Status of COSMO-ART & ICON-ART

Heike Vogel

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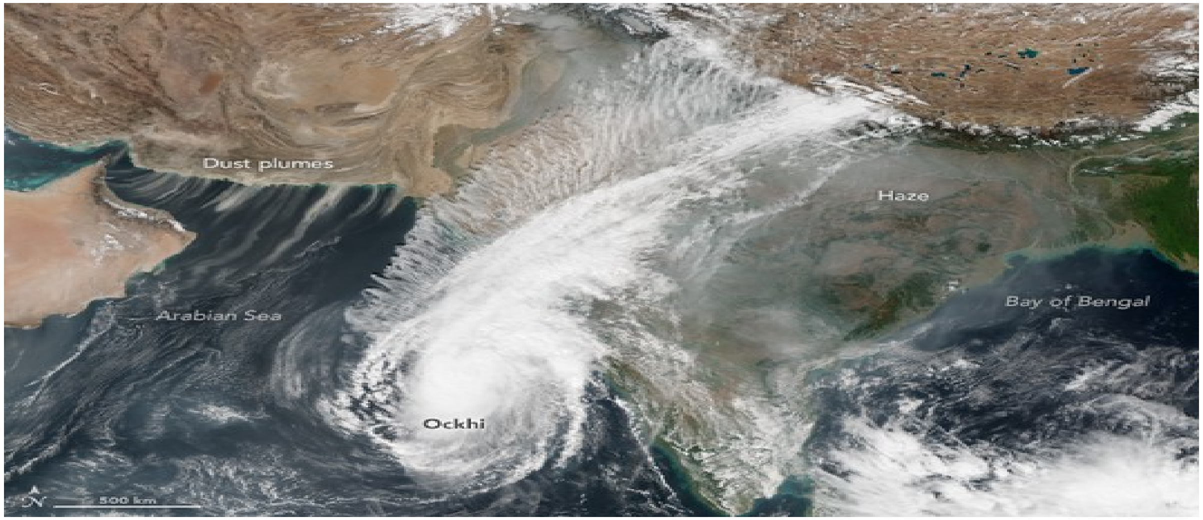
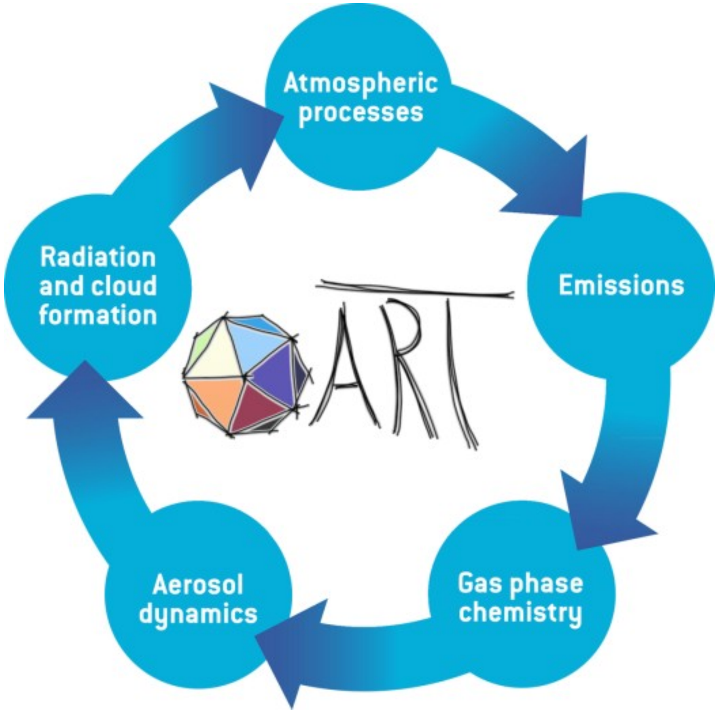


Development and applications of ICON-ART



Implementation of a point source

At a given point:

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<pntSrc id="RNDFACTORY">
  <lon type="real">2.351667</lon>
  <lat type="real">48.856667</lat>
  <substance type="char">testtr</substance>
  <source_strength type="real">1.0</source_strength>
  <height type="real">150.</height>
  <unit type="char">kg s-1</unit>
  <startTime type="char">2014-03-29T00:00:00</startTime>
  <endTime type="char">2014-03-29T01:00:00</endTime>
</pntSrc>
```

Uniform emission profile:

Between surface and given height

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Between given height_bot and height

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  <height type="real">5000.</height>
  <height_bot type="real">1491.</height_bot>
  <unit type="char">kg s-1</unit>
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  <endTime type="char">2014-03-29T01:00:00</endTime>
