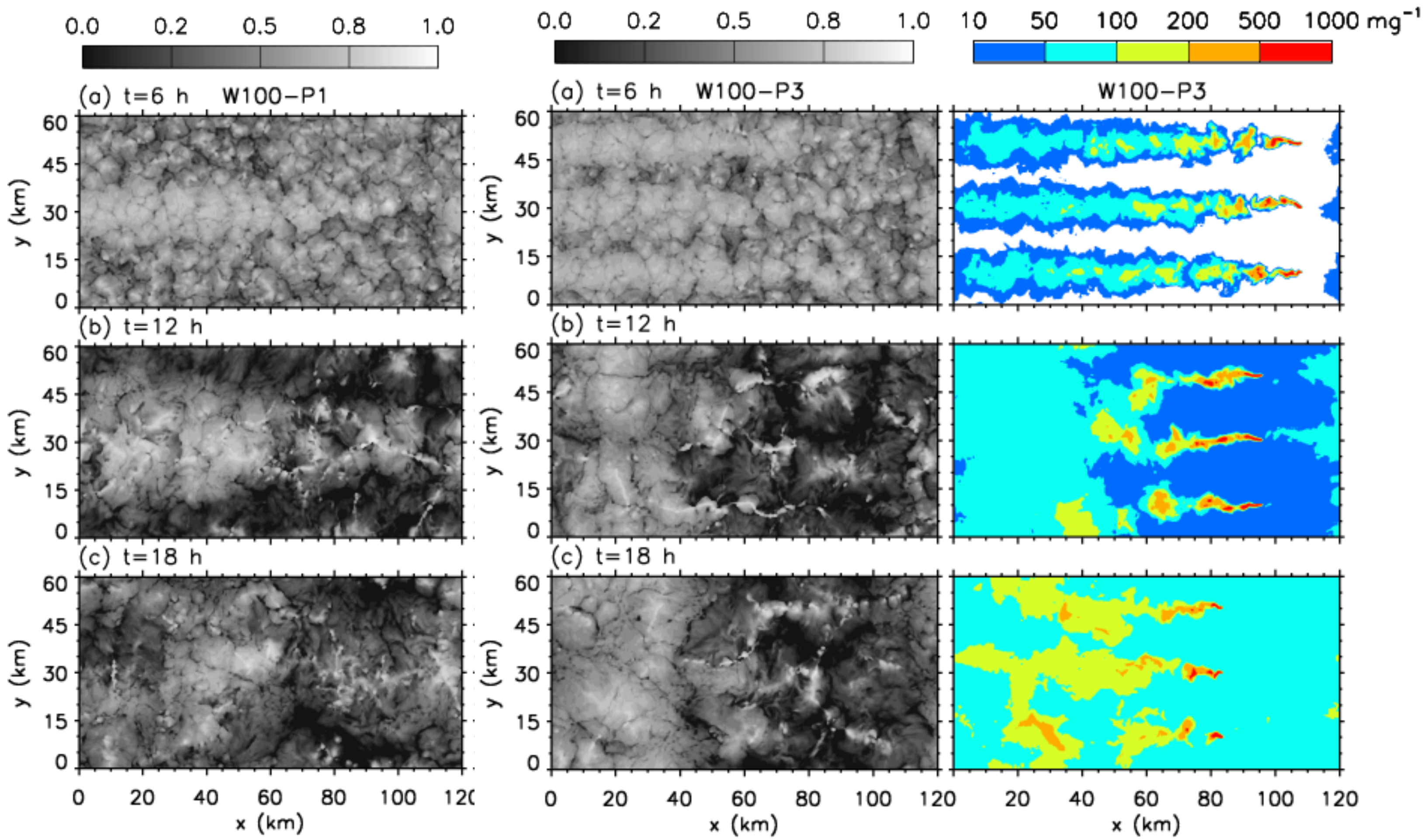
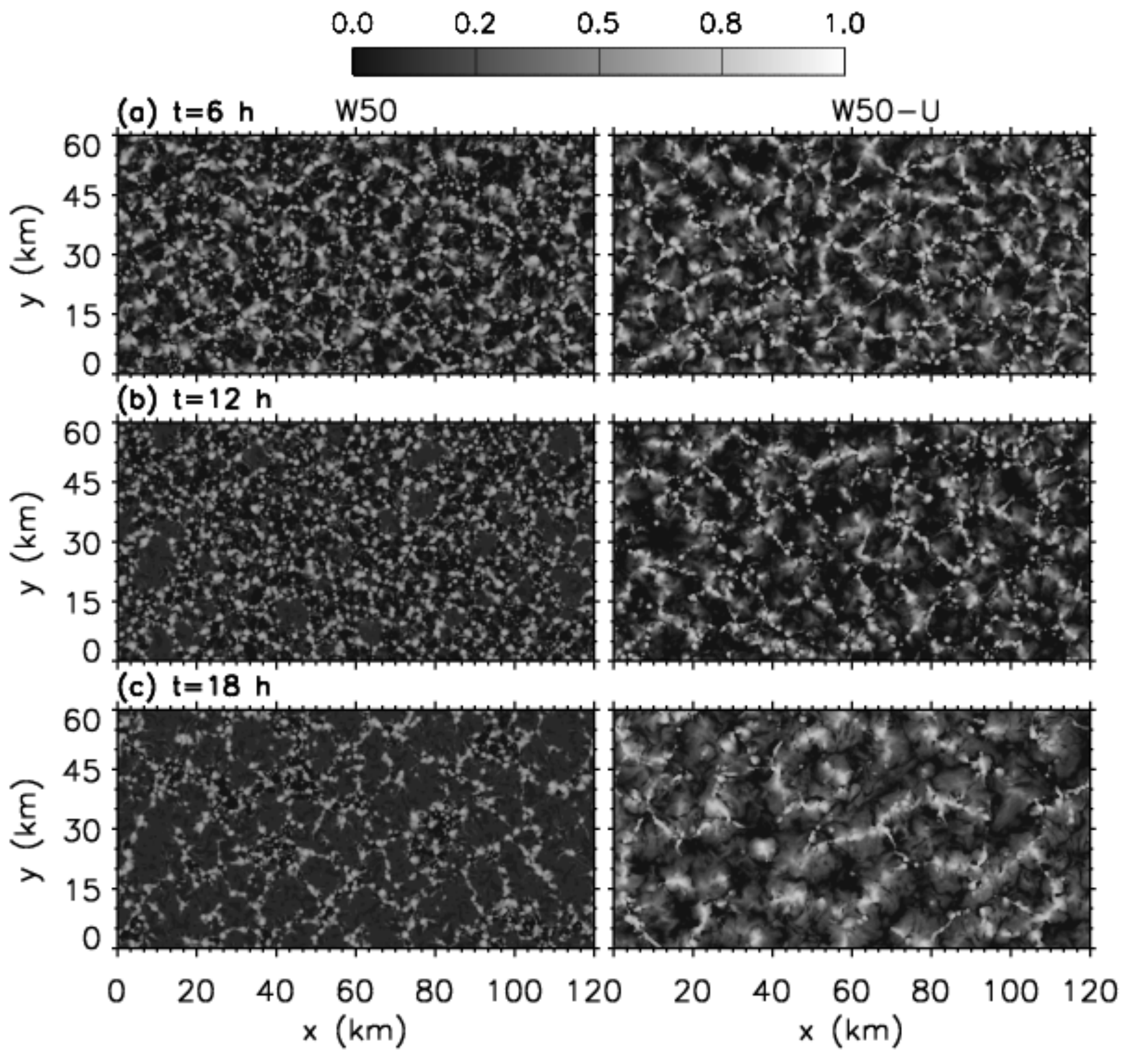
Weakly precipitating case: injected by sprayer(s)



