

# Numerical simulations of microphysical processes in pyro-convective clouds: **Activation of aerosol particles**



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A. Seifert, M. Lawrence

**univer  
sität  
mainz**



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# OUTLINE

- Motivation
- Model evaluation
- Results
- Conclusions & Outlook

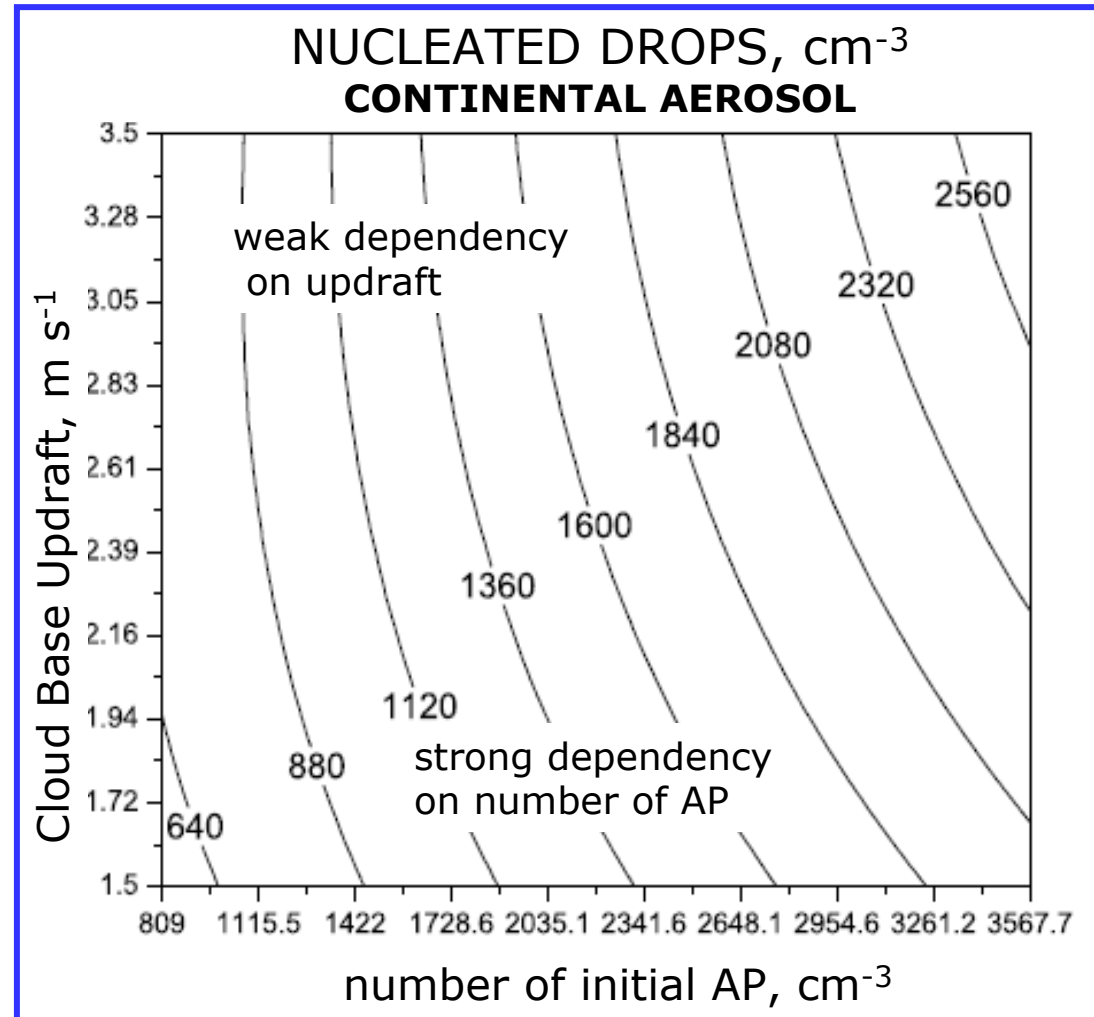
# Example of pyro-clouds

- **Pyrocumulus:**  
A cumulus cloud formed by a rising thermal from a fire, or enhanced by buoyant plume emissions from an industrial combustion process.
- **Extreme dynamical and micro-physical structure.**



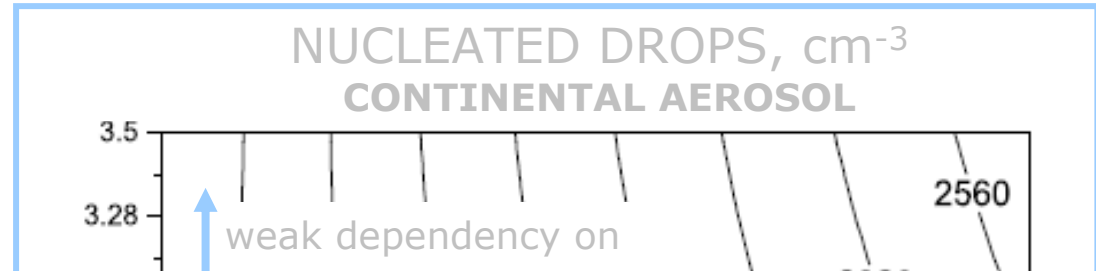
# Study by Segal & Khain, 2006, JGR

- Cloud updraft velocity up to  $3.5 \text{ m s}^{-1}$
- Initial aerosol number up to  $3500 \text{ cm}^{-3}$



## Study by Segal & Khain, 2006, JGR

- Cloud updraft velocity up to  $3.5 \text{ m s}^{-1}$
- Aerosol number up to  $3500 \text{ cm}^{-3}$



Not easily applicable to **pyro-convective** conditions because of:

- High number concentration (up to  $400,000 \text{ cm}^{-3}$ , e.g: Chuang et al., 1992  
Andreae et al., 2004)
- High updraft velocity (up to  $20 \text{ m s}^{-1}$ , e.g: Chuang et al., 1992,  
Trentmann et al., 2006)
- Different chemical composition of biomass burning aerosol

### Open question:

**Dependencies for higher aerosol concentrations and updraft velocities (pyro-conditions)?**

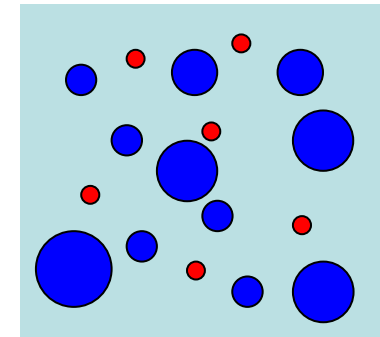
# OUTLINE

- Motivation
- Model evaluation
  - Parcel Model
  - Evaluation of new Köhler model
  - Evaluation with reference study
- Results
- Conclusions & Outlook

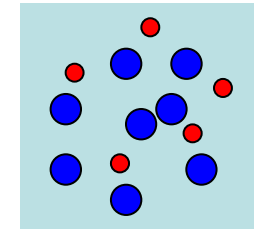
## Parcel model (Simmel et al., 2002)

- detailed spectral microphysics of mixed-phase clouds
- 264 bins: 1 nm to 3.5 mm
- Time step: 0.01 s
- Constant updraft velocity
- aerosol activation & droplet growth (condensation)
- No coalescence, no entrainment

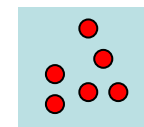
**STOP** at  $0.2 \text{ g kg}^{-1}$  LWC



cloud droplets, AP



aerosol particles (AP)



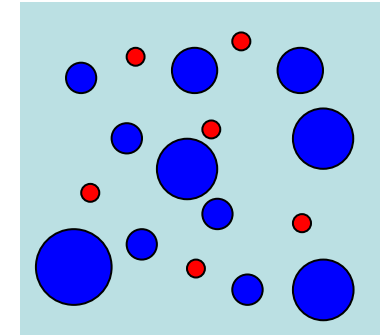
**START** at 95 % rh

Constant updraft velocity

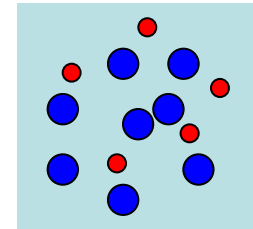
## Parcel model (Simmel et al., 2002)

- detailed spectral microphysics of mixed-phase clouds
- 264 bins: 1 nm to 3.5 mm
- Time step: 0.01 s
- Constant updraft velocity
- aerosol activation & droplet growth (condensation)
- No coalescence, no entrainment
- 2 Köhler models of aerosol activation:
  - a) Osmotic coefficient ( $\Phi$ ) model: concentration-dependent  $\Phi$  (mostly for NaCl or AS)
  - b) Hygroscopicity parameter ( $\kappa$ ) model: concentration-independent  $\kappa$  (Petters & Kreidenweis, 2007)

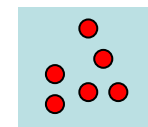
**STOP** at  $0.2 \text{ g kg}^{-1}$  LWC



cloud droplets, AP



aerosol particles (AP)