```

Implementation of a point source

Emission profile:

File Edit View Bookmarks Settings Help

```
<!DOCTYPE tracers SYSTEM "sources_selTrnsp.dtd">

<sources>
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    <source_strength type="real">500.0</source_strength>
    <height type="real">9000.</height>
    <height_bot type="real">1666.</height_bot>
    <emiss_profile type="char">0.0076 * [z_star] - 0.5 * sqrt(pi) * 0.9724 * 0.3078
                           * erf((0.4481 - [z_star]) / 0.3078) / 0.524647415</emiss_profile>
    <unit type="char">kg s-1</unit>
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    <endTime type="char">2014-04-31T00:00:00</endTime>
  </pntSrc>
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    <substance type="char">ash_insol_coa</substance>
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    <height type="real">-4000.</height>
    <emiss_profile type="char">0.5 / (4 * pi) * cos(2 * pi * [z_star] / 0.5) + [z_star]</emiss_profile>
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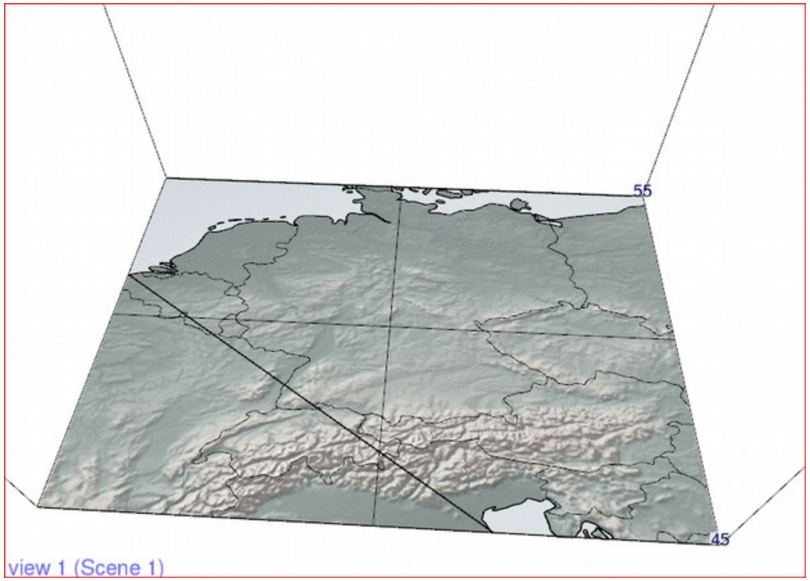
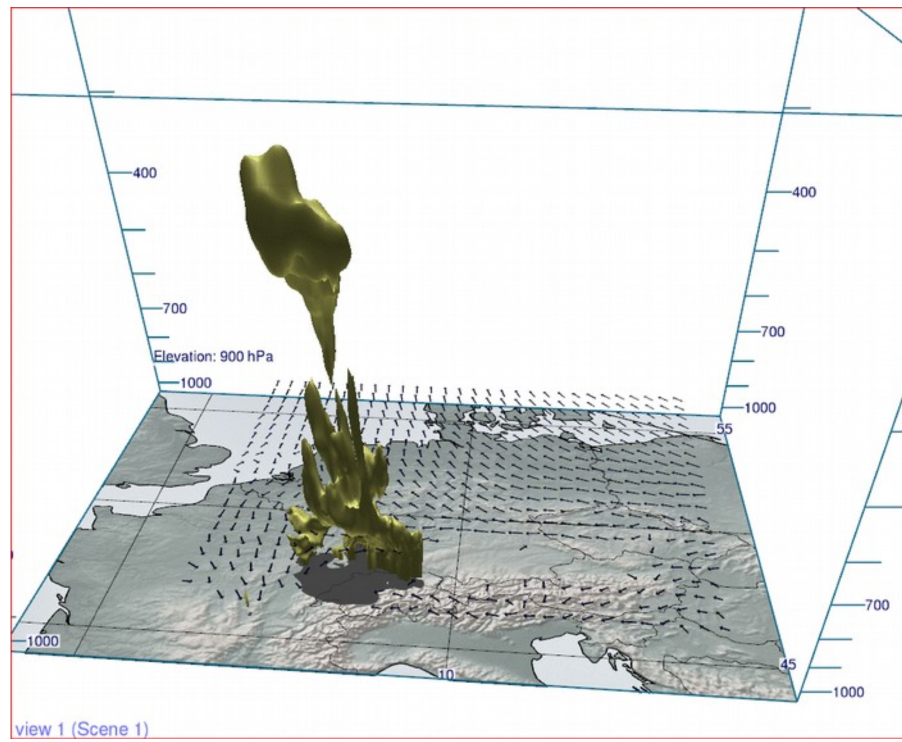
