A. P. KHAIN, N. BENMOSHE, AND A. POKROVSKY

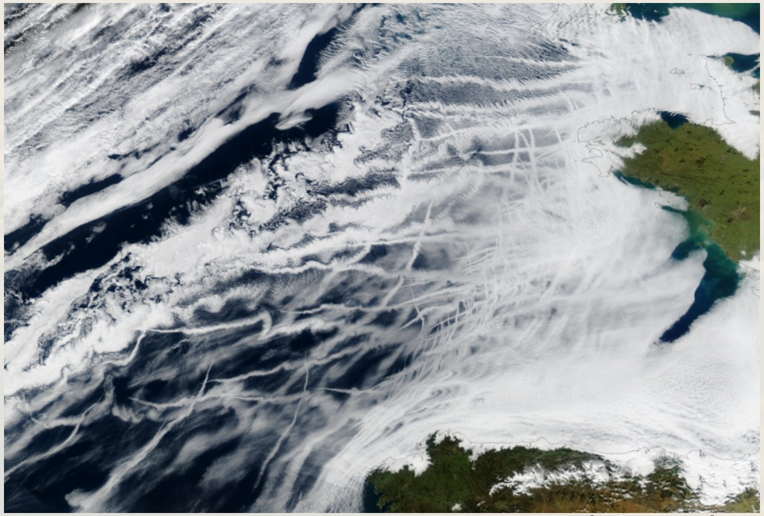
JOURNAL OF THE ATMOSPHERIC SCIENCES
VOLUME 65
JUNE 2008

Factors Determining the Impact of Aerosols on Surface Precipitation from Clouds: An Attempt at Classification

Jaša Čalogović
(jcalogovic@geof.hr), Hvar Observatory, Faculty of Geodesy, Kačićeva 26, HR-10000 Zagreb, Croatia

Introduction

• Atmospheric aerosols affect the cloud mycrophysical structure & formation (observations, numerical studies)



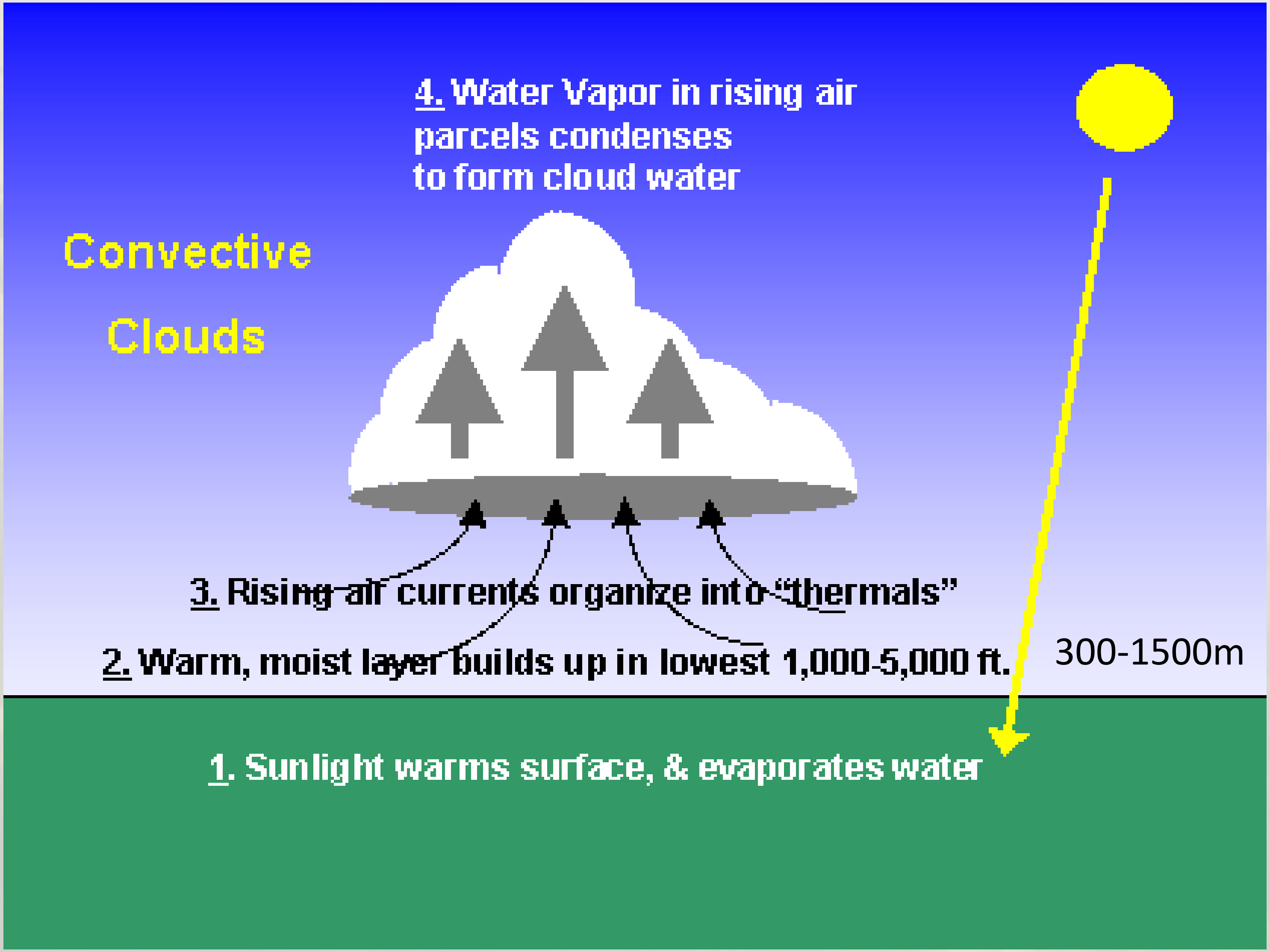
Shiptracks

• An increase of the aerosol particles:
  - increases CCN concentrations
  - decreases the size of droplets
  (Rosenfeld and Lensky 1998; Ramanathan et al. 2001; Andreae et al. 2004)

• Recent model studies and observations:
  - aerosol induced invigoration of deep convection (increase in convective updrafts and downdrafts & cloud size)
  (Khain et. al. 2005, Wang 2005, Lee et. al. 2008, Koren et. al. 2005)

• Effect of aerosols on precipitation:
  - challenging problem
  - no agreement between the results (quantitative and qualitative)