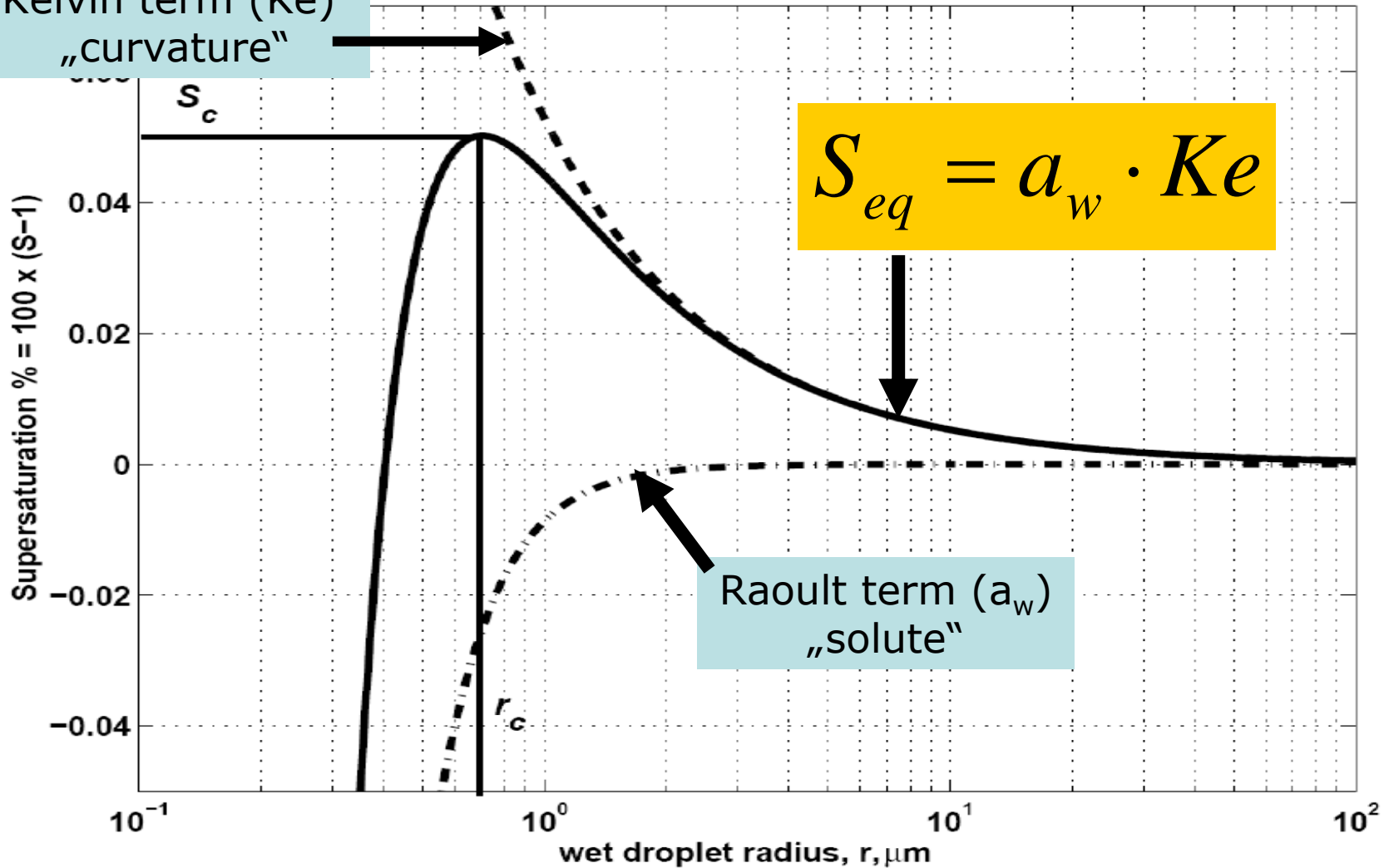
**START** at 95 % rh

Constant updraft velocity

# Köhler theory

Drop growth equation:  $\frac{dx}{dt} \propto S_{air} - S_{eq}$

Kelvin term ( $Ke$ )  
„curvature“



$S_{eq} = a_w \cdot Ke$

Raoult term ( $a_w$ )  
„solute“

## Raoult-term

„ osmotic coefficient ( $\Phi$ ) model “

$$a_w = \exp(-v_s \Phi_s \mu_s M_w)$$

$v_s$ : number of ions per molecule, NaCl=2, AS=3

$\Phi_s$ : osmotic coefficient

$\mu_s$ : molality

$M_w$ : molar mass of water

**Problem:** Detailed information of chemical composition required  
(e.g:  $v_s$  and  $\Phi_s$ )

=> Need for a single parameter description for atmospheric aerosols:

## Raoult-term

„ hygroscopicity parameter ( $\kappa$ ) model “\*

$$a_w = \left( 1 + \kappa \frac{V_s}{V_w} \right)^{-1}$$

$\kappa$ : hygroscopicity factor

$V_s$ : volume of dry particulate matter

$V_w$ : volume of the water

## Raoult-term

„ hygroscopicity parameter ( $\kappa$ ) model “\*

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$\kappa$ : hygroscopicity factor

$V_s$ : volume of dry particulate matter

$V_w$ : volume of the water

$\kappa$  can be estimated through measurements:

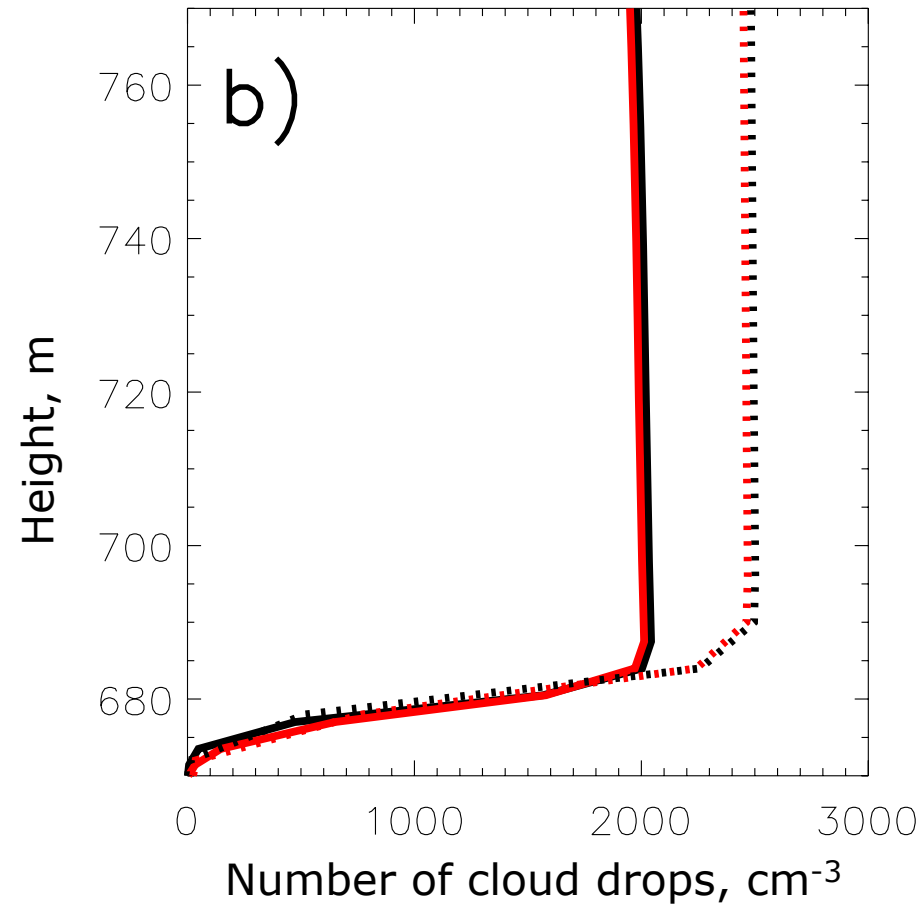
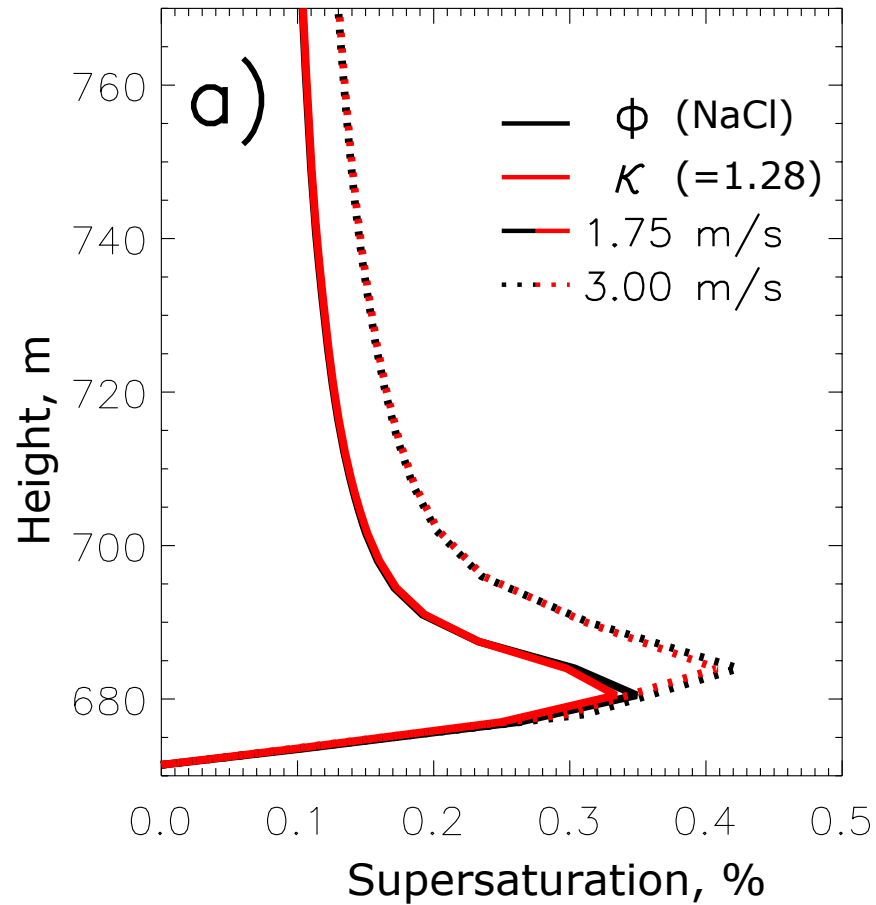
$\kappa = 1.28$  for NaCl