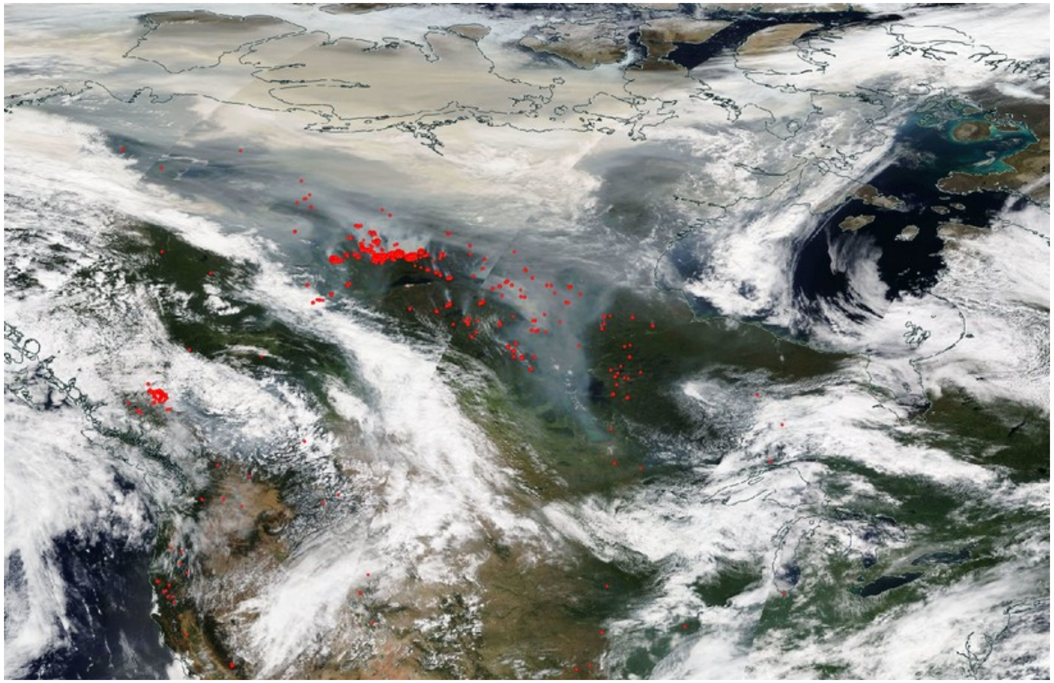
Examples for a point source



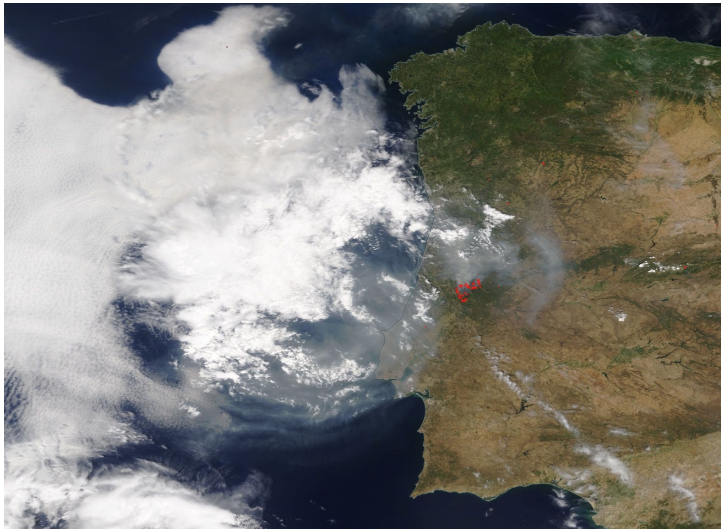


Implementation of vegetation fire emissions

Canada 2017

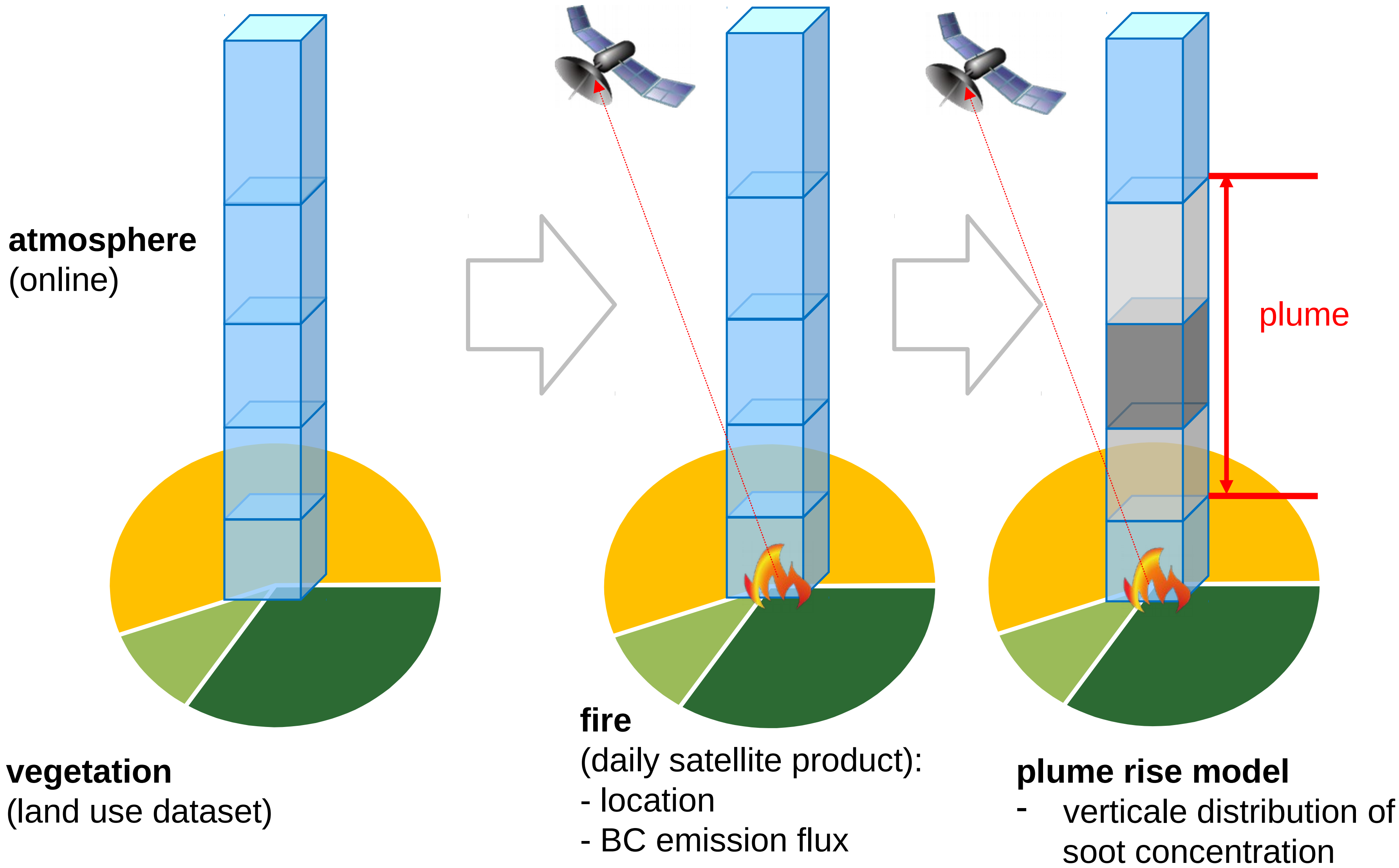


Portugal 2017

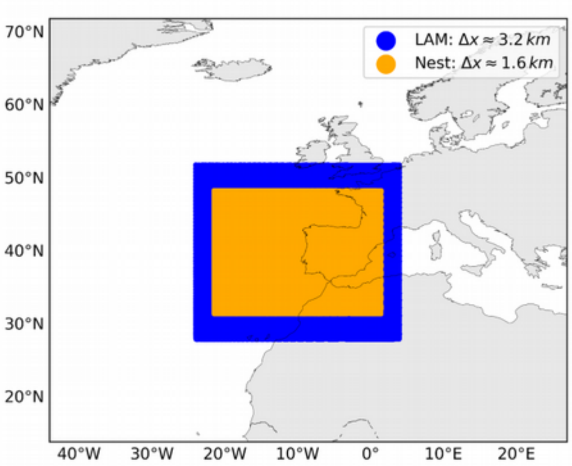


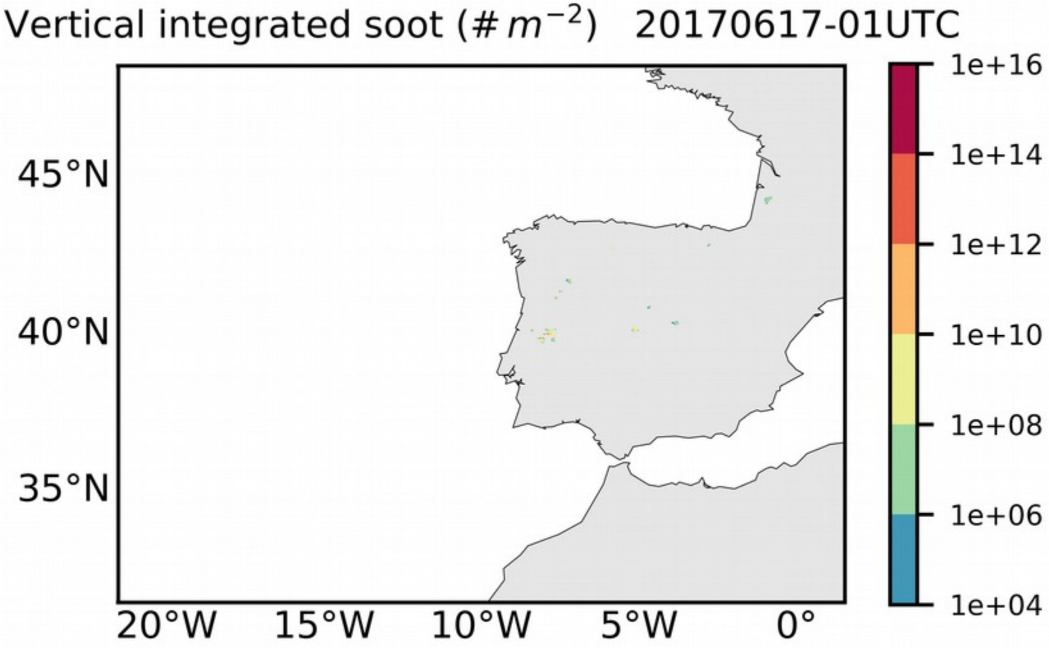
https://worldview.earthdata.nasa.gov

Plume rise model (Freitas et al. 2006, Walter et al. 2014)

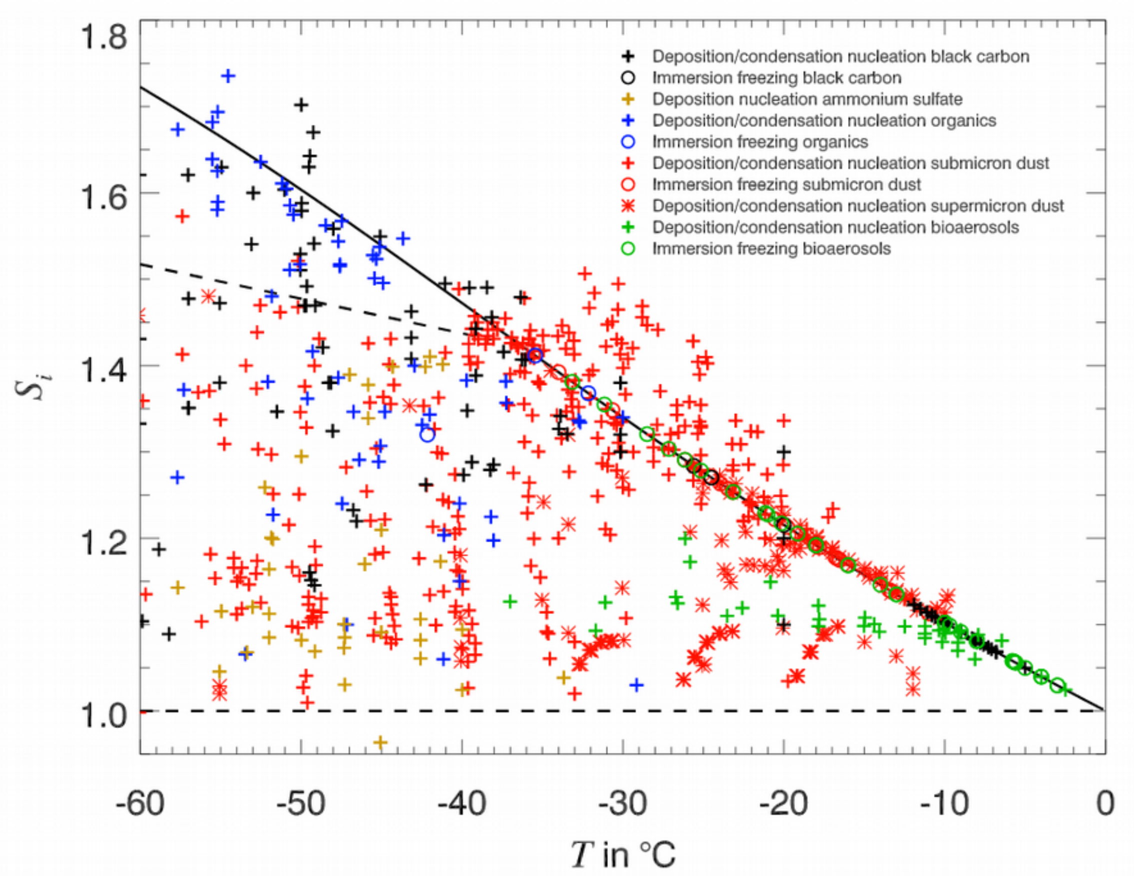


Portugal 2017



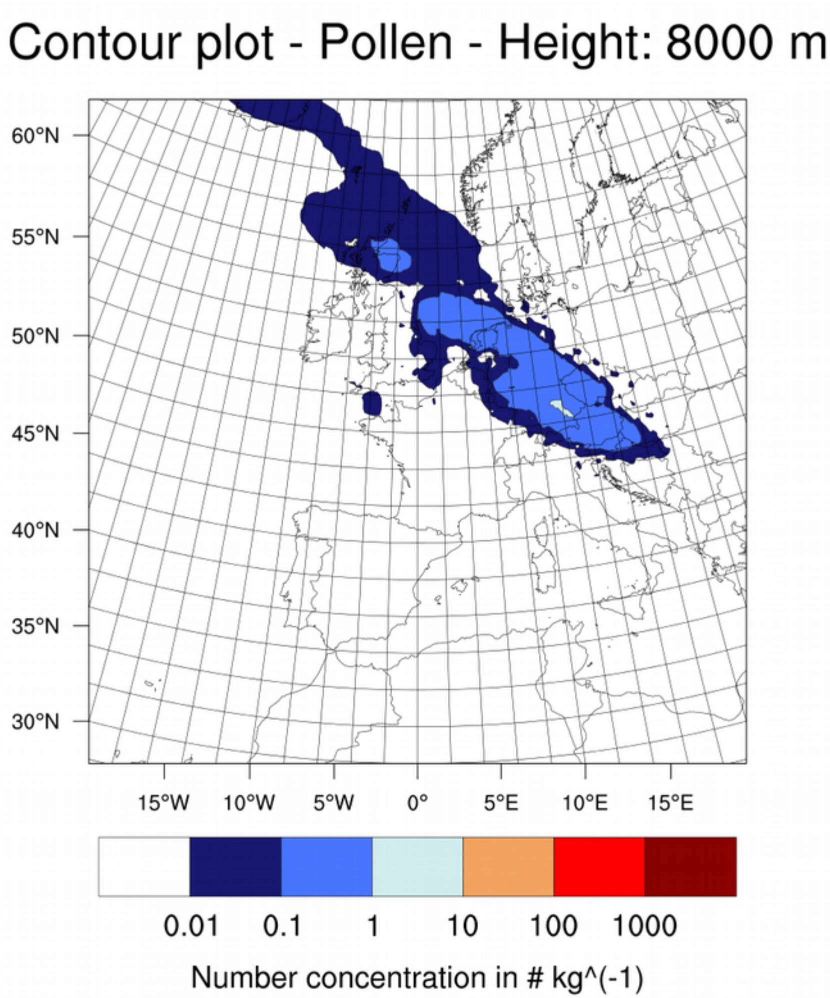


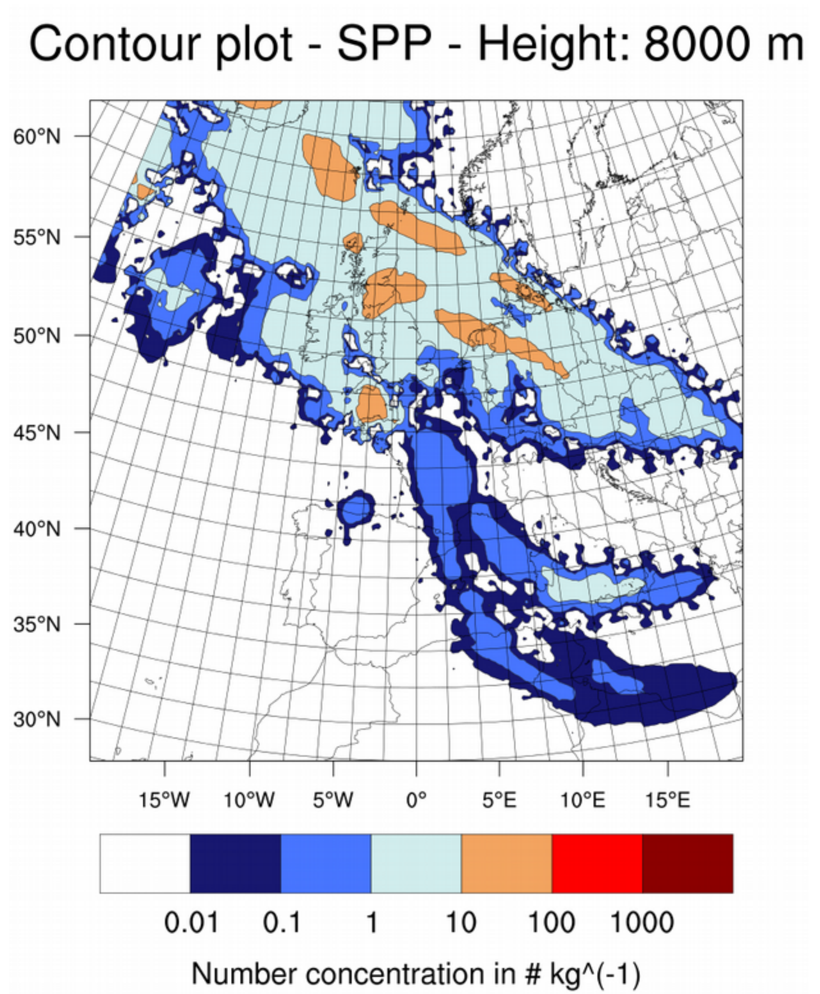
Overview of ice nucleation onset temperatures and saturation ratios



Hoose and Möhler, Atmos. Chem. Phys. Atmos. Chem. Phys., 12, 9817-9854, https://doi.org/10.5194/acp-12-9817-2012, 2012

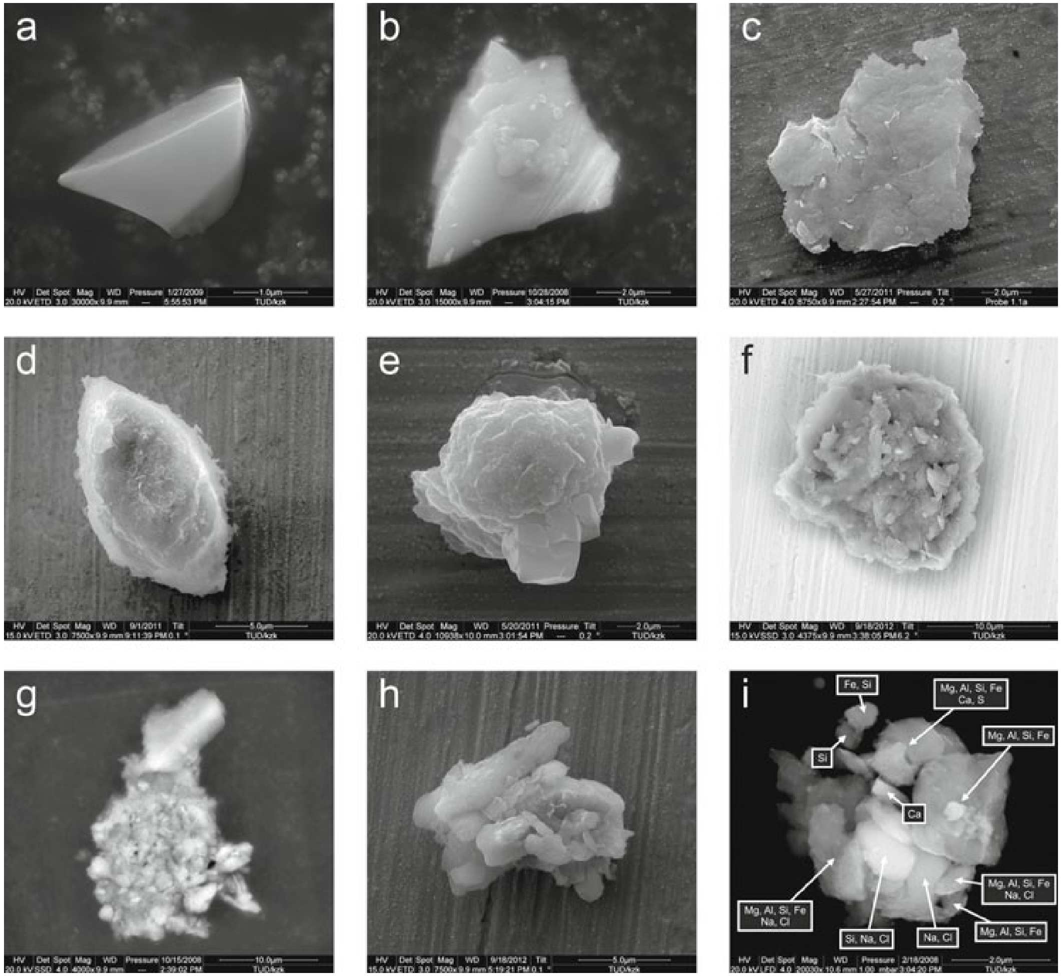
Horizontal distribution of pollen and sub-pollen

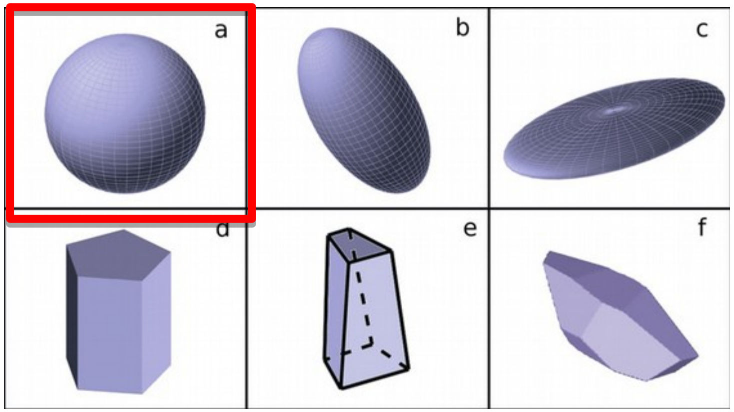




Dust particle shapes

Reality **Models**





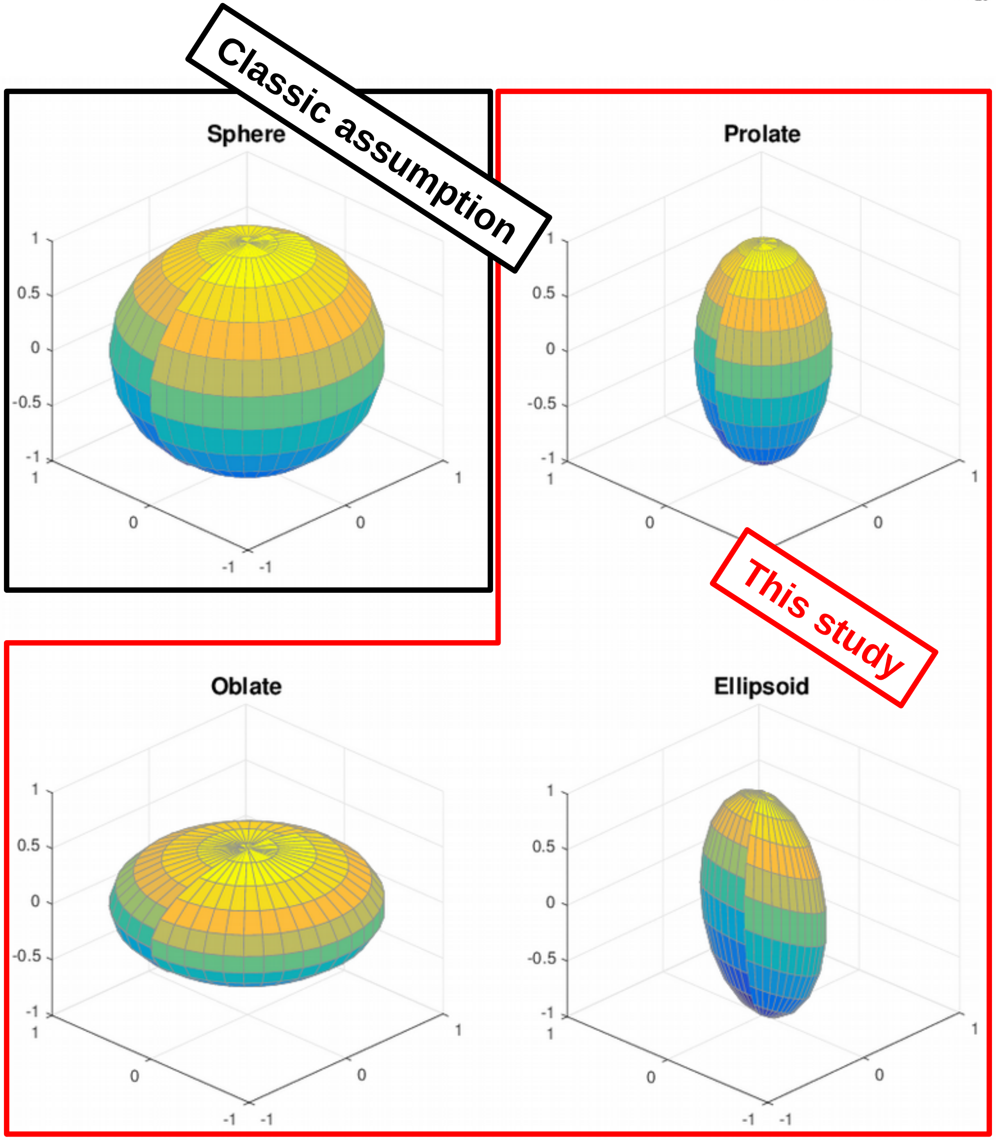
Dust forecast models usually assume spherical dust. But spheres fail to reproduce the magnitude and angular distribution of the scattering.