Convective clouds



Aerosol effect on precipitation

- Aerosols suppress precipitation in stratocumulus and small cumulus clouds (Rosenfeld 2000, Givati and Rosenfeld 2004, Feingold et. al. 2005)
- Aerosols increase precipitation from deep convective clouds (Wang 2005, Lynn et. al. 2005)
- Increase of aerosols - decreases or increases the precipitation depending on **environmental conditions** (eg. humidity, atmosphere stability) (Khain 2004, 2005, Tao 2007)

dry, unstable atmosphere
↓
increase in aerosol particles
↓
less precipitation

wet atmosphere
↓
increase in aerosol particles
↓
more precipitation

- Different atmospheric conditions or cloud types - different results for precipitation (need for classification)

Quality of numerical models

Generation of the condensate (drop condensation, ice deposition), drying and heating

P = G - L **G, L >> P**

Precipitation

Loss of the condensate (drop evaporation, ice sublimation), moistening and cooling

- Small error in terms (G, L) causes large error in precipitation (P)
  - discrepancies in numerical model results
- G & L depend on droplet size distributions (DSD)
  - evolution with different heights and aerosol concentrations
  - limited number of observations

Purpose of the study

1. Reproduce the microphysical characteristics of the developing green ocean (GO), smoky (S) and pyroclouds (P) using a spectral microphysics cloud model.

2. Analyze the mechanisms by which aerosols affect the precipitation formation in these clouds. Extremely continental (dry) and maritime (wet) clouds are also analyzed.

Model description

Hebrew University spectral microphysics cloud model (HUCM) (Khain et. al. 2004, 2005)

- 2D, nonhydrostatic model
- solution of a kinetic equations system for the size distribution functions of:
  - water drops
  - ice crystals (plate, columnar, branch types)
  - aggregates
  - graupel (ρ=0.4 gcm^{-3}, r > 100 μm)
  - hail/frozen drops (ρ=0.9 gcm^{-3}, r > 1000 μm)
  - aerosol particles
- 33 mass-doubling bins for the size distributions
- computational domain 178km x 16km
- 250m horizontal and 150m vertical resolution

Characteristics of simulated clouds and experimental design

Green ocean (GO) clouds
Clean air
AP: 100 / 400 cm^{-3}
AP aerosol particle concentration

Smoky (S) clouds
Polluted air
AP: 6880 cm^{-3}

Pyroclouds(P)
extremely polluted air
AP: 6880 cm^{-3}
in fire zone: 13760 cm^{-3}

- temp. and dewpoint profiles according to Andreae et. al (2004), LBA-SMOCC campaign
- 50% relative humidity (RH) near the surface
- cloud base height: 1.8-2km
- freezing level 4.2km
- max. dry AP radius: ~1μm, max. radius of nucleated droplet: ~4 μm
- sensitivity tests for P clouds (P1, P2, P3), different surface temp. and heating rates
- all simulations: heating rate: 0.01°C s^{-1} (600s), unchangeable surface temp. & water vapor mixing ratio, dynamical time step 5s, duration: 3-4h

Characteristics of simulated clouds and experimental design

T Clouds
continental conditions, Texas summertime

- very dry, unstable, dirty atmosphere
- 30% RH near the surface
- Aerosol particle (AP) concentration: 2500 cm^{-3}
- cloud base height: ~ 3km
- max. dry AP radius: ~1μm
- max. radius of nucleated droplet: ~4 μm
- sensitivity test: T-m simulation (AP conc. 100 cm^{-3})

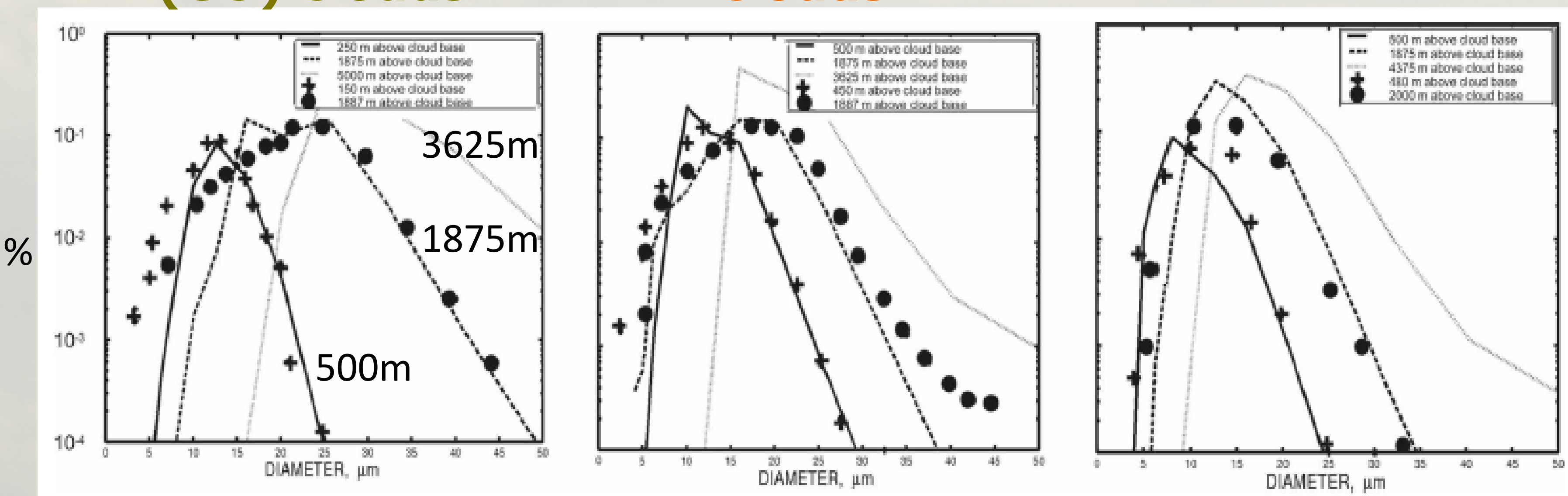
M Clouds
maritime conditions, experiment GATE-74

- clean, wet, stable maritime atmosphere
- 90% RH near the surface
- AP concentration: 100 cm^{-3}
- cloud base height: 1km
- max. dry AP radius: ~2μm
- max. radius of nucleated droplet: ~8 μm
- sensitivity tests: M-c simulation (AP conc. 2500 cm^{-3}), M-80 simulation (RH: 80%)

Droplet size distributions (DSD)

- determines the microphysical structure and the precipitation
- reliability of all results