Distribution of sprayers and magnitude of the flux matter

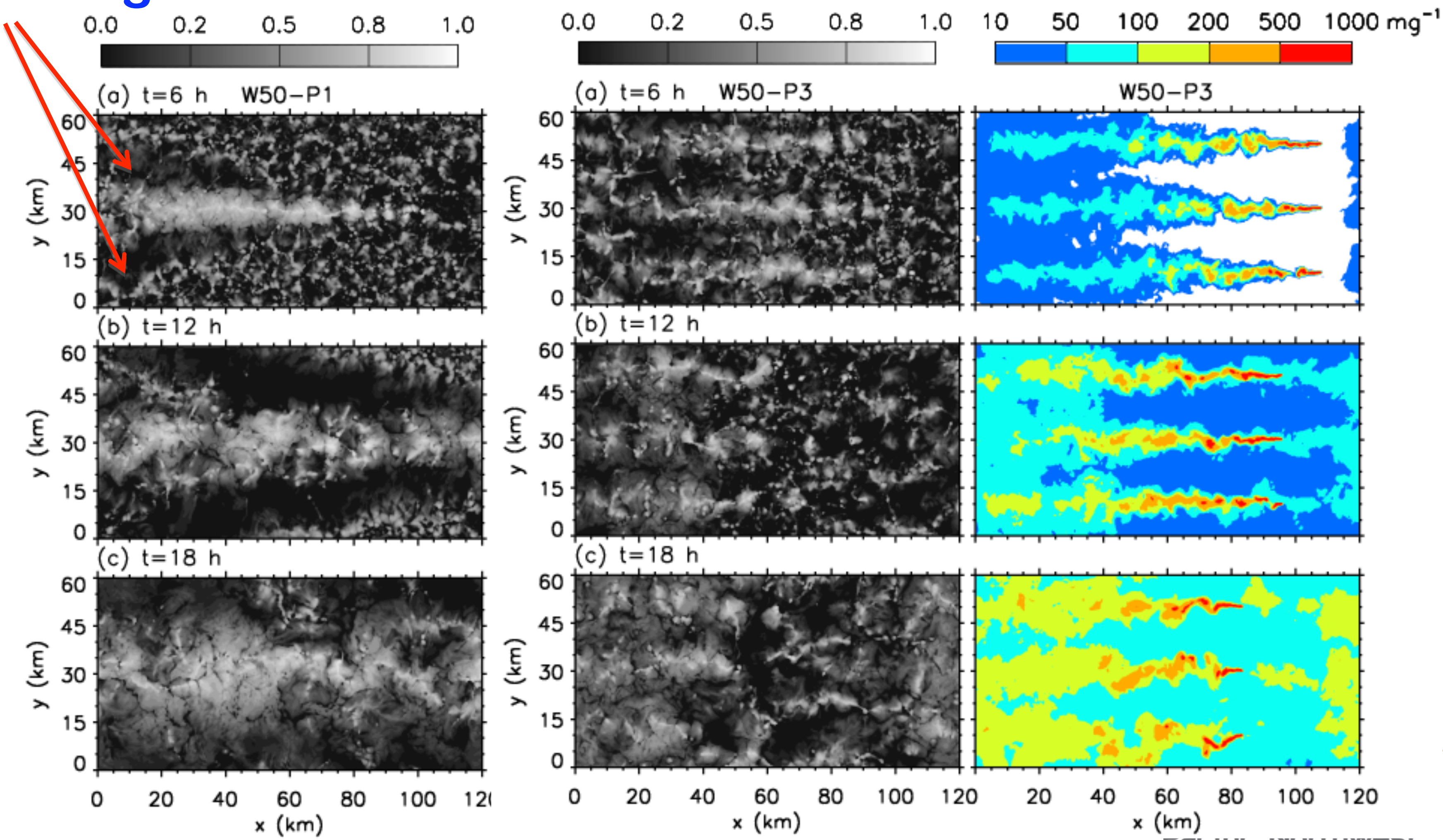
Results: strongly precipitating case (W50)