Nousiainen and Kandler 2015

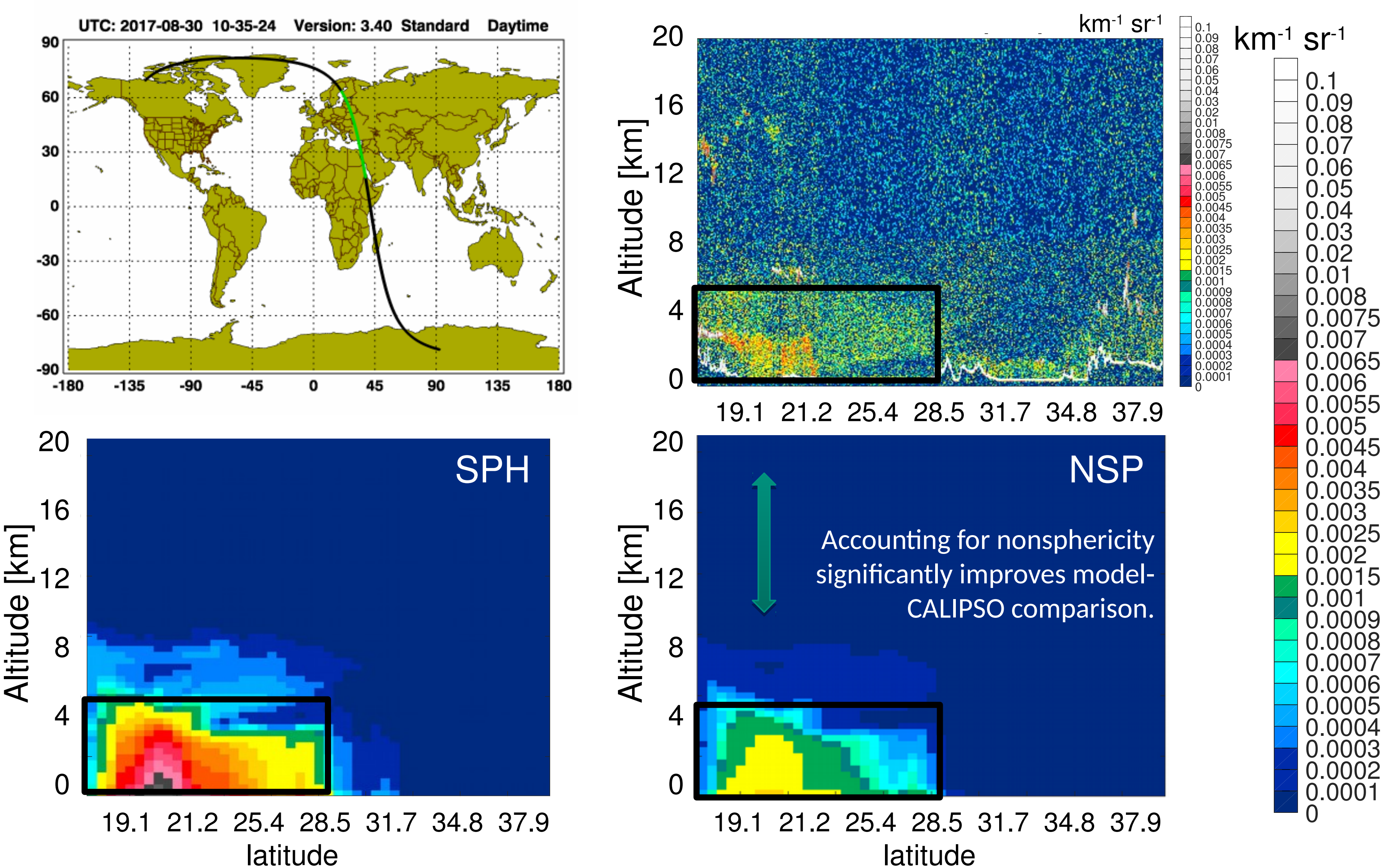
Dust particle shapes: optical properties

- **Tri-axial ellipsoids** better reproduce the laboratory measurements (Meng et al 2010).

- We use a mixture of 35 ellipsoid shapes with aspect ratio of 1.1 to 3.3.



Verification: AB 1064 nm on 30.08.2017

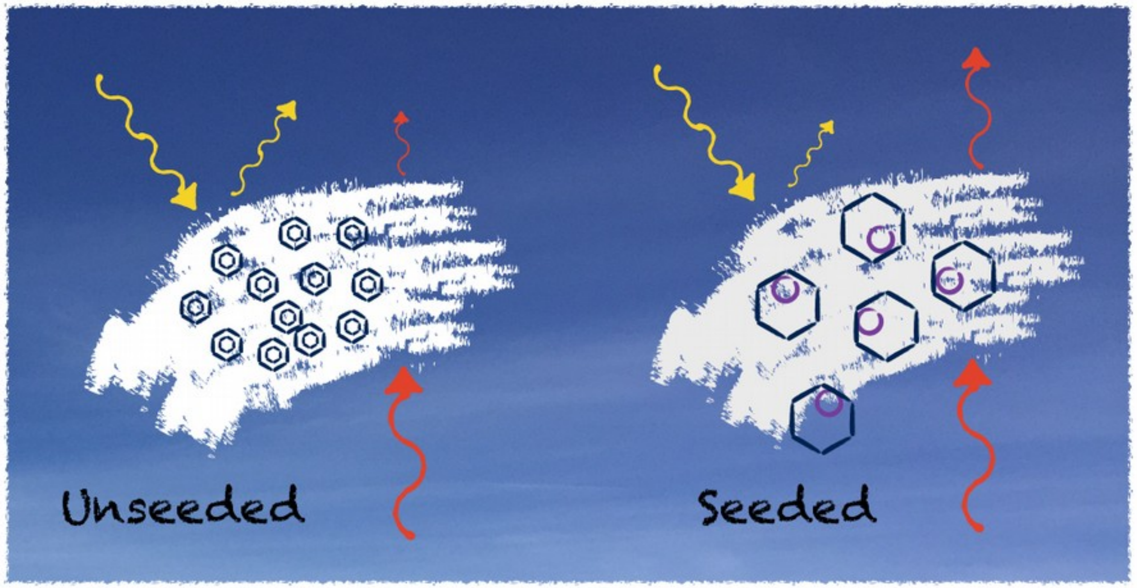


Summary

- Improvement of ABS for NSP particles
- Minor changes for AOD
- Particle size distribution seems to be more important in case of AOD

Hoshyaripour, G., Bachmann, V., Förstner, J., Steiner, A., Vogel, H., Wagner, F. , Vogel, B. Accounting for Particle Non-sphericity in a Dust Forecast System: Impacts on Model-Observation Comparison, submitted to JGR

Climate Engineering by Arctic Winter CirrusThinning



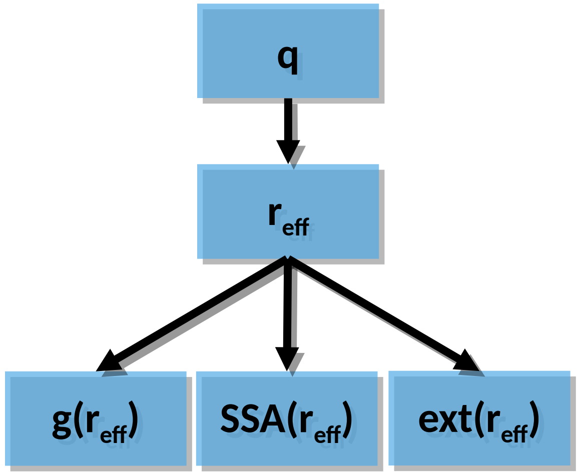
after Storelvmo et al., 2013

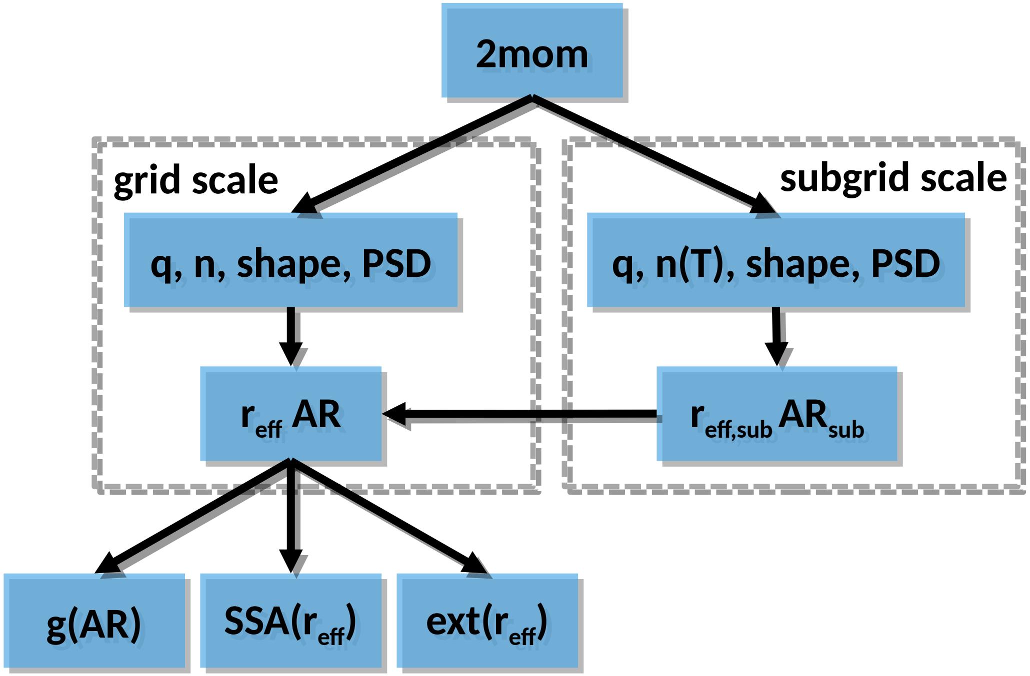
Optical Properties of Hydrometeors

Karlsruher Institut für Technologie

- old
- look-up tables of $r_{eff}(q)$
- cloud ice, cloud droplets

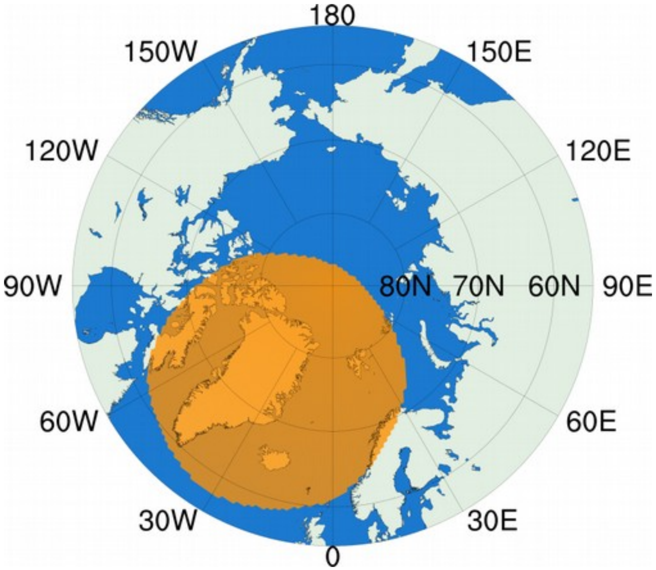
- new
- explicitly consider number conc.