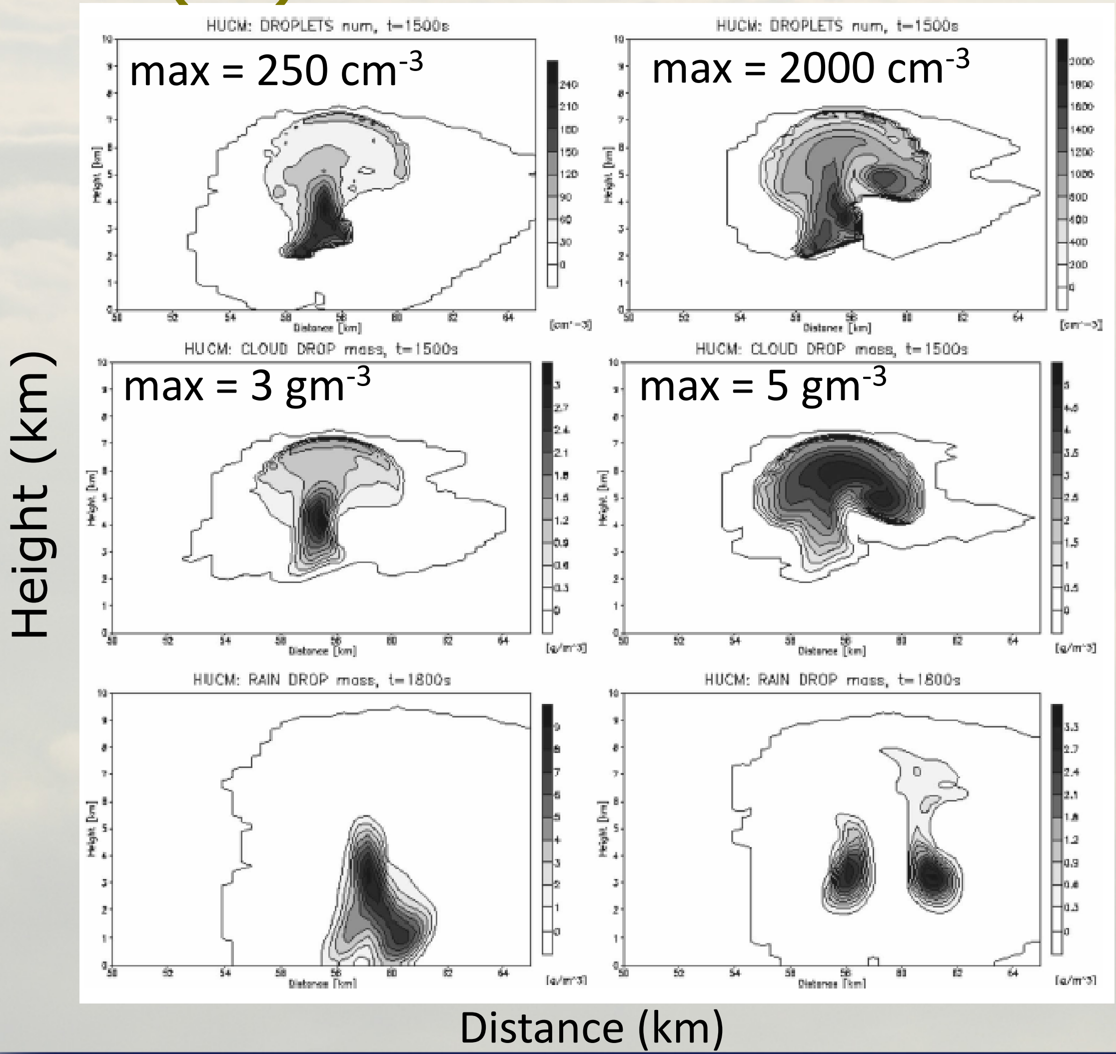
Green ocean (GO) clouds | **Smoky (S) clouds** | **Pyroclouds(P)**