$\kappa = 0.3 \pm 0.1$  for continental

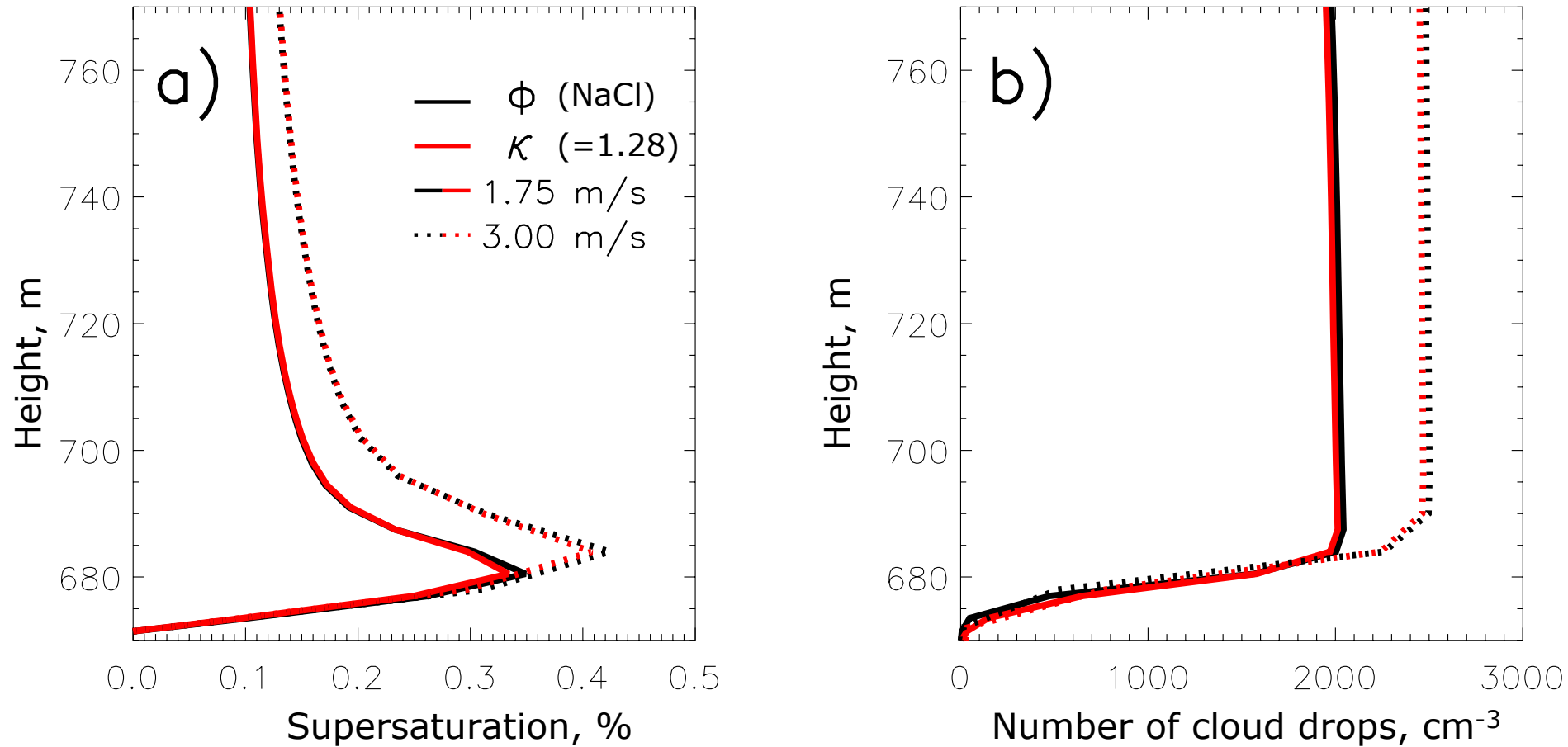
$\kappa = 0.7 \pm 0.2$  for marine

$\kappa = 0.01 - 0.55$  for biomass burning aerosol (Andreae & Rosenfeld, 2008)

# Comparison between different Köhler models for 3000 AP/cm<sup>3</sup>



# Comparison between different Köhler models for 3000 AP/cm<sup>3</sup>



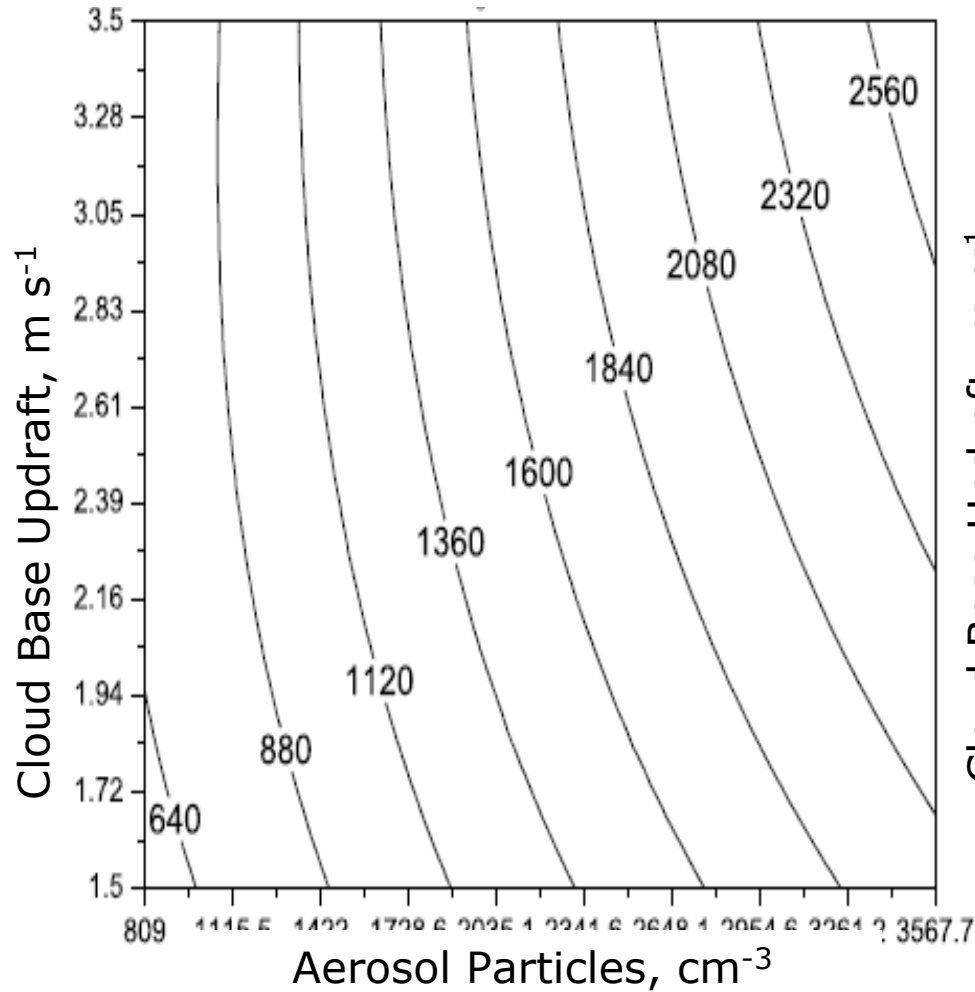
**Very good agreement between the Köhler models!**

The following calculations use the single hygroscopic parameter  $\kappa$

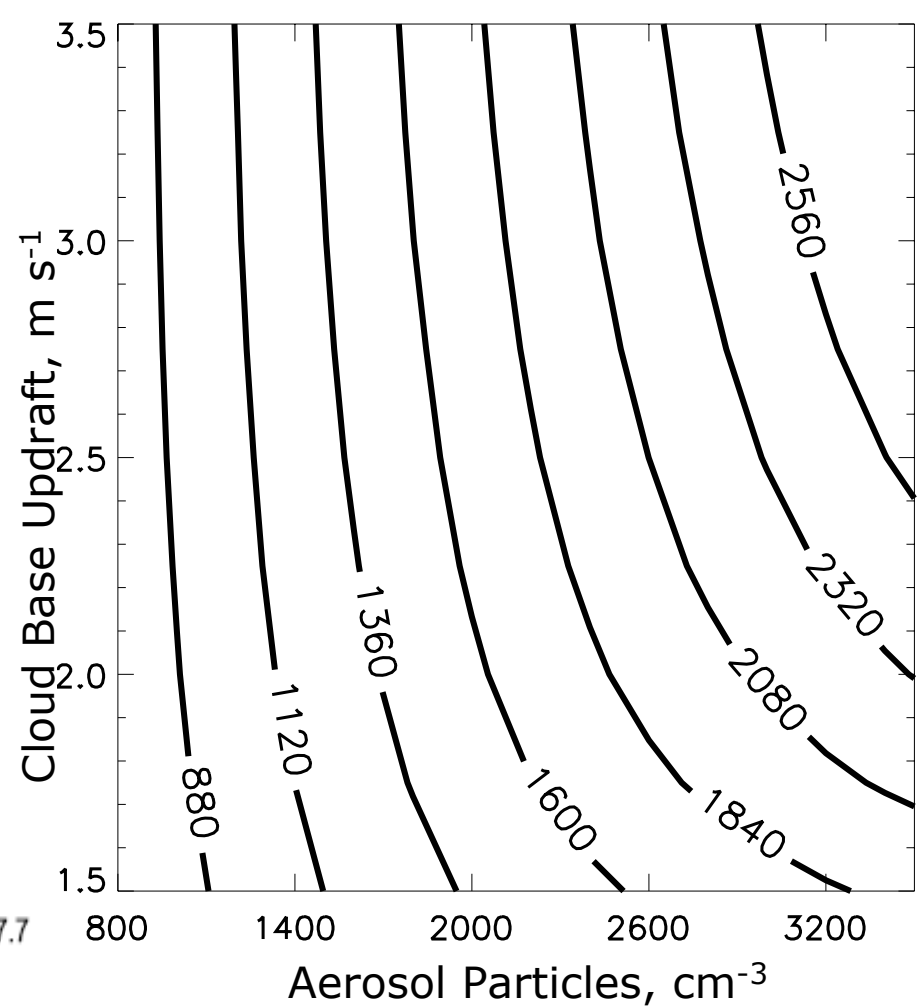
# Evaluation with Segal and Khain study

$D_m = 60$  nm,  $\sigma = 1.35$ , NaCl ( $\kappa = 1.28$ )