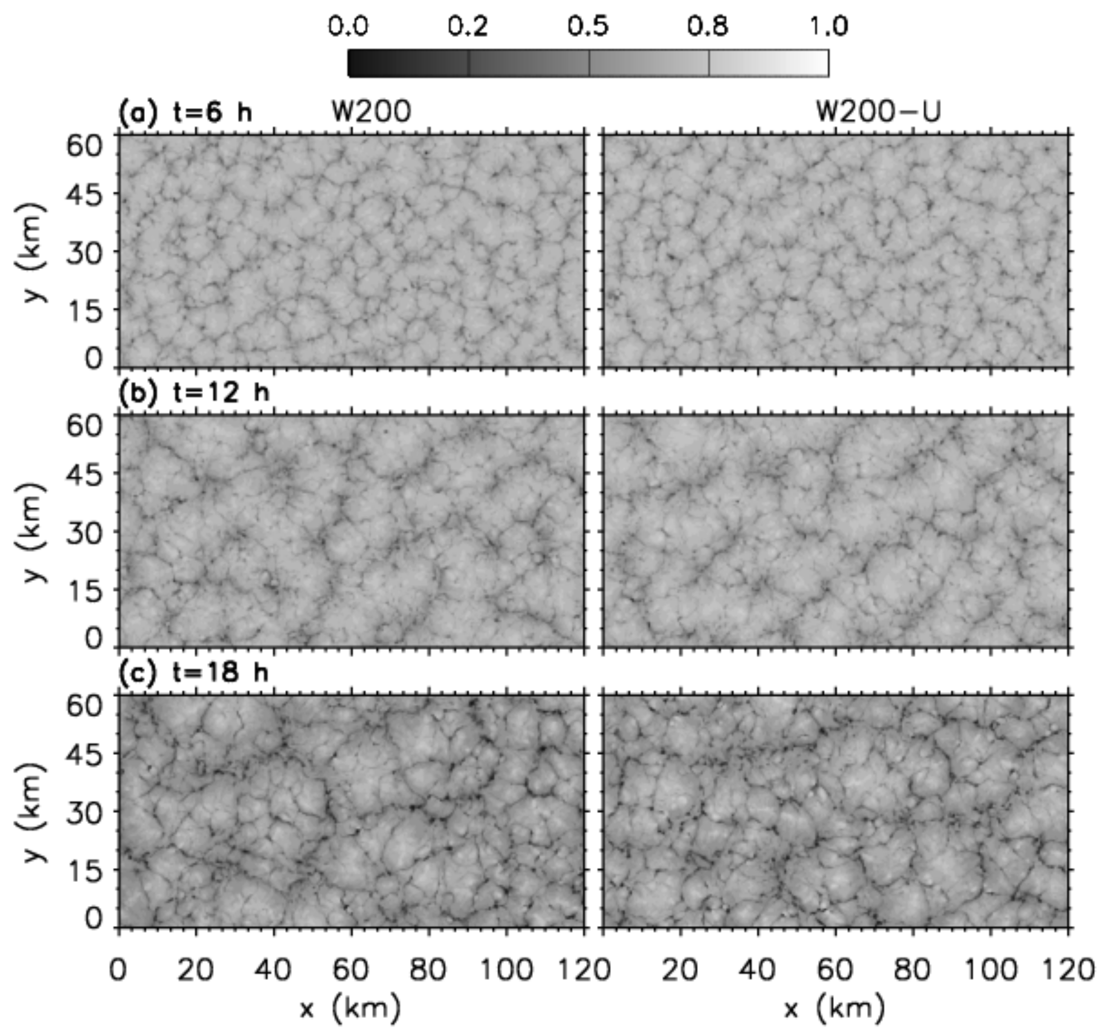
The uniform injection changes cloud cover and albedo, but not the overall cloud cellular structure

Strongly precipitating case: injected by sprayer(s)

Clearing on either side of the track!



Results: non-precipitating wet case (W200)



Visually, no difference

Summary on MCB

- The impact of CCN injection on clouds depends on meteorology and aerosol background:
  - Cloud brightening is effective in
    - Weakly precipitating BL where additional CCN can weaken rain and retain cloud water (areal coverage)
    - CCN-limited scenario which occurs after heavy and/or persistent rain (local concentration)
  - It is less effective in
    - Strongly precipitating regime if injected CCN cannot significantly weaken precipitation
    - Very polluted regime where clouds are already bright
    - Water-limited (dry) regime where droplets are small.
- Injection strategy is critical in determining the spatial distribution of CCN (areal coverage vs. concentration)
- Outstanding issues