mean: 25 µm | mean: 15 µm | mean: 12 µm

Results: Microphysical structure of the green-ocean and smoky clouds

Green ocean (GO) clouds | **Smoky (S) Clouds** | t= 25-30min



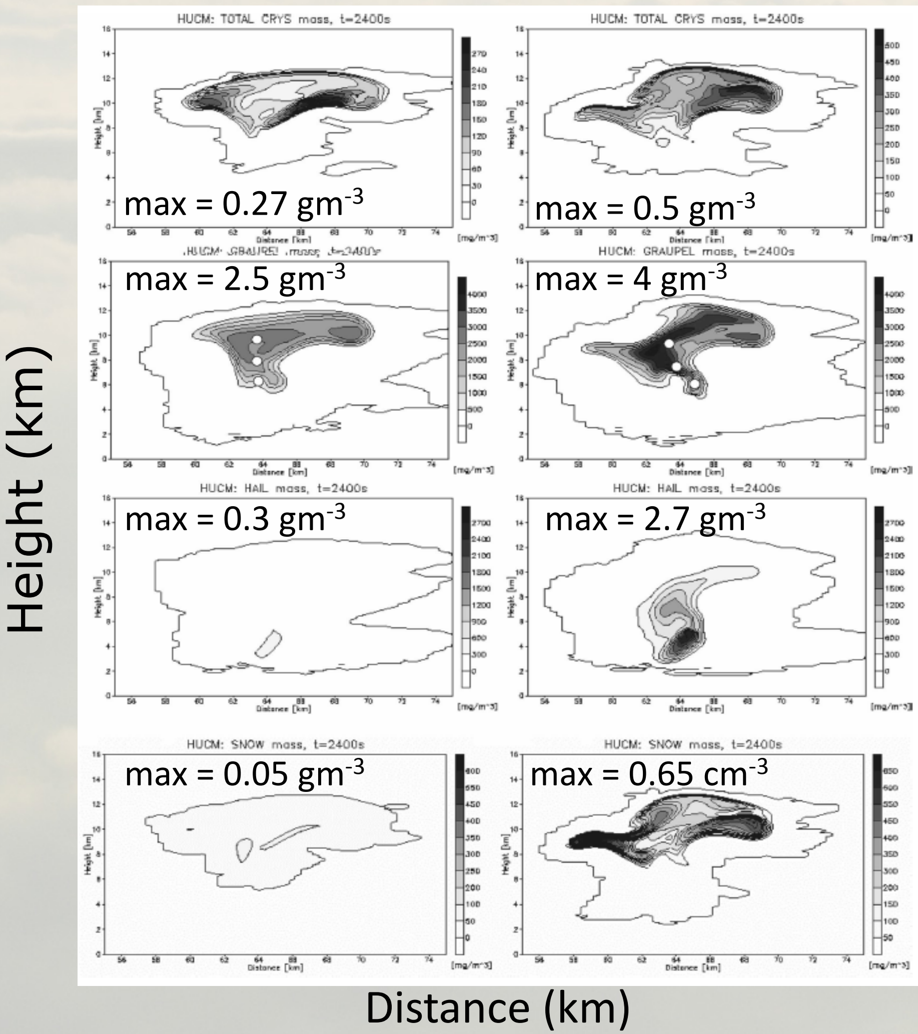
Droplet concentration

Cloud drop mass

Rain drop mass

Results: Microphysical structure of the green-ocean and smoky clouds

Green ocean (GO) clouds | **Smoky (S) Clouds** | t= 40min



Mass of Crystals

Graupel mass

Hail mass

Snow mass

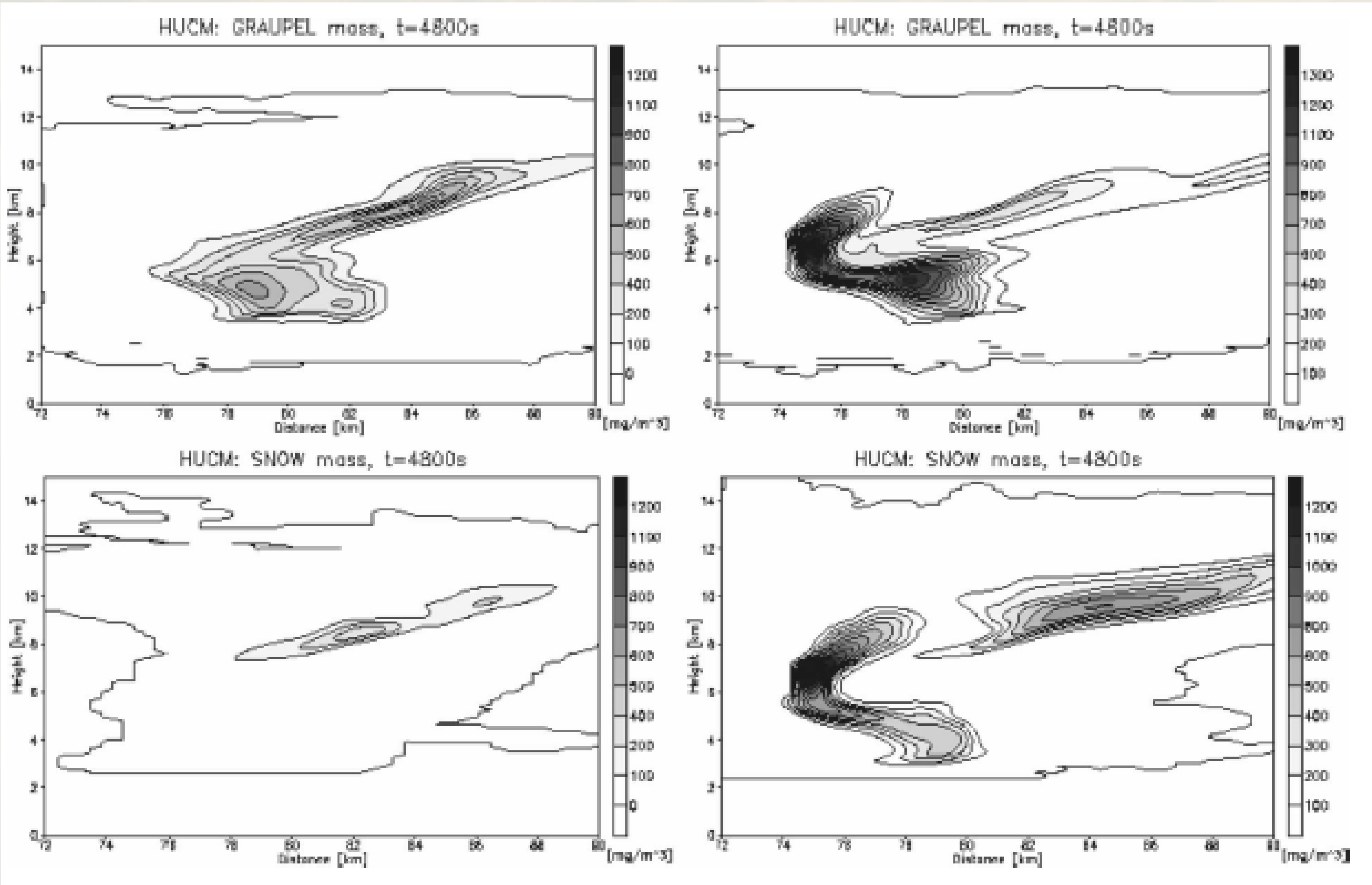
Results: Microphysical structure of the green-ocean and smoky clouds

Green ocean (GO) clouds

Smoky (S) Clouds

t= 80min

Height (km)



Graupel mass

Snow mass

Distance (km)

Results: Microphysical structure of pyroclouds

permanent heating rate (0.01 $^{\circ}Cs^{-1}$)

Pyroclouds(P1)