Reference (Segal & Khain)



NUCLEATED DROPLETS, cm<sup>-3</sup>

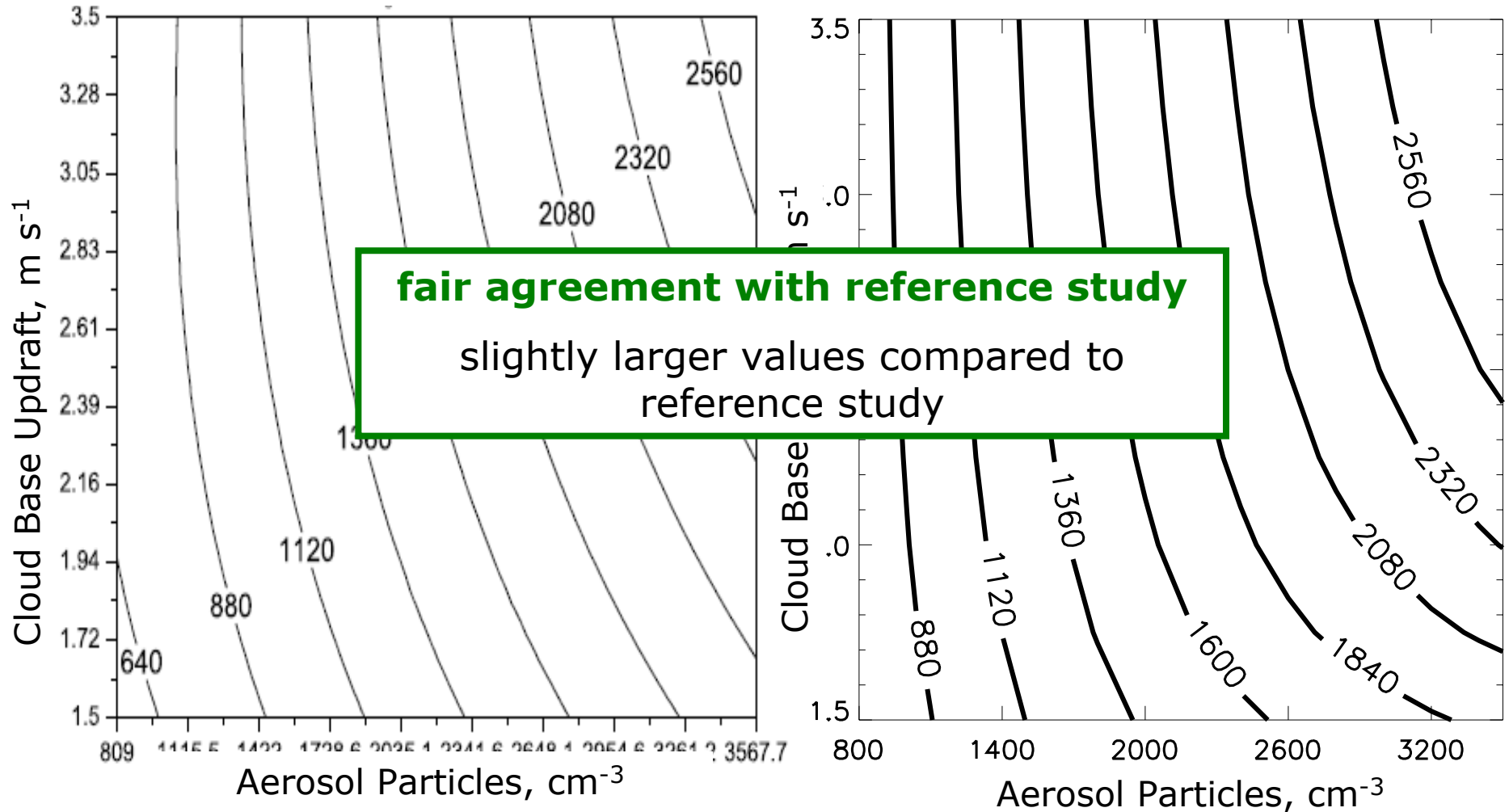


# Evaluation with Segal and Khain study

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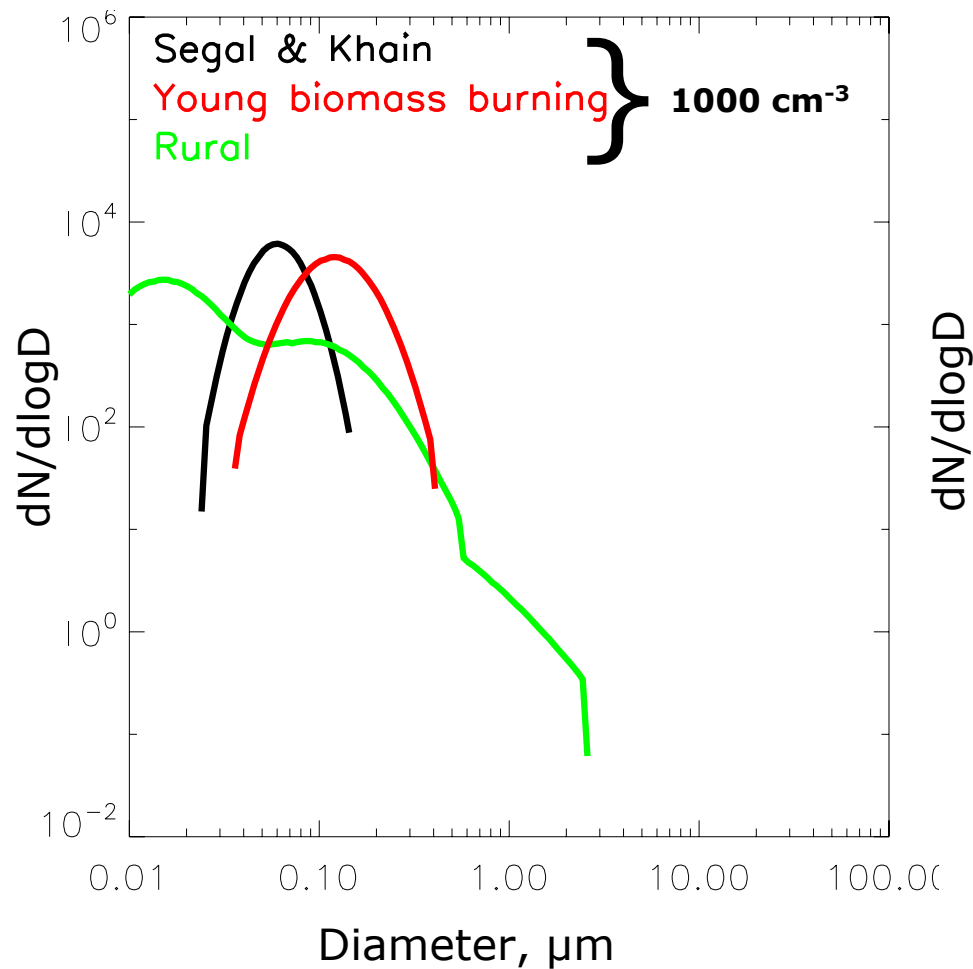
**fair agreement with reference study**  
slightly larger values compared to reference study

# OUTLINE

- Motivation
- Model evaluation
- **Results**
  - Cloud drop dependency on:
    - Aerosol distribution
    - Updraft and initial AP concentration
    - Pyro-convective conditions
- Conclusions & Outlook

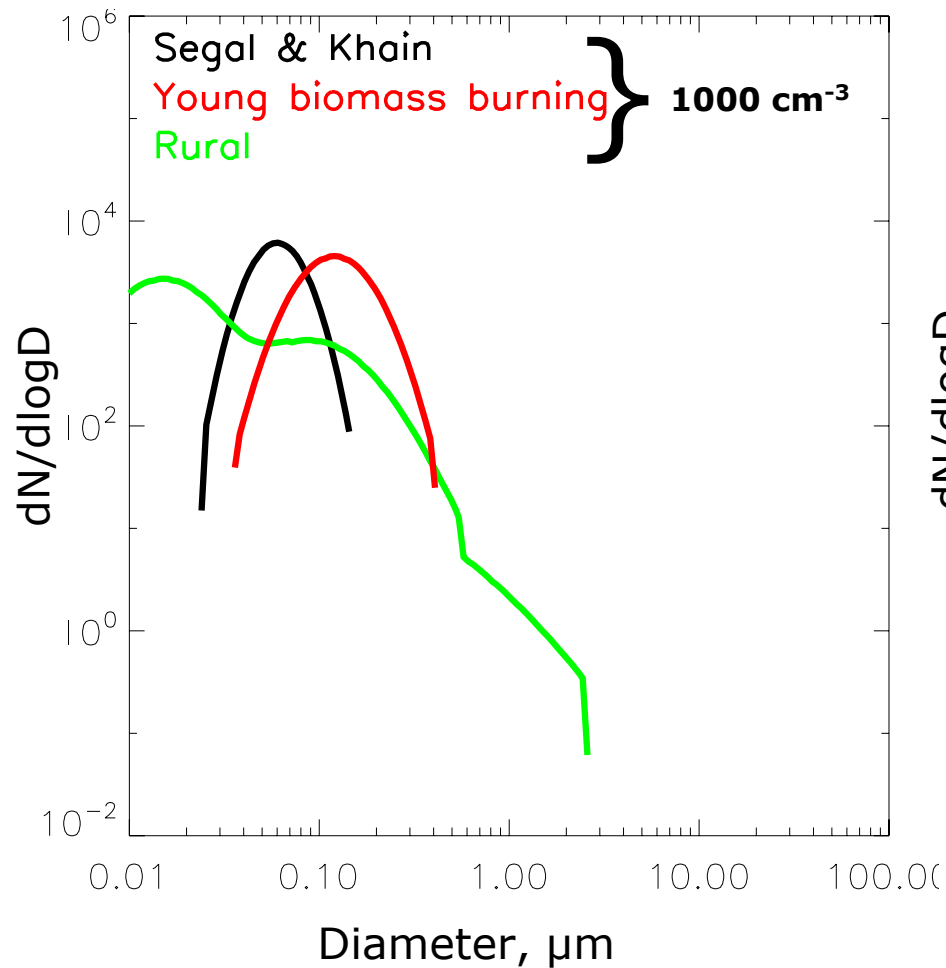
# Influence of different size distributions with $\kappa = 0.3$ , $3 \text{ m s}^{-1}$ and $1000 \text{ AP cm}^{-3}$