- cloud ice, cloud droplets, rain, snow, graupel





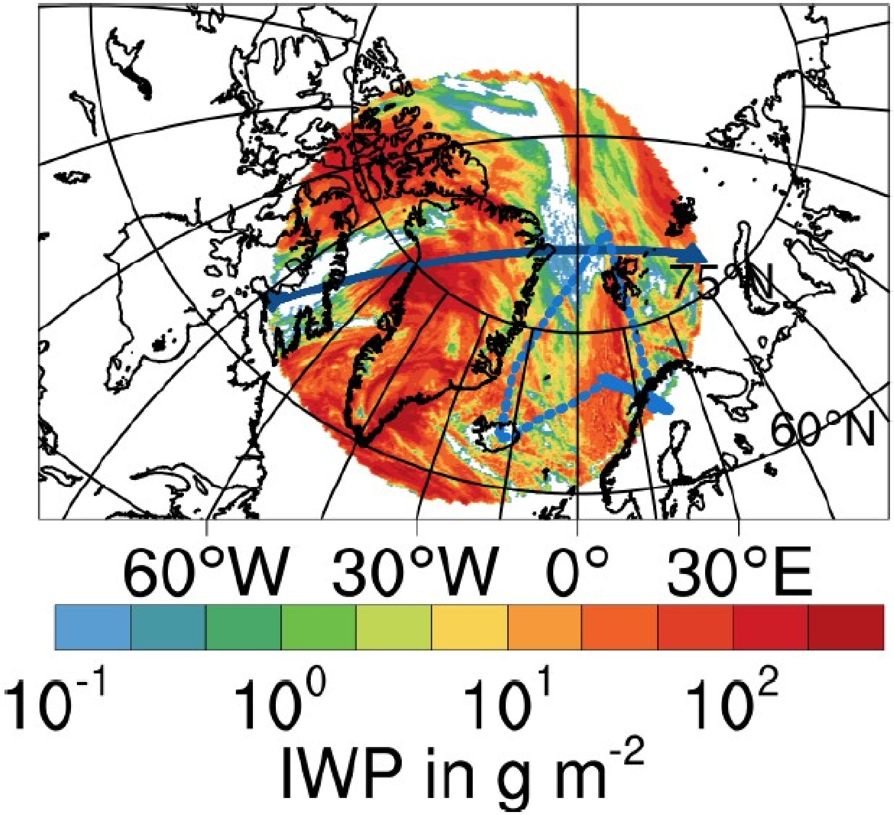
Model setup: ICON-ART LAM

- R2B09 (~5 km)
- two-moment microphysics: Seifert and Beheng (2006)
- cloud optical properties: Fu et al. (1998), Fu (2007), Hu and Stamnes (1993)
- nucleation: Barahona and Nenes (2009)
- heterogeneous nucleation: Phillips,et al. (2013)
- activation of CCN: Bangert et al. (2012)

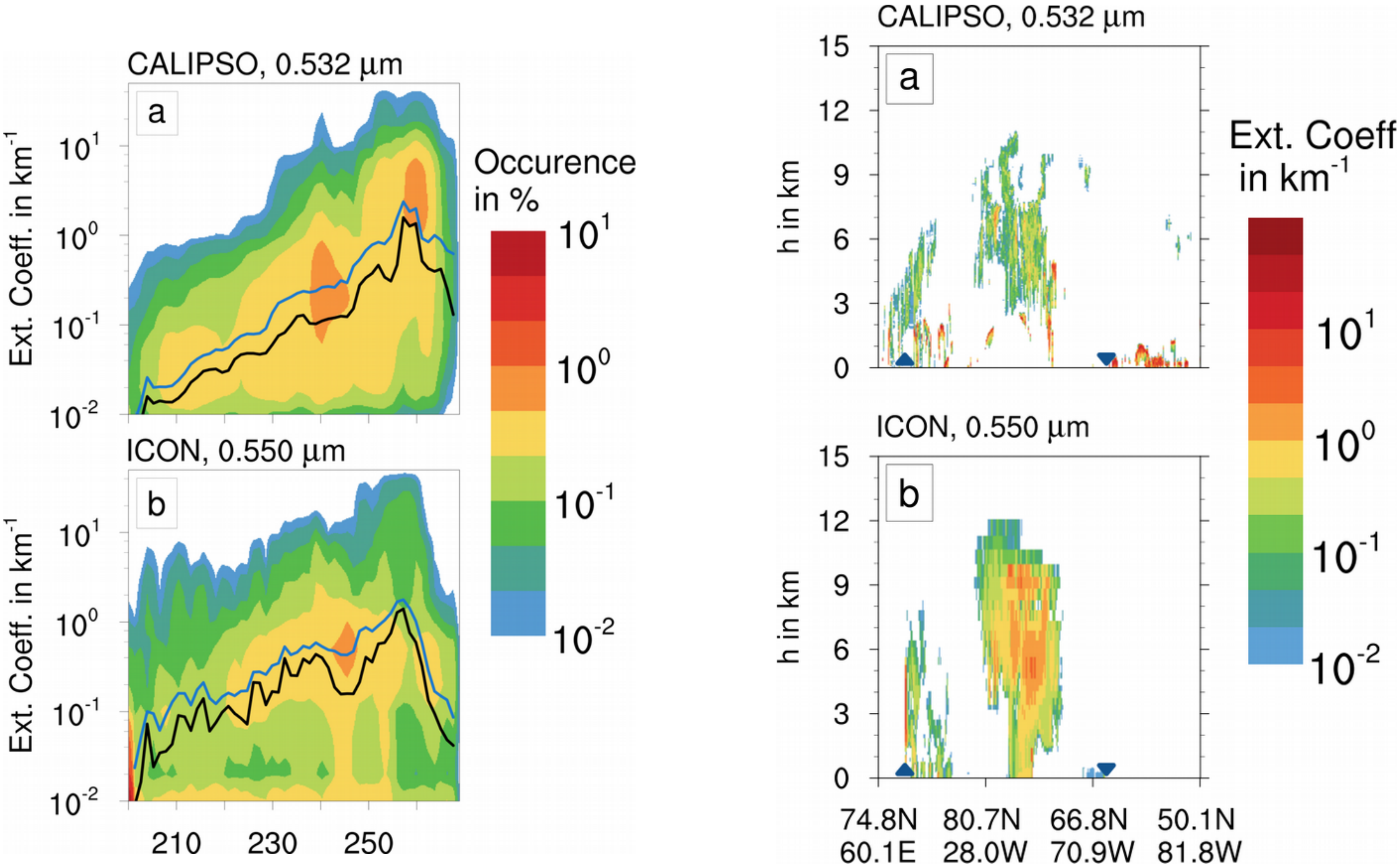


Gruber et al., 2018

Calipso and Halo flight tracks

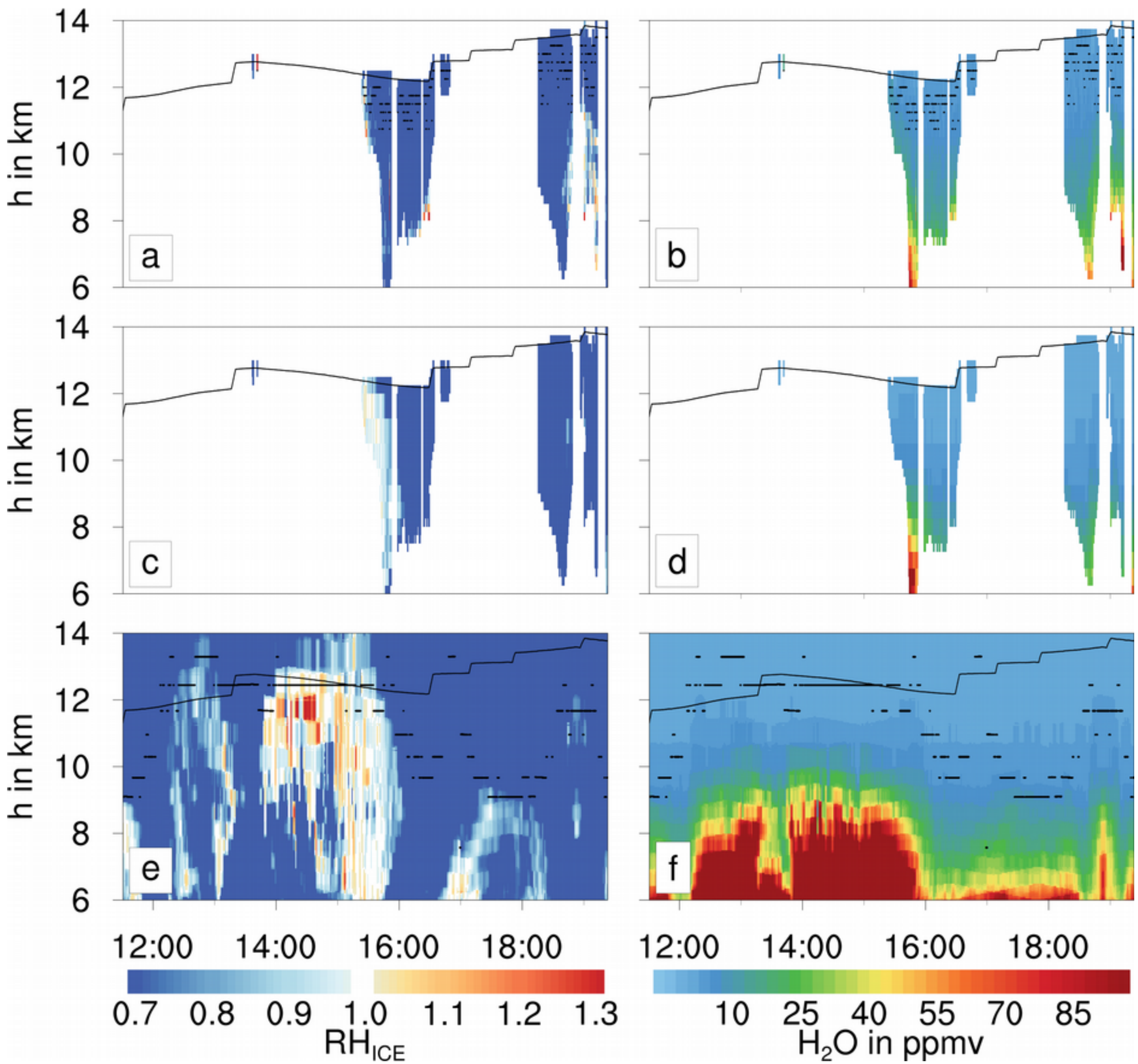


Validation: Calipso



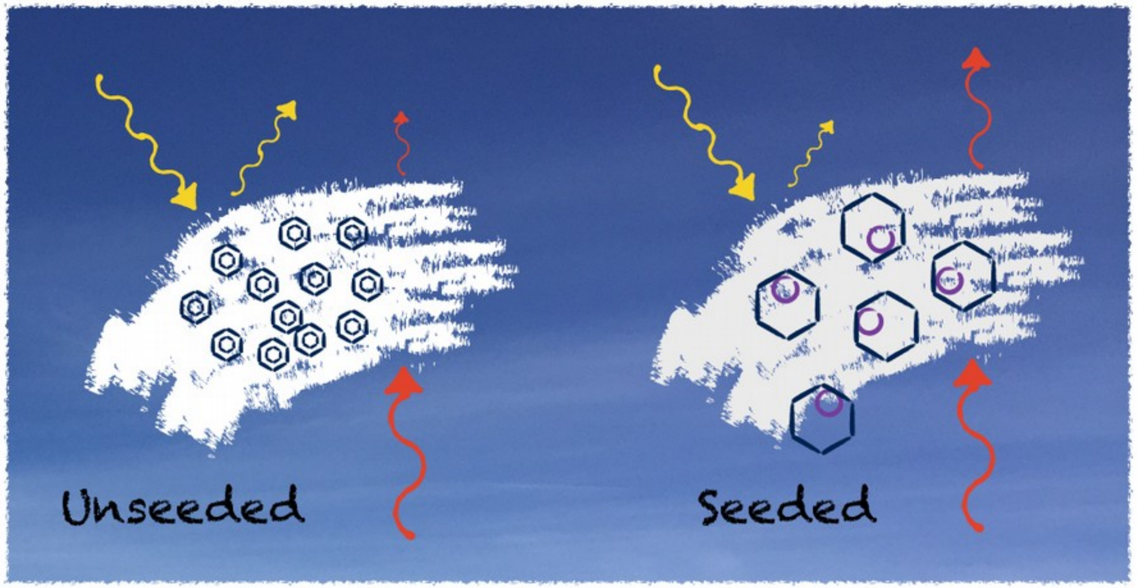
Validation: POLSTRACC, GLORIA

RHice



H_2O

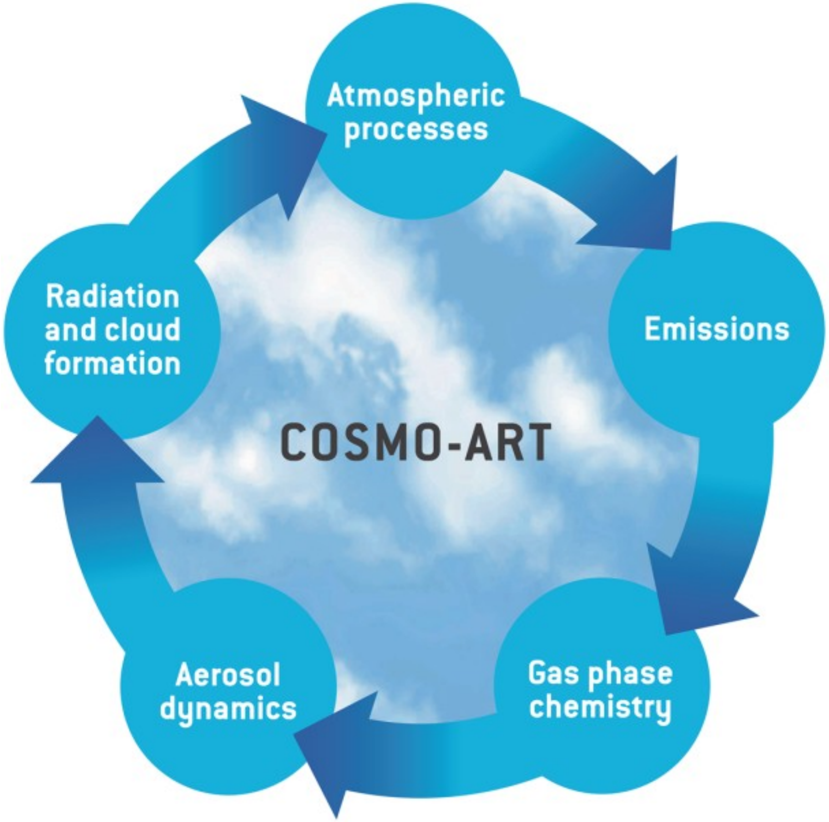
Climate Engineering by Arctic Winter CirrusThinning



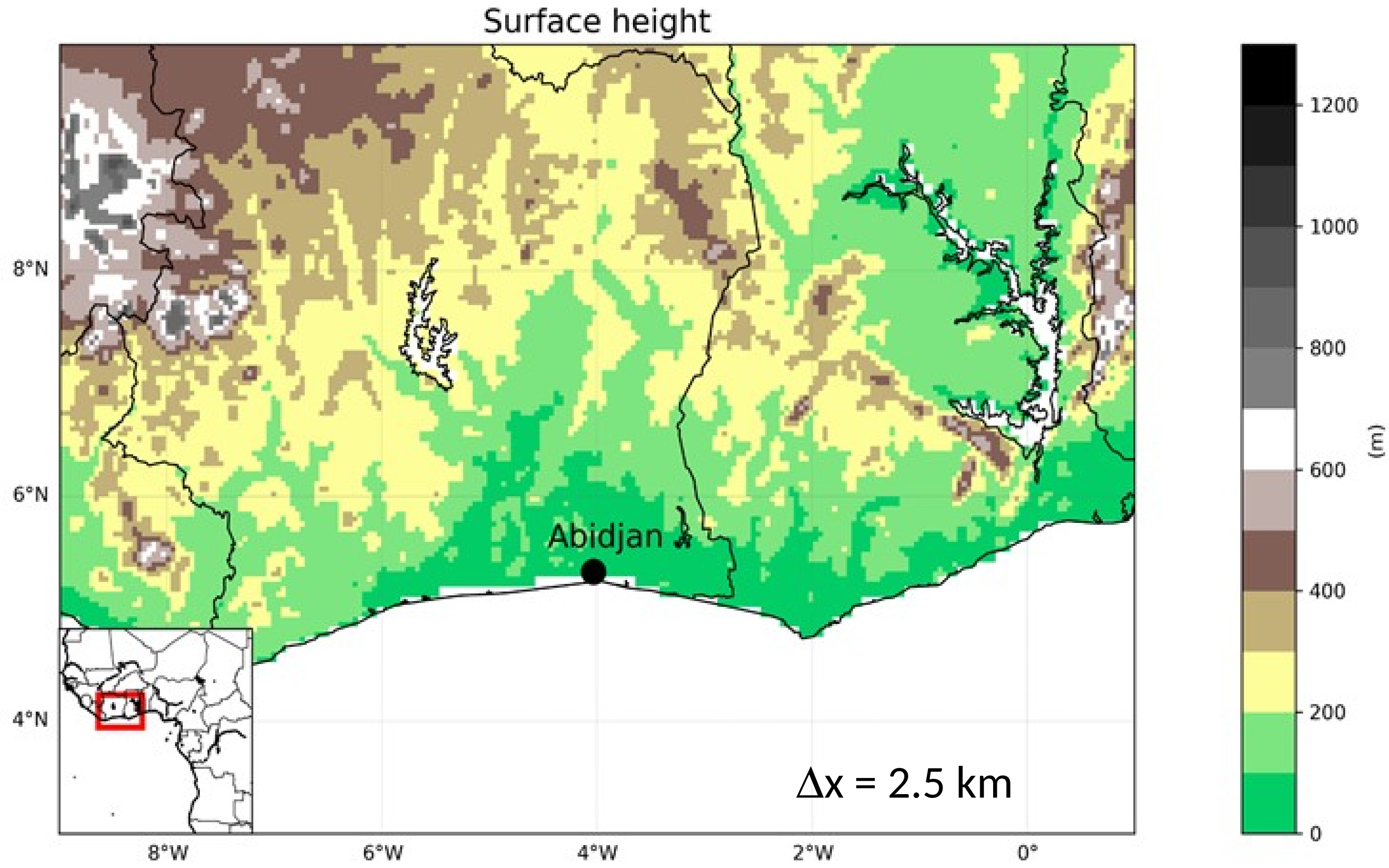
after Storelvmo et al., 2013

Gruber, S., U. Blahak, F. Haenel, Ch. Kottmeier, Th. Leisner, H. Muskatel, T. Storelvmo, and B. Vogel,