t= 35min

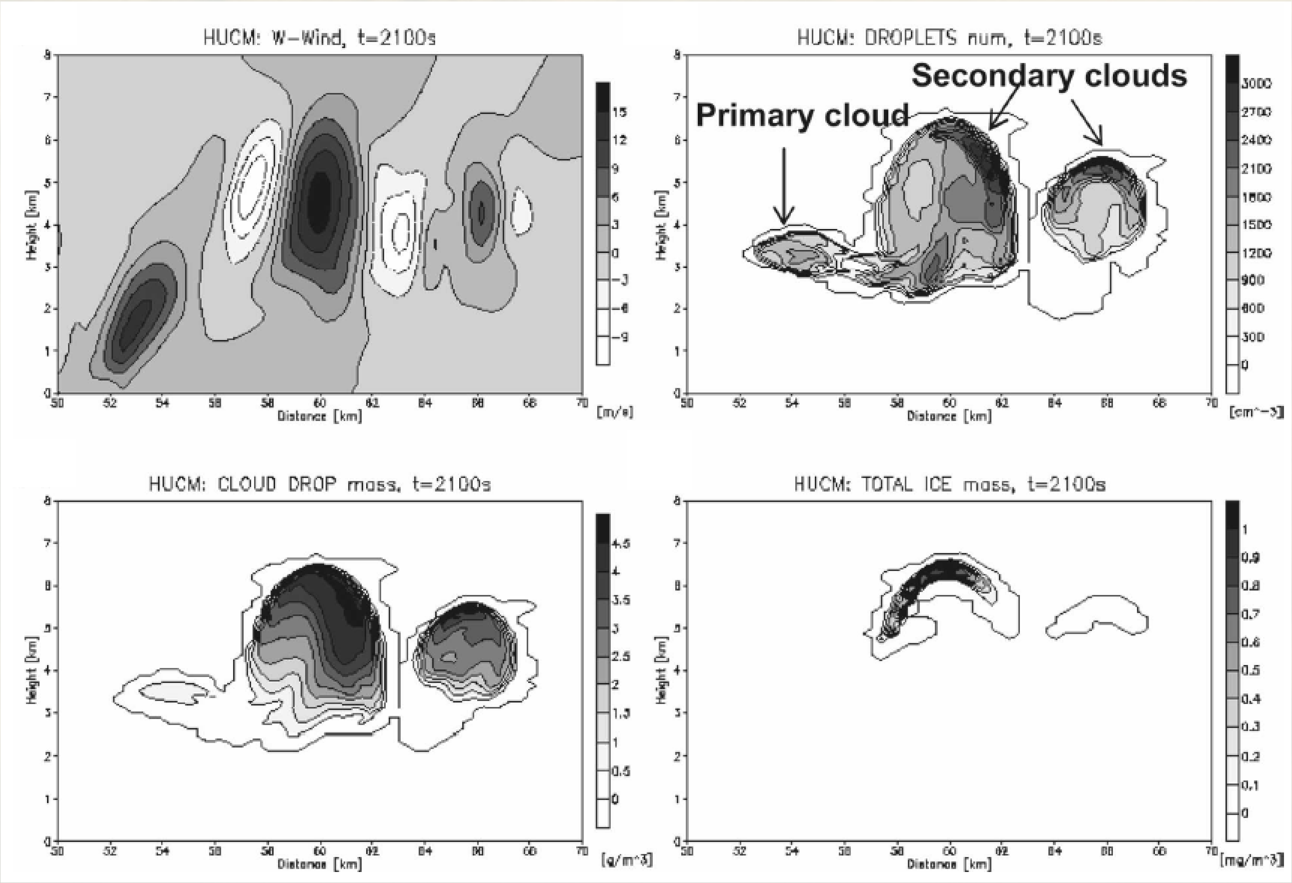
Vertical velocity

Droplet conc.

Cloud drop mass

Total ice mass

Height (km)



Distance (km)

Results: Microphysical structure of pyroclouds

Pyroclouds(P3)

permanent heating rate (0.075 Cs^{-1})

t= 40min

Droplet concentration

Graupel mass

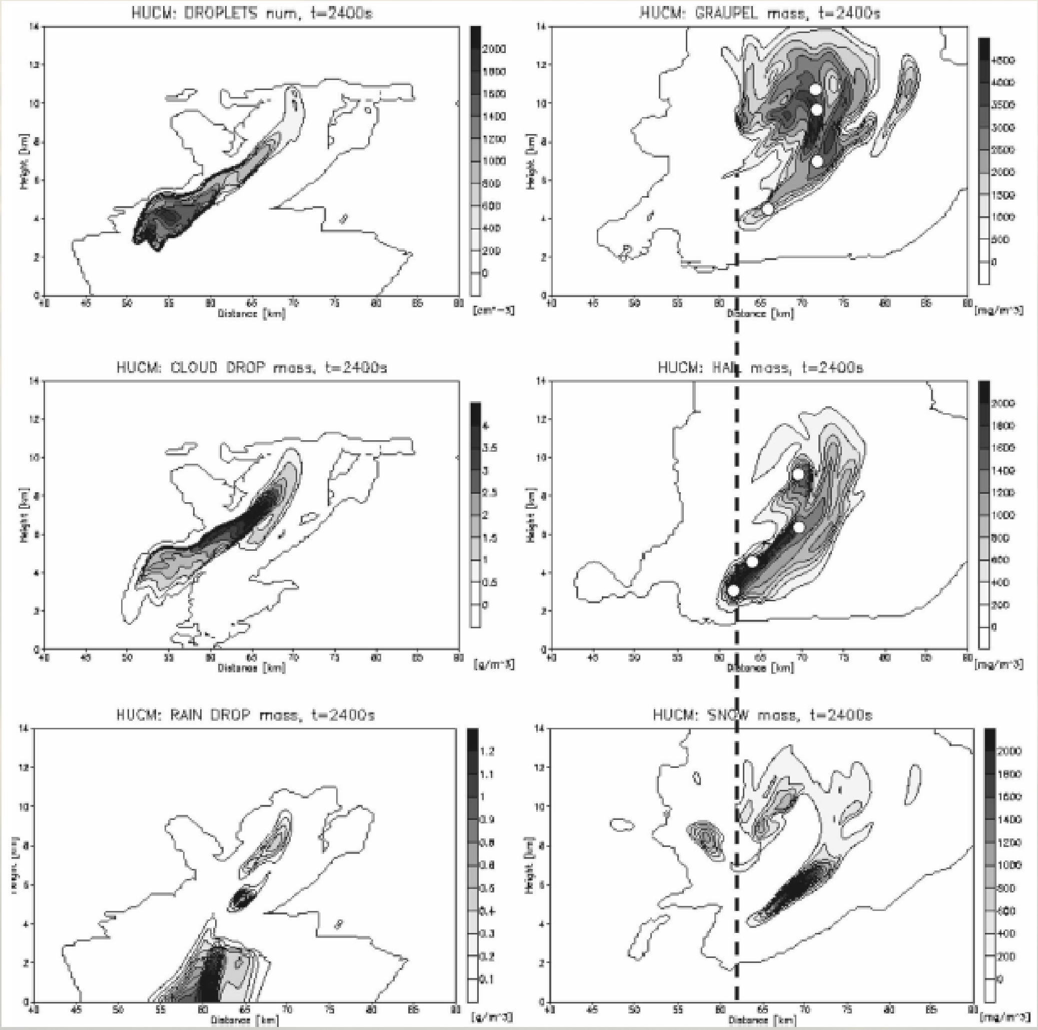
Cloud drop mass

Hail mass

Rain drop mass

Snow mass

Height (km)



Distance (km)

Results: Microphysical structure of pyroclouds

permanent heating rate (0.075 Cs^{-1})