## Dry aerosol distribution

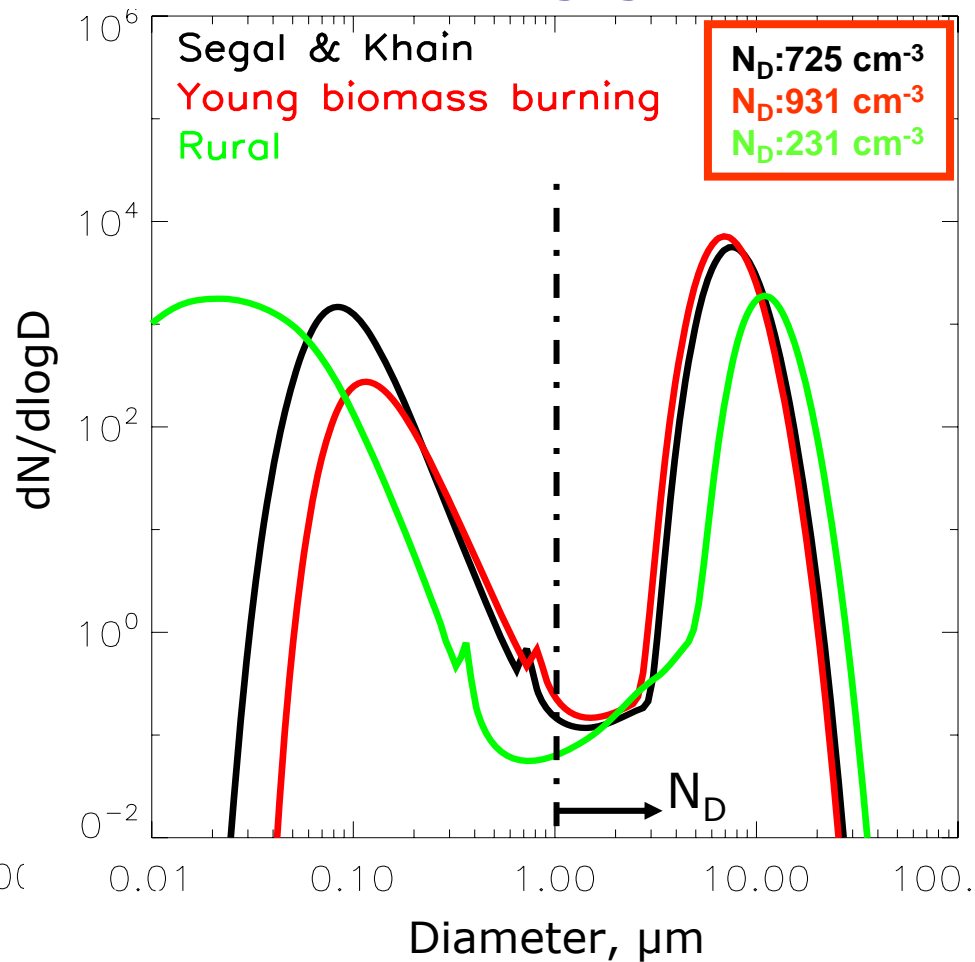


# Influence of different size distributions with $\kappa = 0.3$ , $3 \text{ m s}^{-1}$ and $1000 \text{ AP cm}^{-3}$

**Dry aerosol distribution**

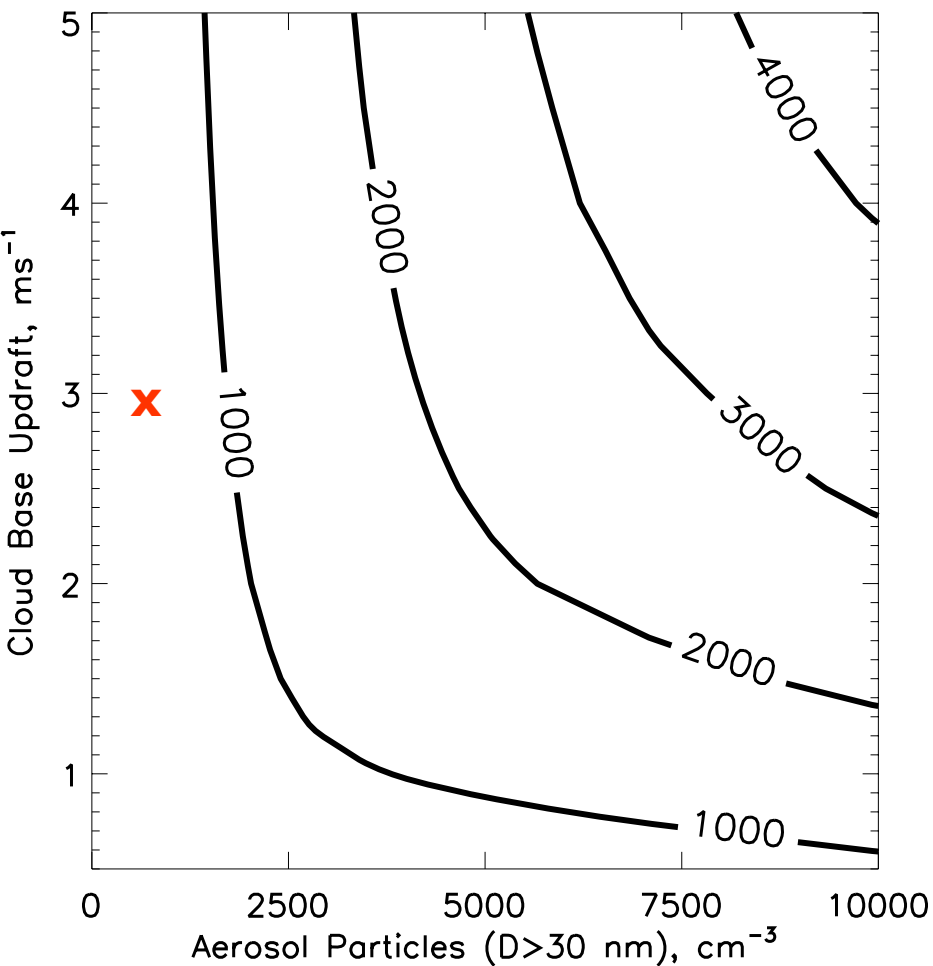


**Final size distribution  
at  $0.2 \text{ g kg}^{-1}$  LWC**

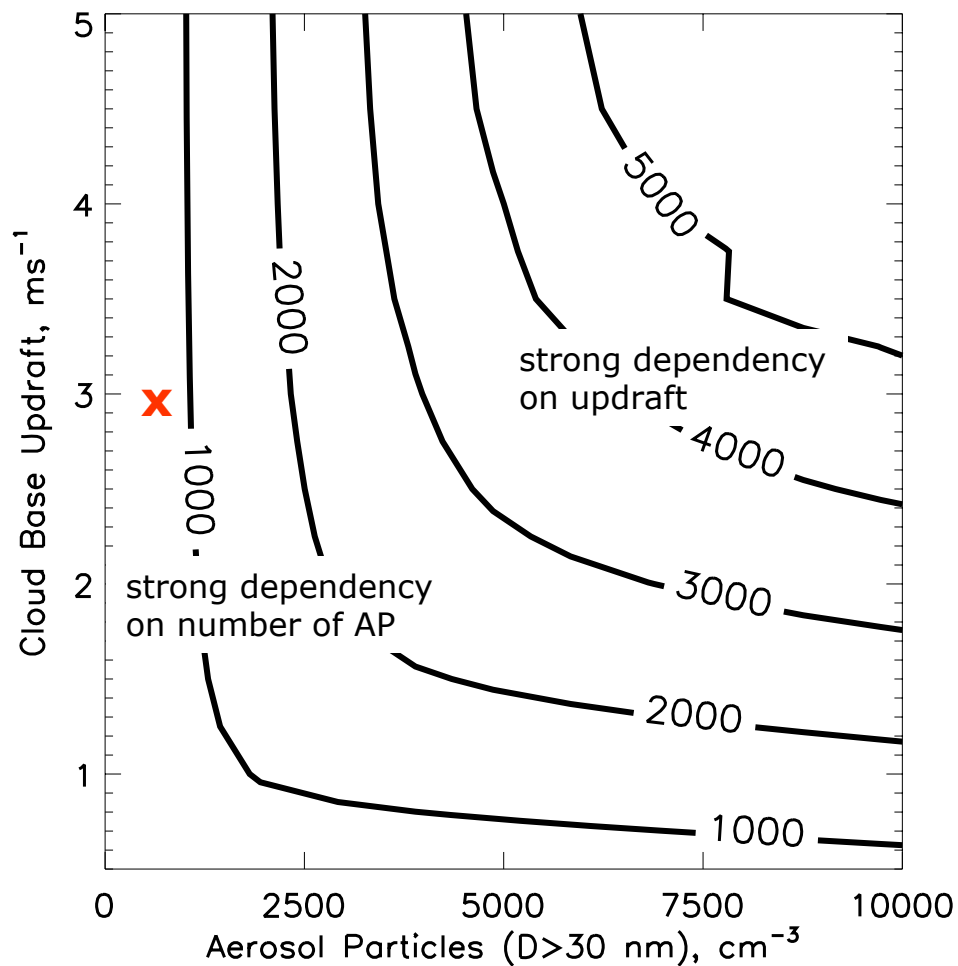


# Cloud droplet dependency for up to 10 000 AP cm<sup>-3</sup> and 5 m s<sup>-1</sup>

**Rural background aerosol**



**Young biomass burning aerosol**



# Cloud droplet dependency