A process study on thinning of Arctic winter cirrus clouds with high-resolved ICON-ART simulations, in preparation

Applications of COSMO-ART



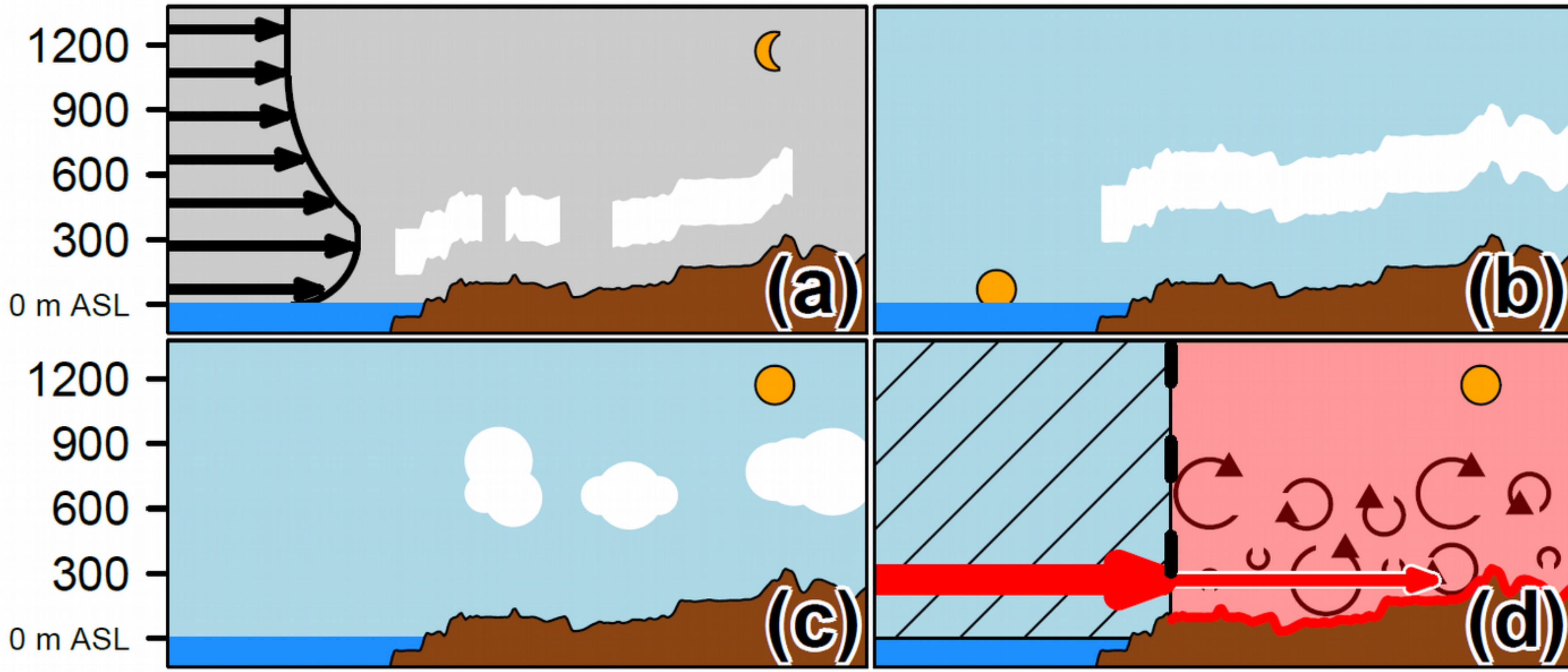
Impact of aerosols on clouds and atmospheric dynamics over southern West Africa



Δx = 5 km

Deetz et al., 2018

Characteristics



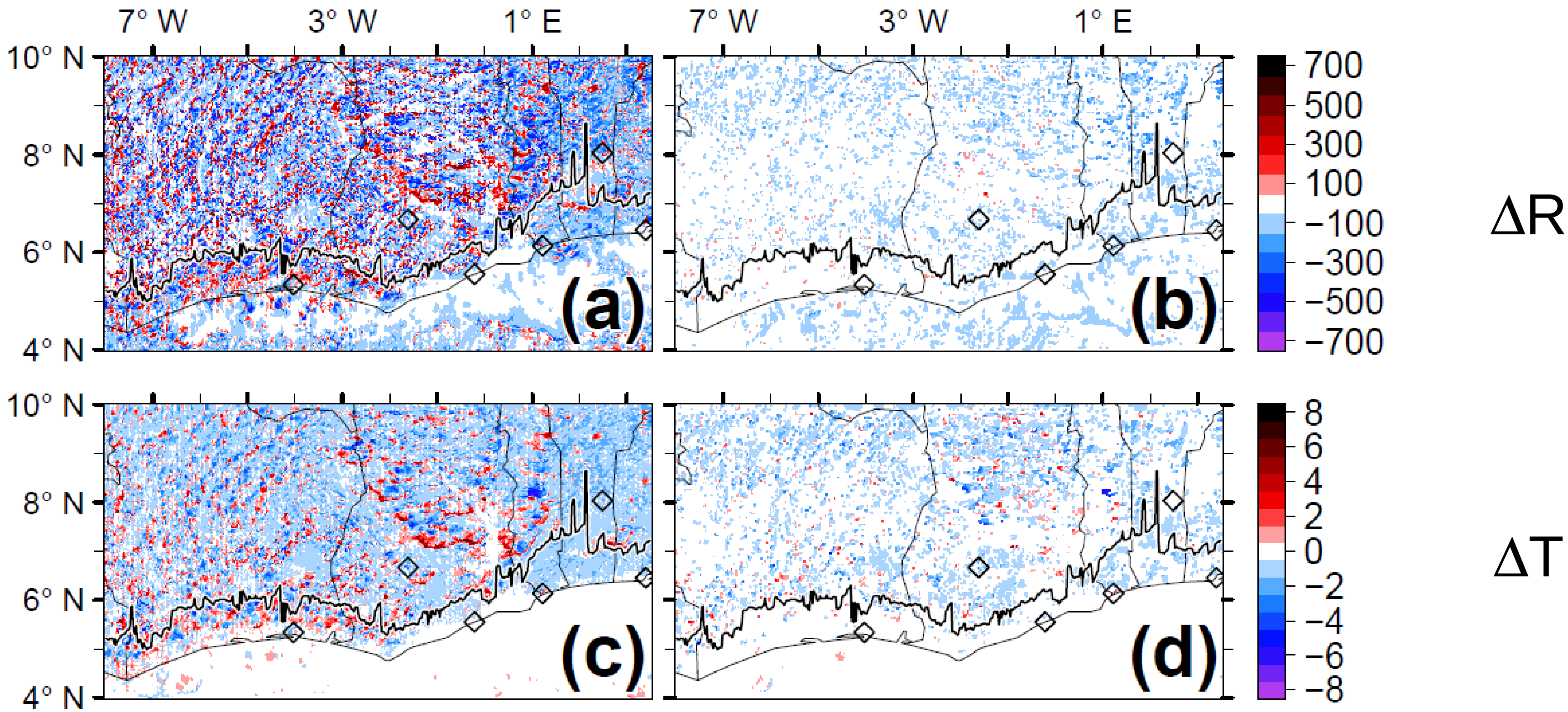
Deetz et al., 2018 ACP

Sensitivity runs

Abbreviation	Description of Simulation
$\text{AIE}_{0.1}\text{ADE}_{0.1}$	$F_{AIE} = 0.1$ and $F_{ADE} = 0.1$
$\text{AIE}_{0.25}\text{ADE}_{0.25}$	$F_{AIE} = 0.25$ and $F_{ADE} = 0.25$ (clean case)
$\text{AIE}_{0.5}\text{ADE}_{0.5}$	$F_{AIE} = 0.5$ and $F_{ADE} = 0.5$
$\text{AIE}_{1.0}\text{ADE}_{1.0}$	$F_{AIE} = 1.0$ and $F_{ADE} = 1.0$ (reference case)
$\text{AIE}_{2.0}\text{ADE}_{2.0}$	$F_{AIE} = 2.0$ and $F_{ADE} = 2.0$