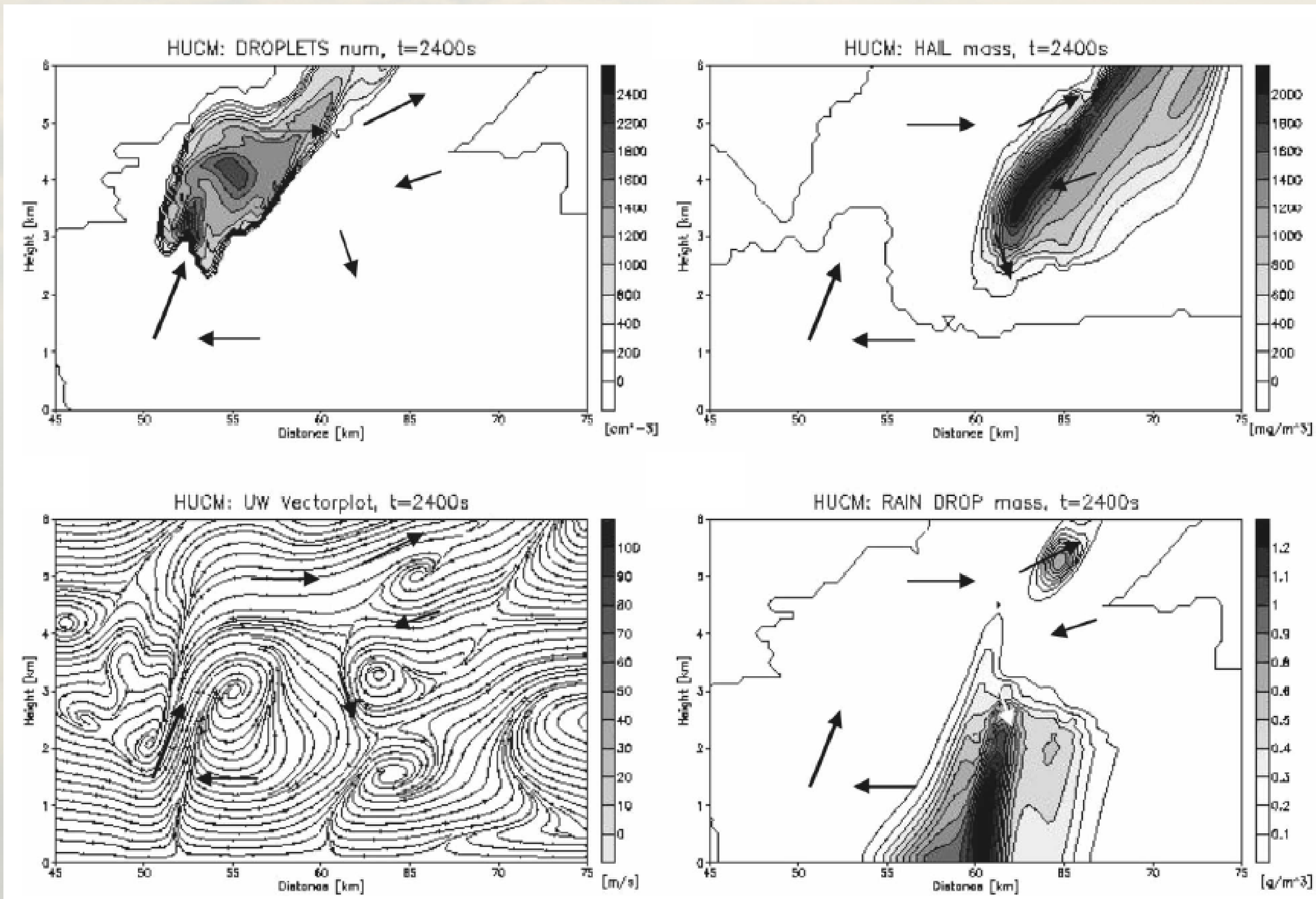
Pyroclouds(P3)

t= 40min

Droplet conc.

Hail mass

Height (km)



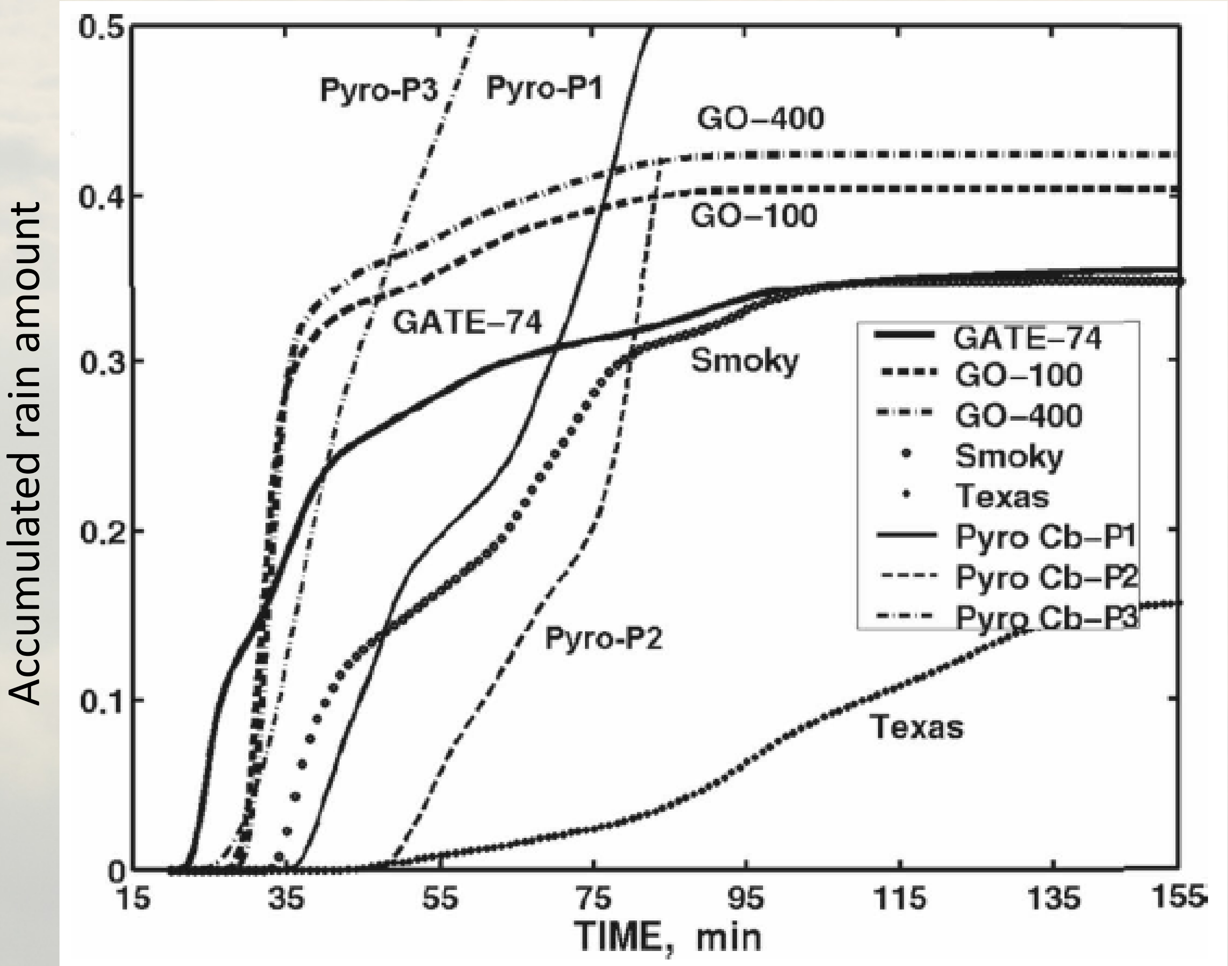
Stream-function

Rain drop mass

Distance (km)