for up to 10 000 AP $\text{cm}^{-3}$ and 5 $\text{m s}^{-1}$

Young biomass burning aerosol

**Next step:**

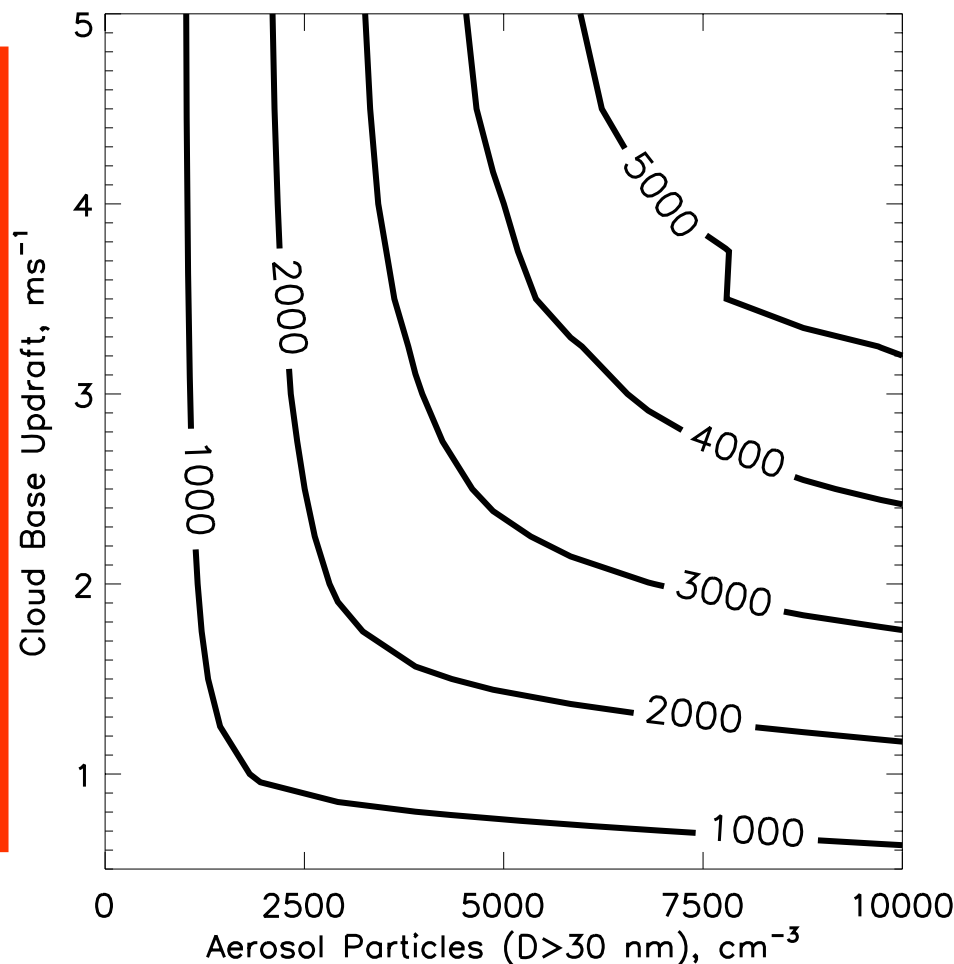
**Expansion to**

**pyro-convective  
conditions**

**(100,000  $\text{cm}^{-3}$  and 20  $\text{m s}^{-1}$ )**

**for**

**Young biomass burning  
aerosol**

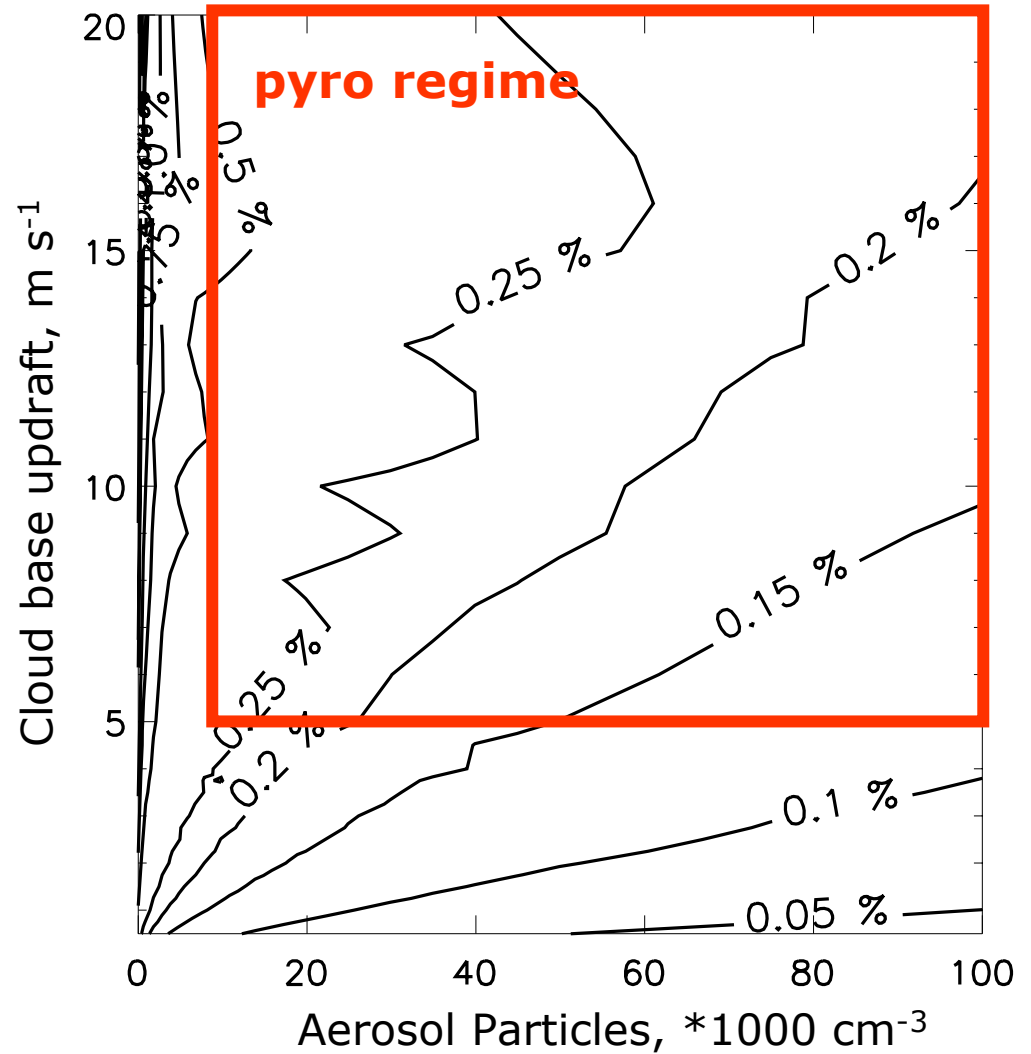
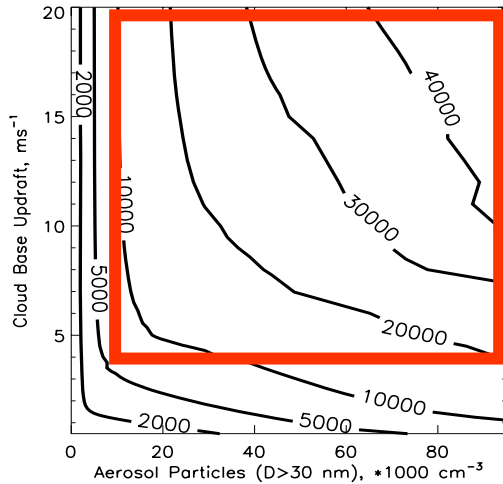


# Expansion of young biomass burning aerosol distribution to pyro-convective conditions (up to $100,000 \text{ cm}^{-3}$ and $20 \text{ m s}^{-1}$ )