$\text{AIE}_{4.0}\text{ADE}_{4.0}$	$F_{AIE} = 4.0$ and $F_{ADE} = 4.0$ (polluted case)

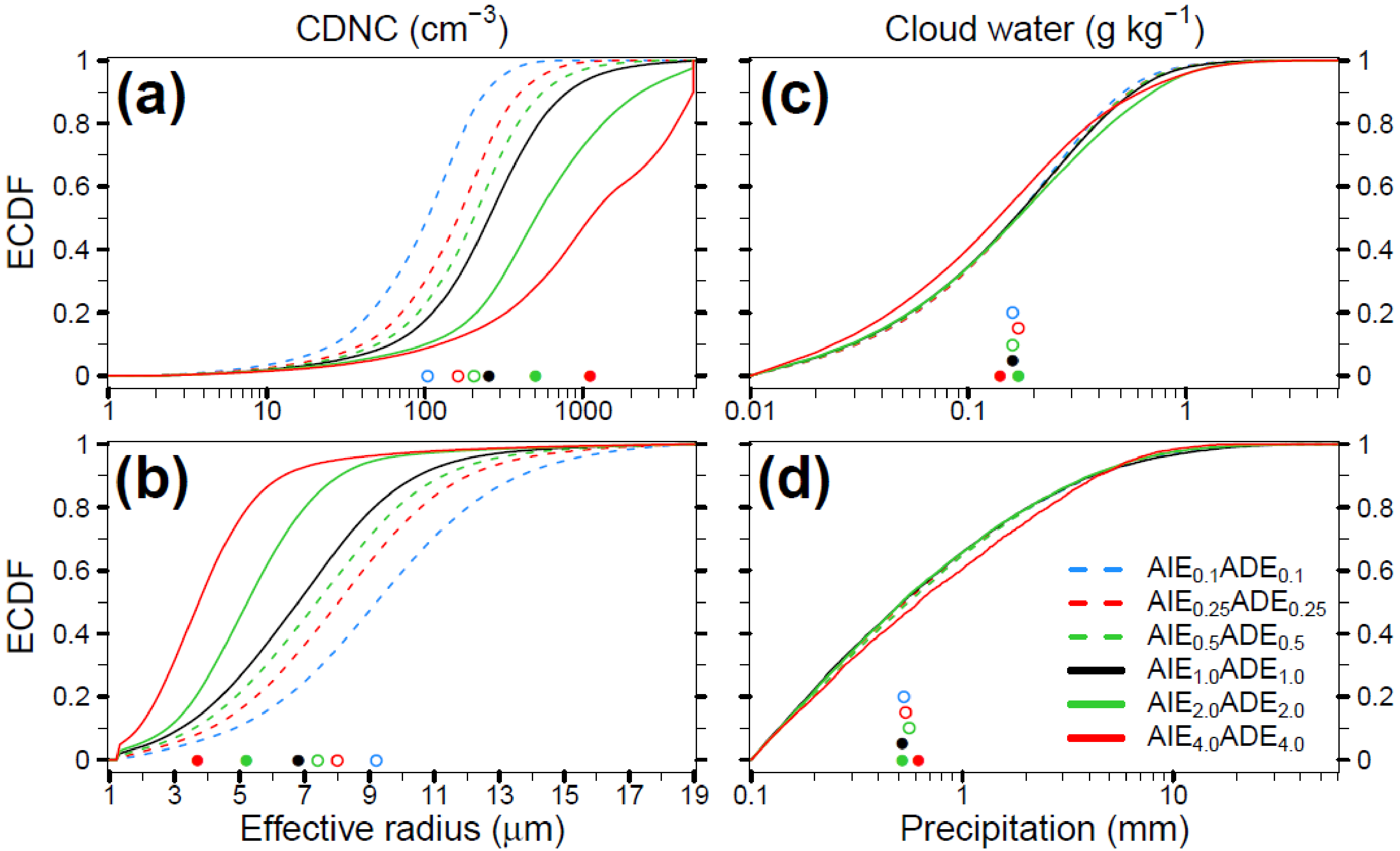
Deetz et al., 2018 ACP

Impact on radiation



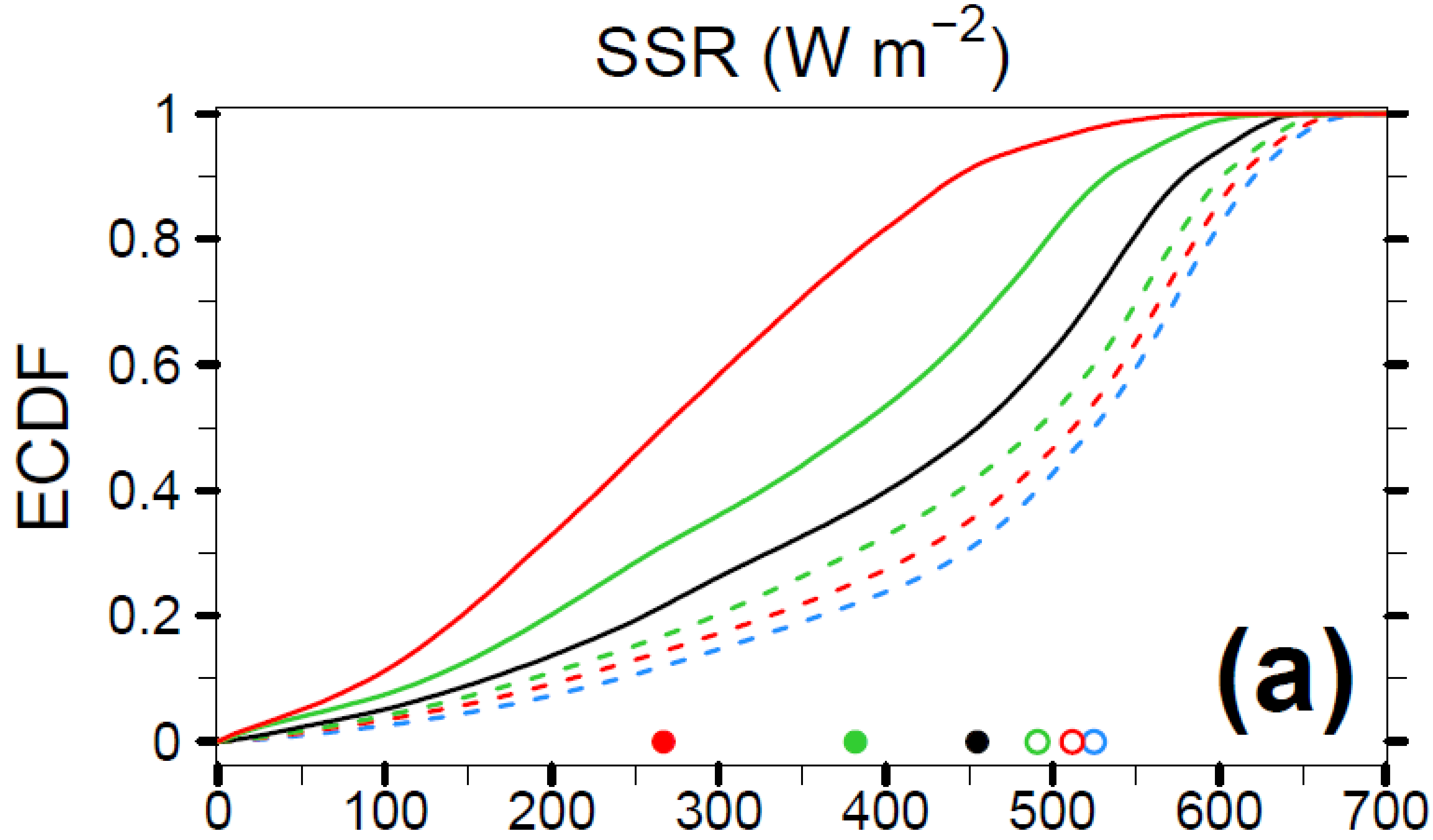
Deetz et al., 2018 ACP

Impact on physical properties and precipitation



Deetz et al., 2018 ACP

Impact on shortwave radiation at surface



Deetz et al., 2018 ACP

Summary of this study

- **Aerosol strongly effects cloud effective radii.**
- **LWC and precipitation show no significant change.**
- **Strong impact of modified clouds on radiation.**
- **Strong contribution from biomass burning in central Africa.**

K. Deetz, H. Vogel, P. Knippertz, B. Adler, J. Taylor, H. Coe, K. Bower, S. Haslett, M. Flynn, James Dorsey, Ian Crawford, Christoph Kottmeier, B. Vogel
Numerical simulations of aerosol radiative effects and their impact on clouds and atmospheric dynamics over southern West Africa, Atmos. Chem. Phys., 18, 9767-9788, https://doi.org/10.5194/acp-18-9767-2018, 2018