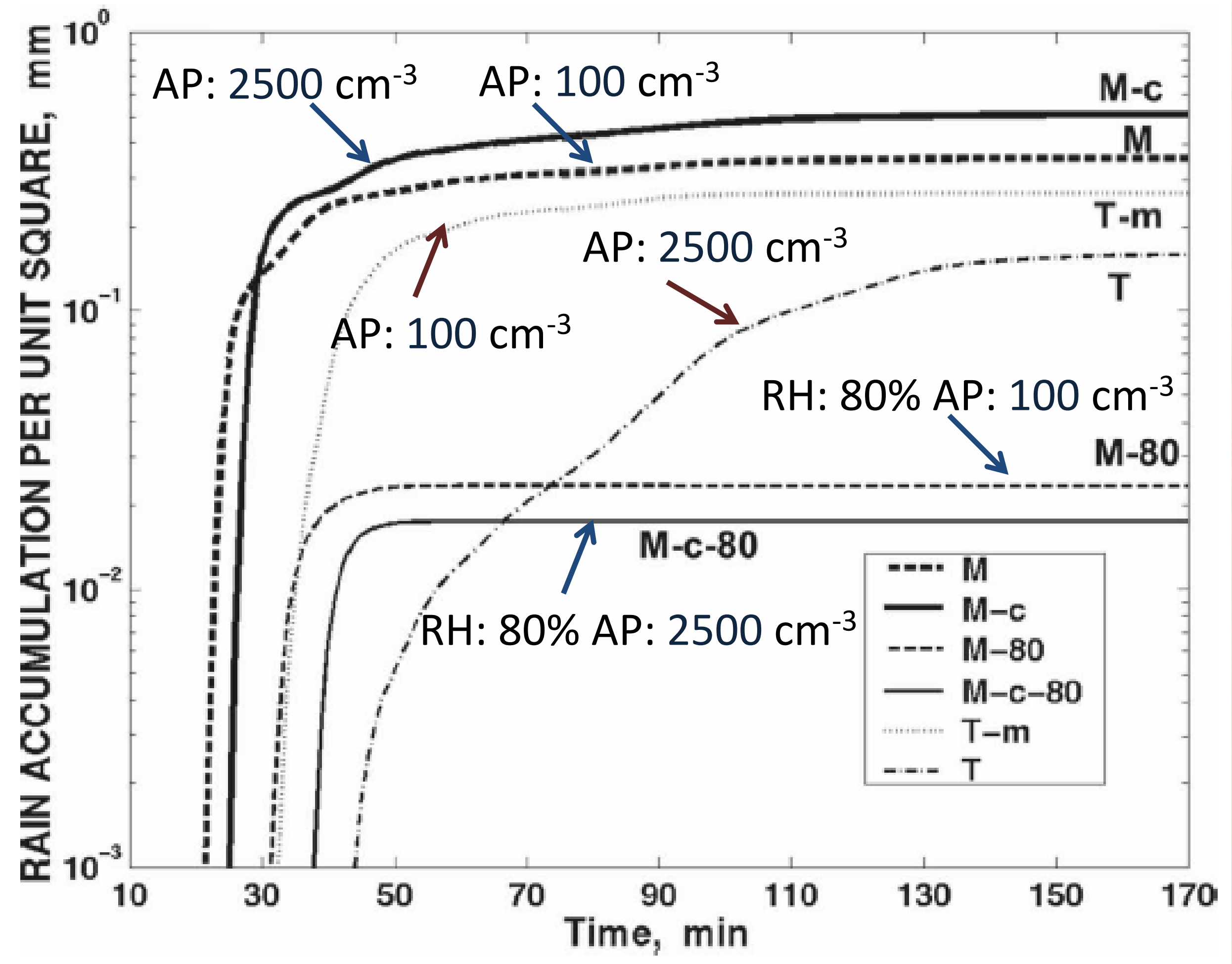
Aerosol effects on precipitation

Time dependence of the accumulated rain amount in all simulations



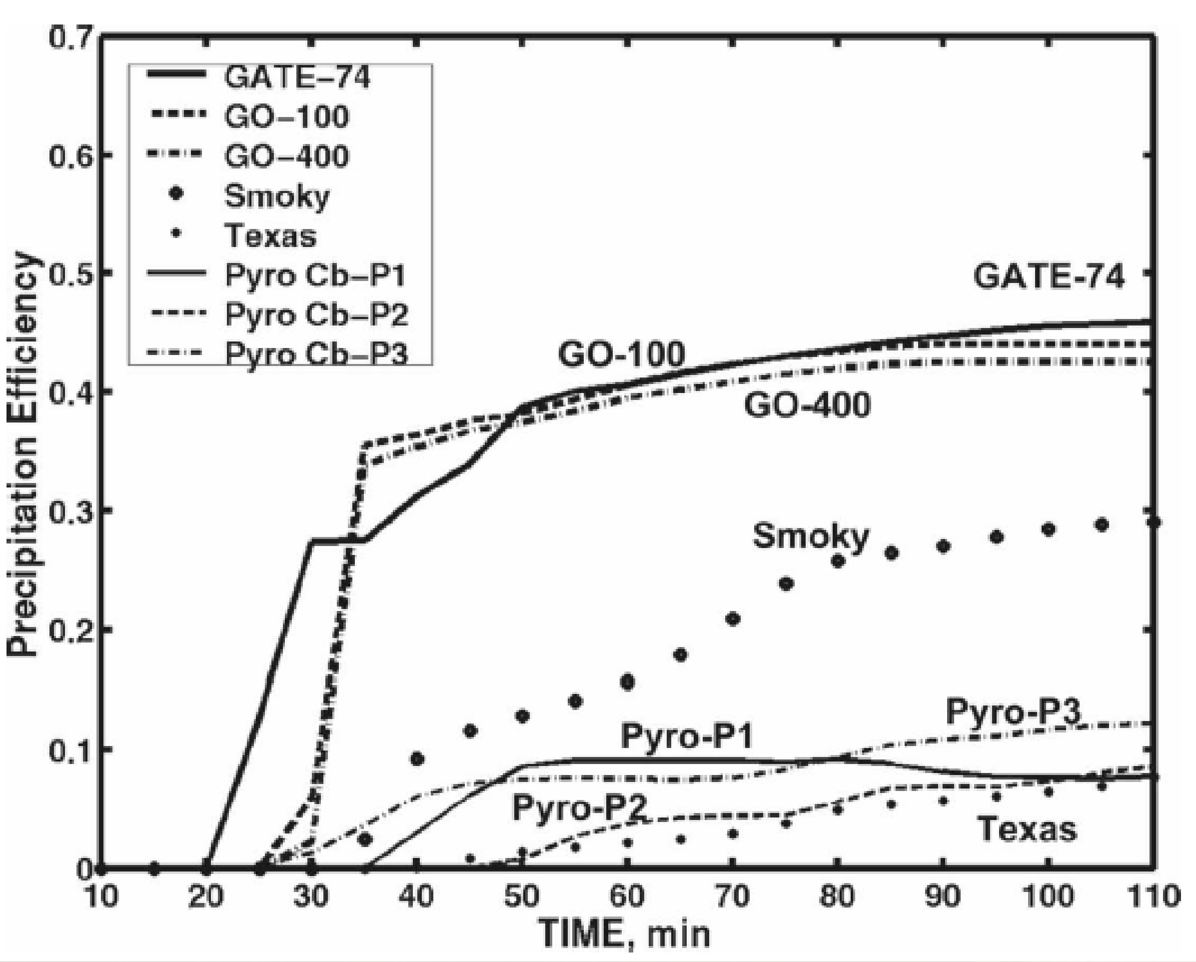
Aerosol effects on precipitation

Time dependence of the accumulated rain amount in M and T simulations (with sensitivity tests)



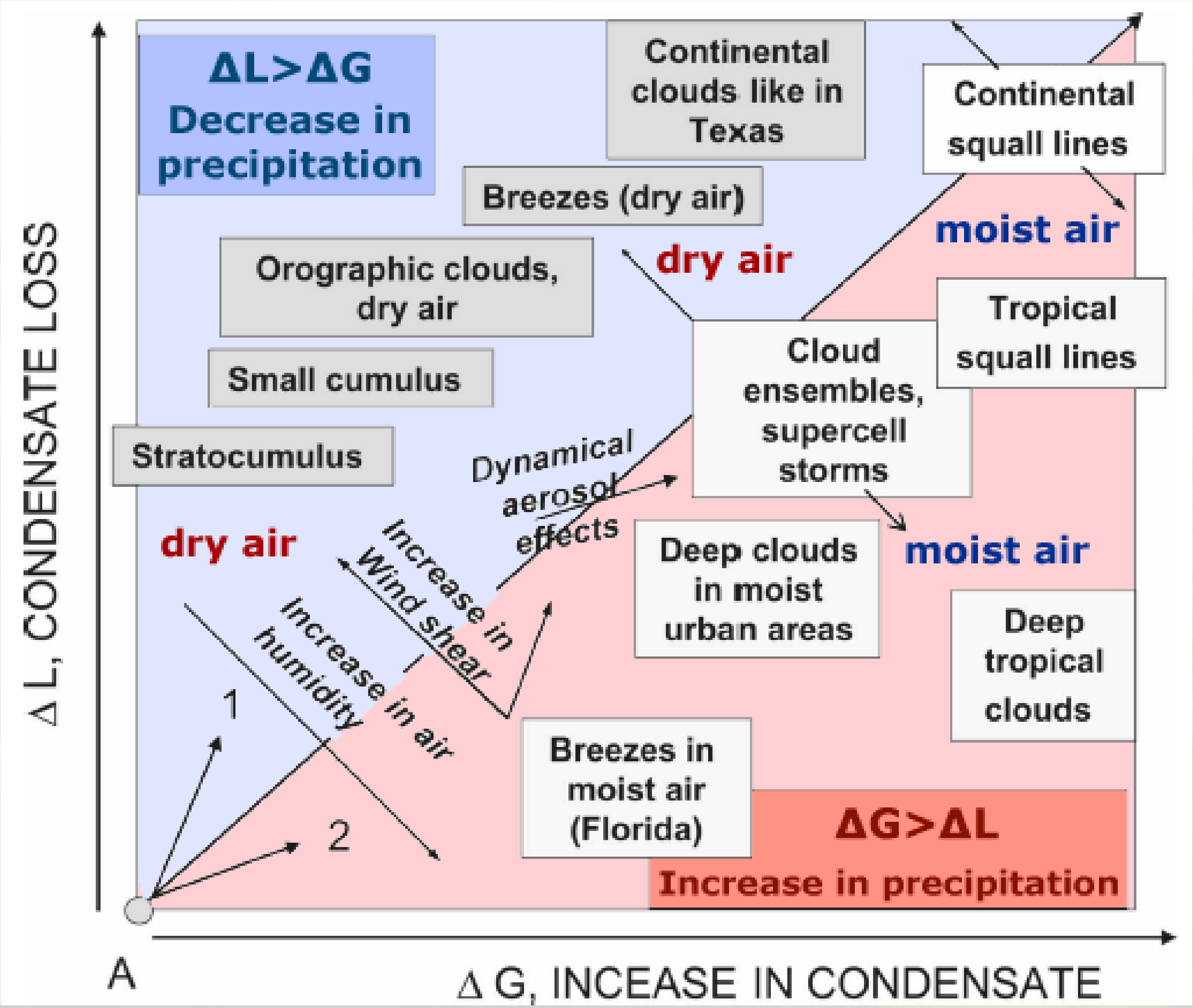
Aerosol effects on precipitation efficiency

Time dependence of the precipitation efficiency (PE) in different simulations.



PE = P / G

Aerosol effects on clouds and cloud systems of different types



$$\Delta P = \Delta G - \Delta L$$

Conclusions

- aerosols increase the contents of all types of ice (e.g. graupel, hail) in clouds
- precipitation in the polluted clouds (S, P clouds) forms with significant time delay
- high aerosol concentration inhibit the warm rain – precipitation is caused by melting particles
- if wind shear exists in polluted (P) clouds - formation of secondary clouds which precipitate (lower surface heating)
- high surface heating rate forms the hydrometeor recirculation where (P) clouds precipitate
- polluted clouds produce larger mass of condensate, but the condensate loss is also greater than in the clean air clouds

Conclusions

- relative humidity determines the sign of the precipitation response to aerosols:
  - dry air – aerosol induced loss is greater than the condensate generation – less precipitation
  - moist air – aerosol induced condensate generation is greater than the loss – more precipitation
- wind shear and atmospheric instability also affect generation and loss of the condensate (precipitation)
- this classification scheme concerns only the cloud systems with a high (>4km) freezing level

Conclusions

Important consequences

- aerosols can also influence the dynamic of mesoscale systems (tropical cyclones)

- aerosols can redistribute precipitation depending on the local thermodynamic conditions