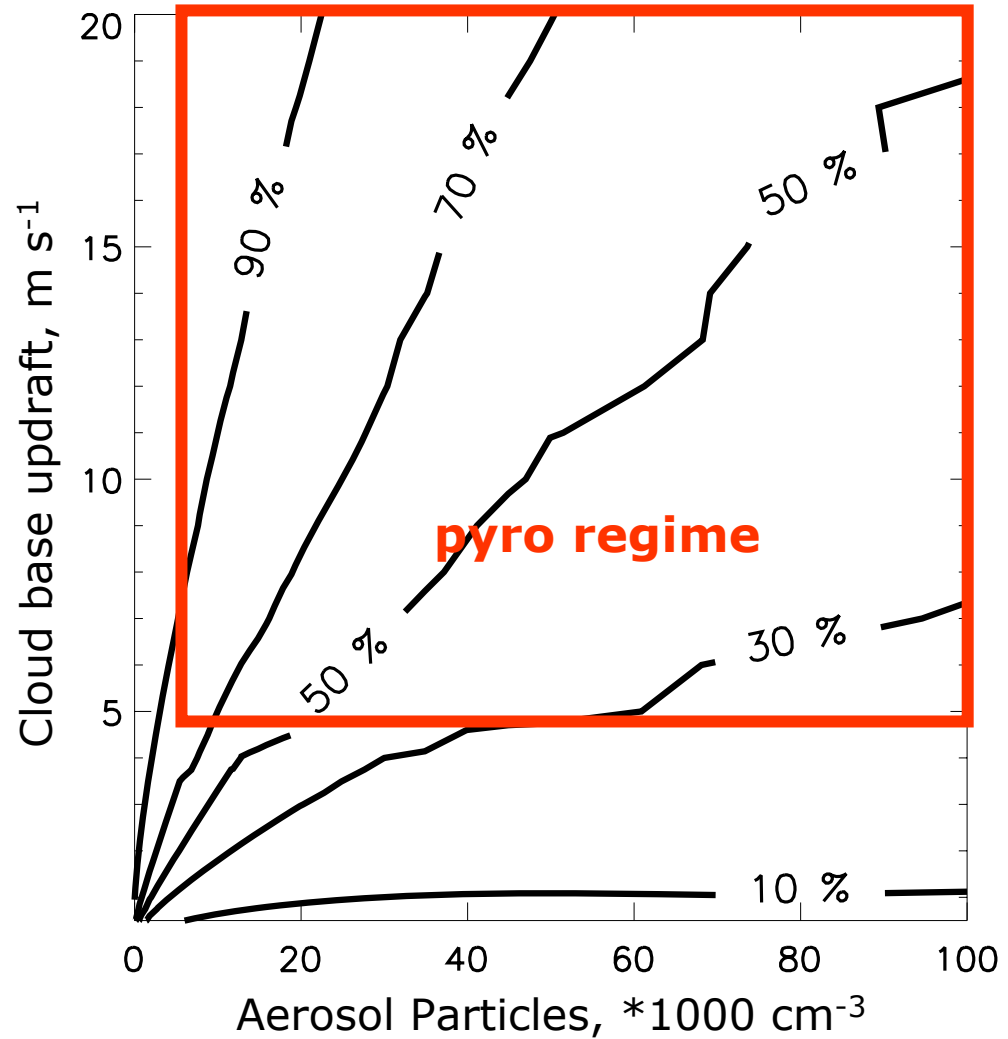
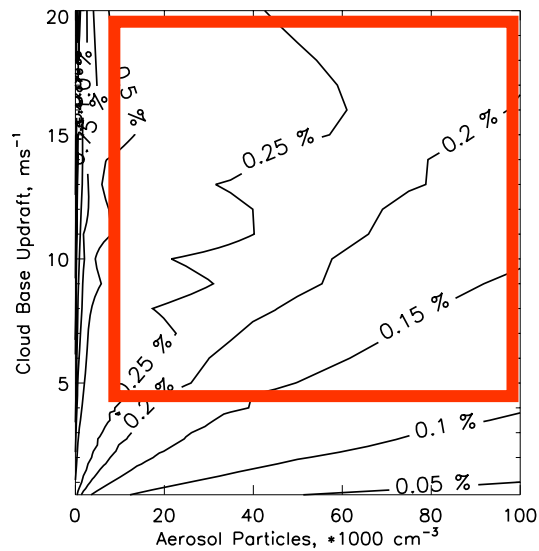
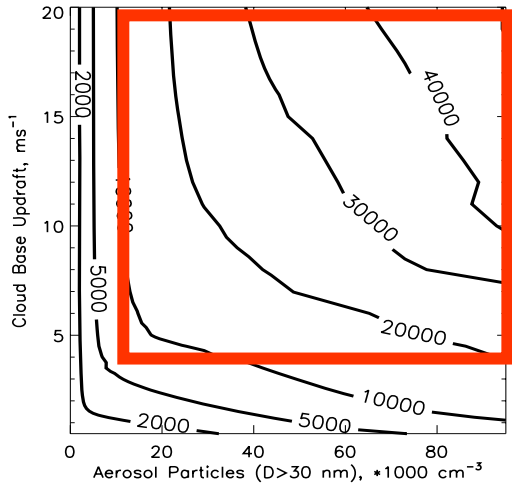


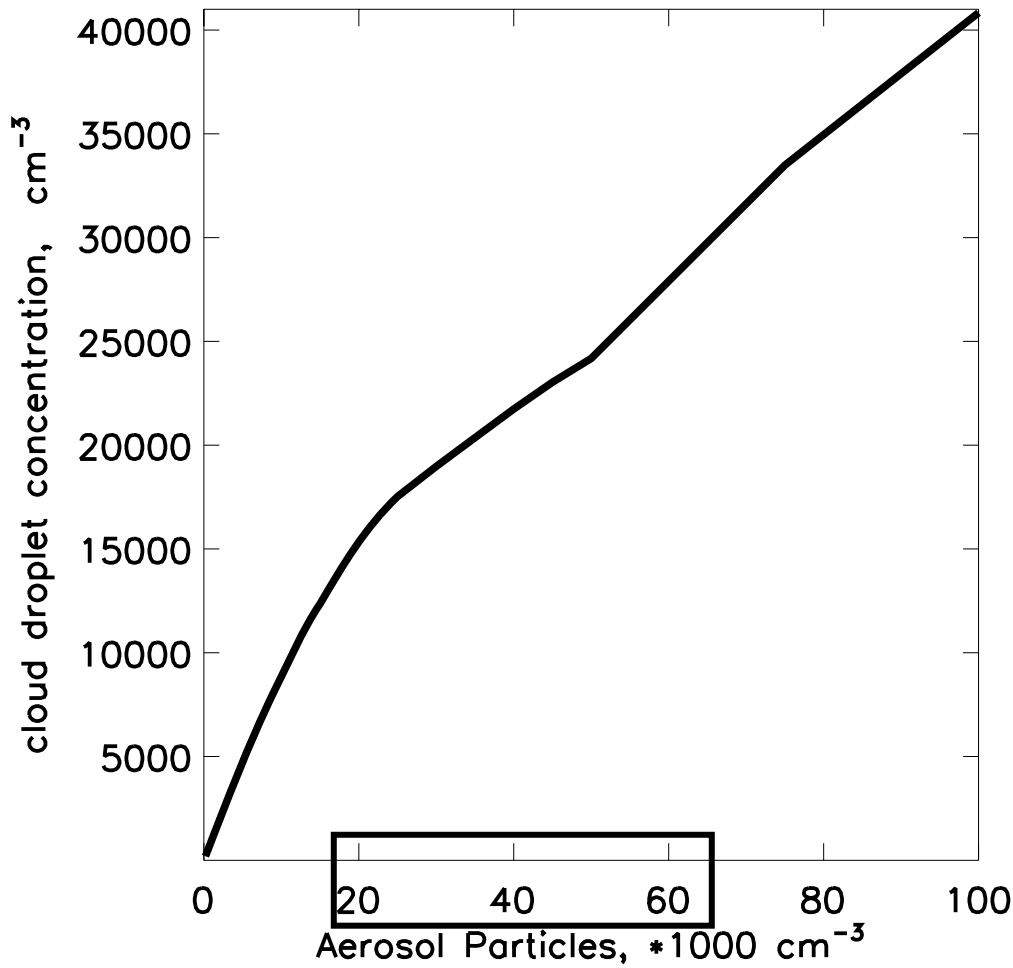
Result of 2000  
model runs

# Maximum supersaturation for young biomass burning aerosol distribution



# Percentage of activated aerosol particles for young biomass burning aerosol distribution

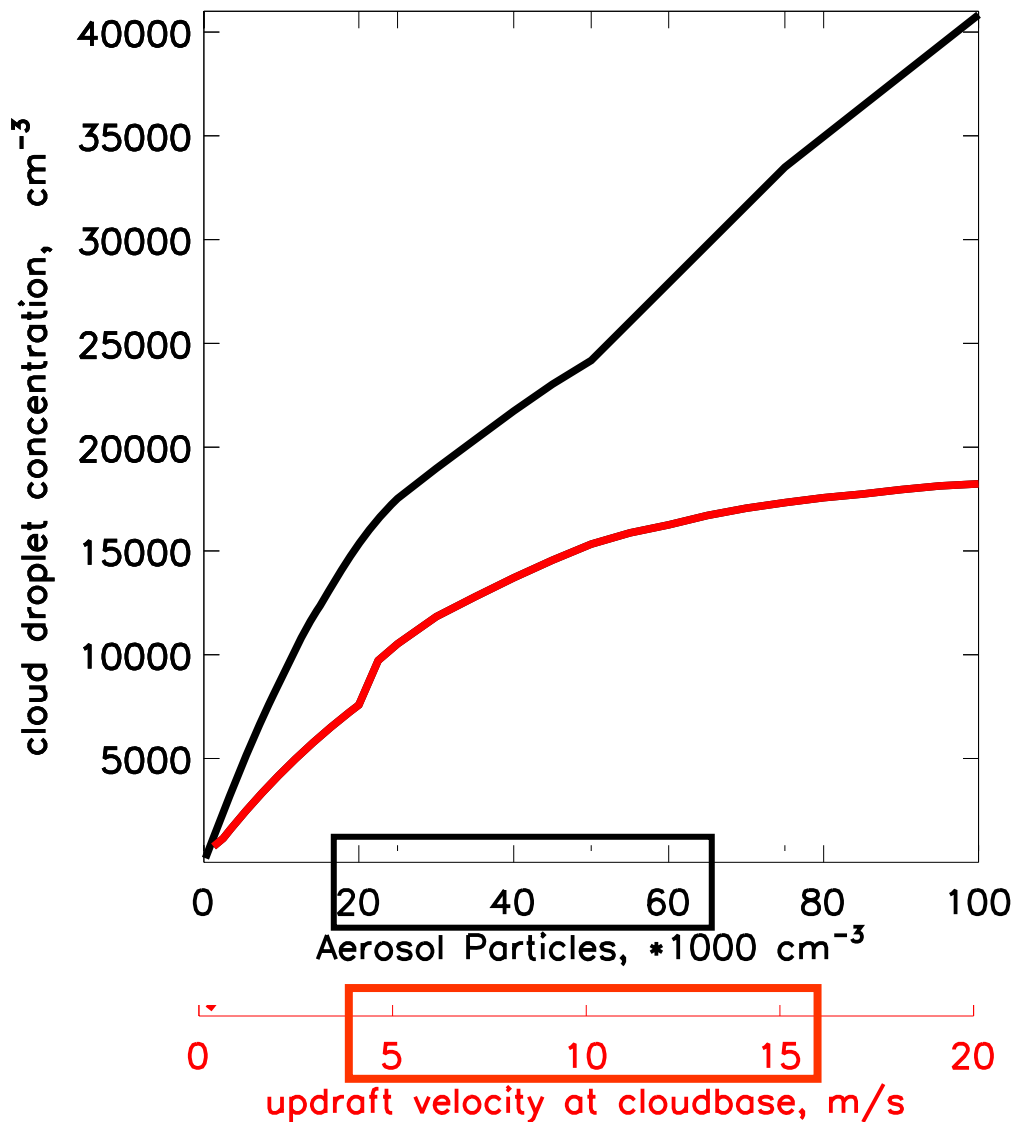




**Influence of:**

**aerosol  
concentration**  
(for 10 m/s and  $\kappa = 0.3$ )

**on cloud droplet  
concentration**

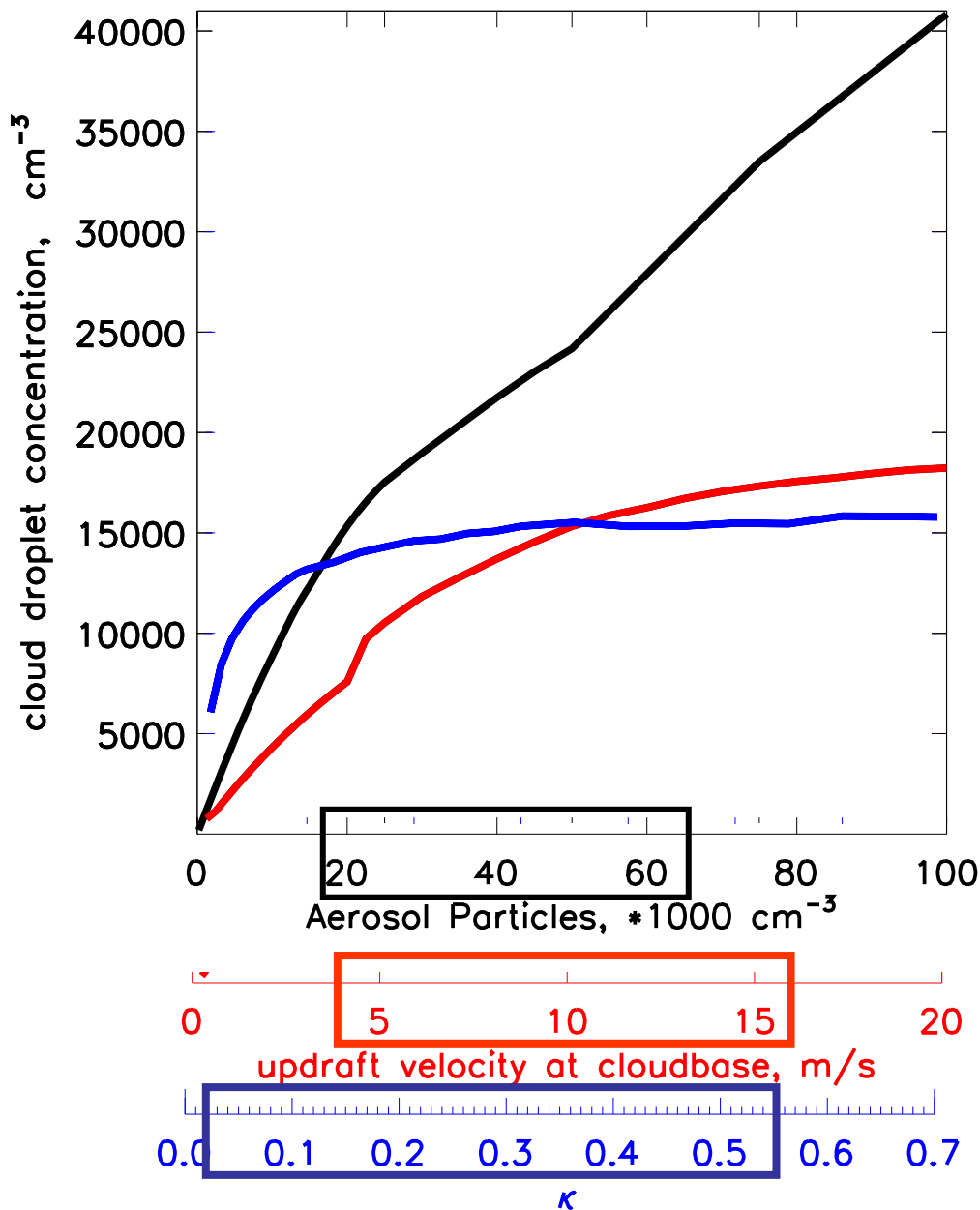


**Influence of:**

**aerosol concentration**  
 (for 10 m/s and  $\kappa = 0.3$ )

**updraft velocity**  
 (for 20000 cm<sup>-3</sup> and  $\kappa = 0.3$ )

**on cloud droplet concentration**



**Influence of:**

**aerosol concentration**  
(for 10 m/s and  $\kappa = 0.3$ )

**updraft velocity**  
(for 20000 cm<sup>-3</sup> and  $\kappa = 0.3$ )

**κ**  
(for 10 m/s and 20000 cm<sup>-3</sup>)

**on cloud droplet concentration**

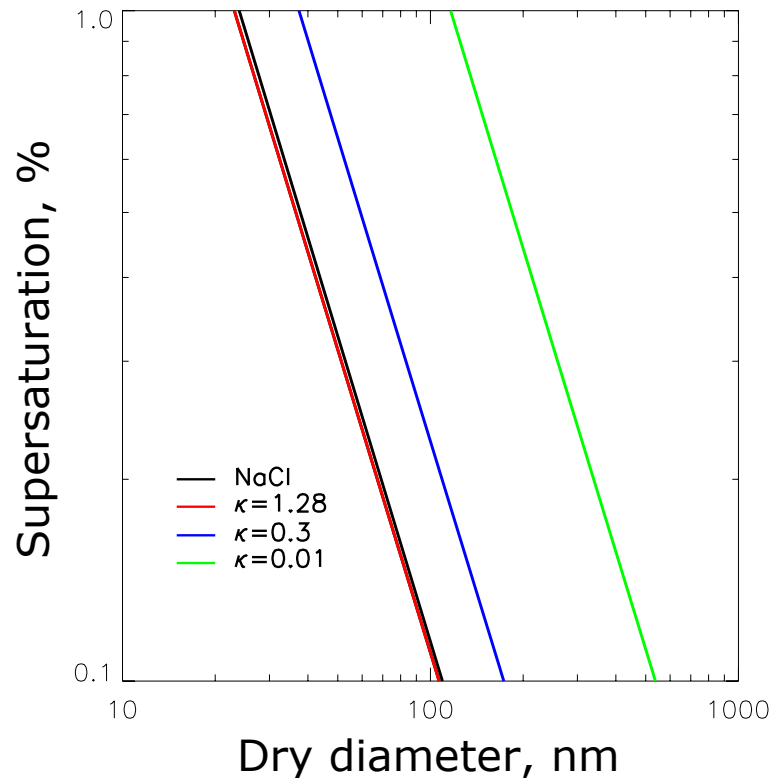
## CONCLUSIONS

- A single parameter representation of hygroscopic growth included into a cloud parcel model.
- Influence of hygroscopicity parameter  $\kappa$  on cloud droplet number concentration for values  $< 0.2$ .
- 30 – 70 % of aerosol particles activated in pyro-clouds.
- Number of aerosol particles are dominating factor for cloud droplet number.

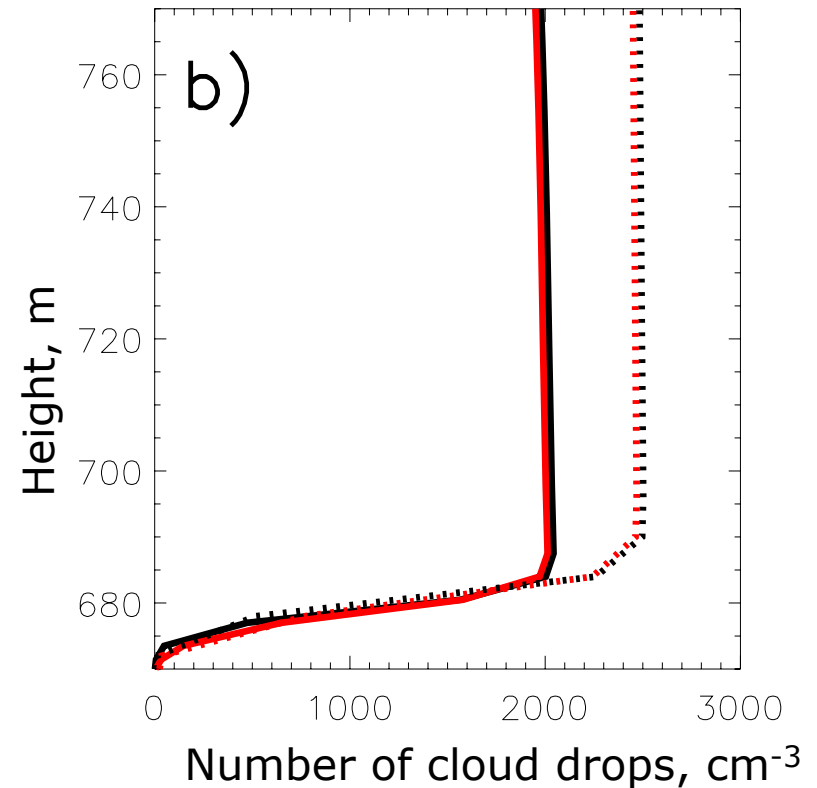
## OUTLOOK

- Investigate the interplay of dynamics and microphysics in pyro-convective clouds in a 3-d model (ATHAM)

# Comparison between different Köhler models for 3000 AP/cm<sup>3</sup>



Critical supersaturation and dry diameter for NaCl and different values of  $\kappa$



Vertical profile of the cloud number concentration for the  $\Phi$ - and the  $\kappa$ -formulation.