K. Deetz, H. Vogel, S. Haslett, P. Knippertz, H. Coe, B. Vogel
Aerosol liquid water content in the moist southern West African monsoon layer and its radiative impact Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2018-420, 2018

KIT-ART-Team

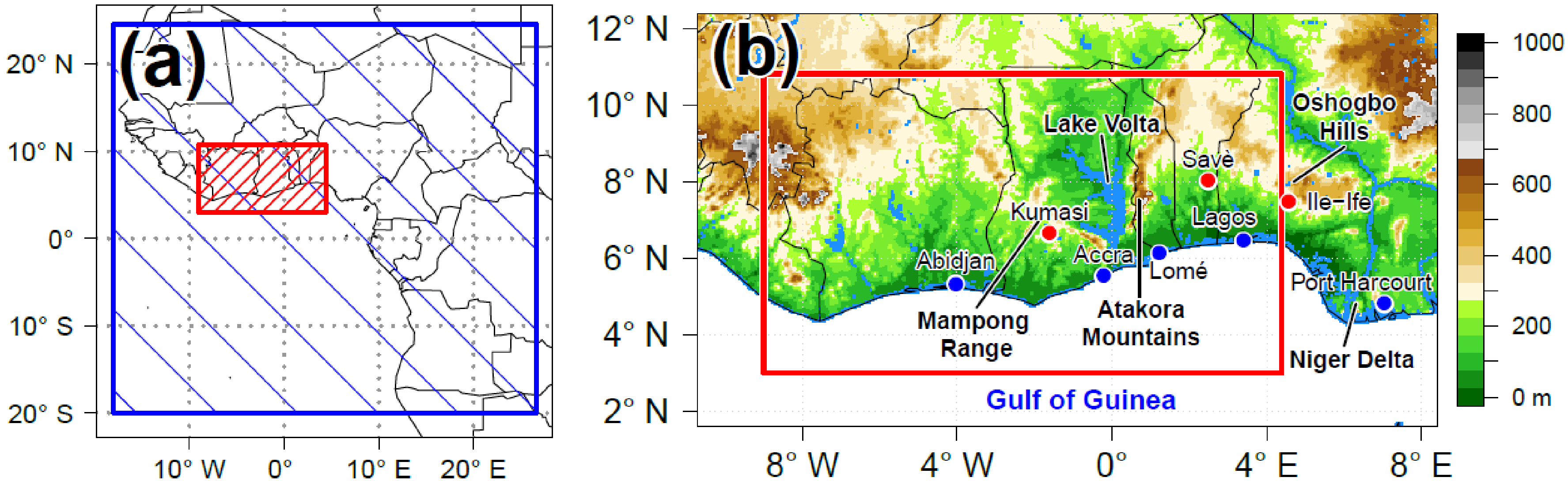
Karlsruhe Institute of Technology

Current Projects

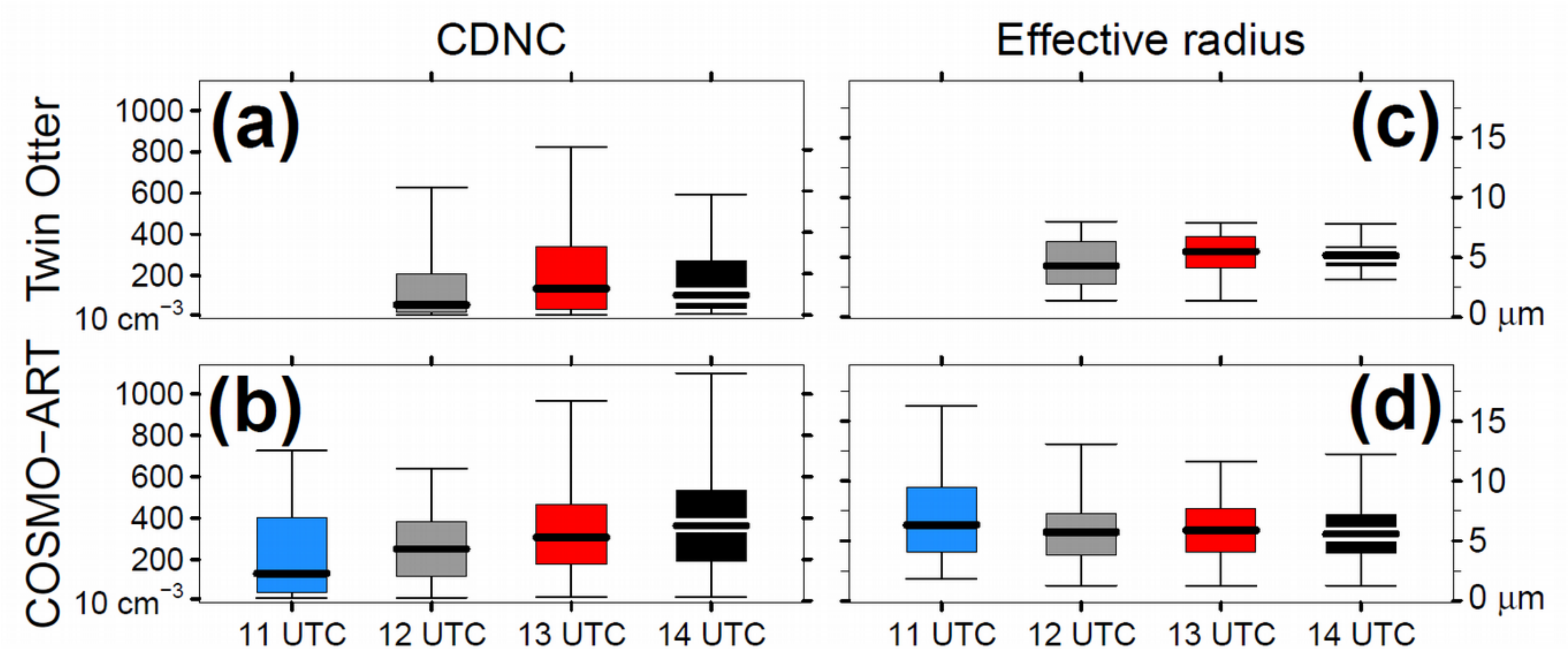
- Research themes
  - Impact of volcanic ash on atmospheric processes
  - Dust-cloud-radiation feedback
  - Scale dependency of aerosol cloud interaction
  - Climate engineering
  - Biomass burning aerosol
  - Impact of sub pollen particles

  - Emission driven annual cycles
  - Chemistry-climate interactions, including PSCs
  - Water isotopologues (weather/climate)
  - Composition assimilation

Additional material Africa simulations

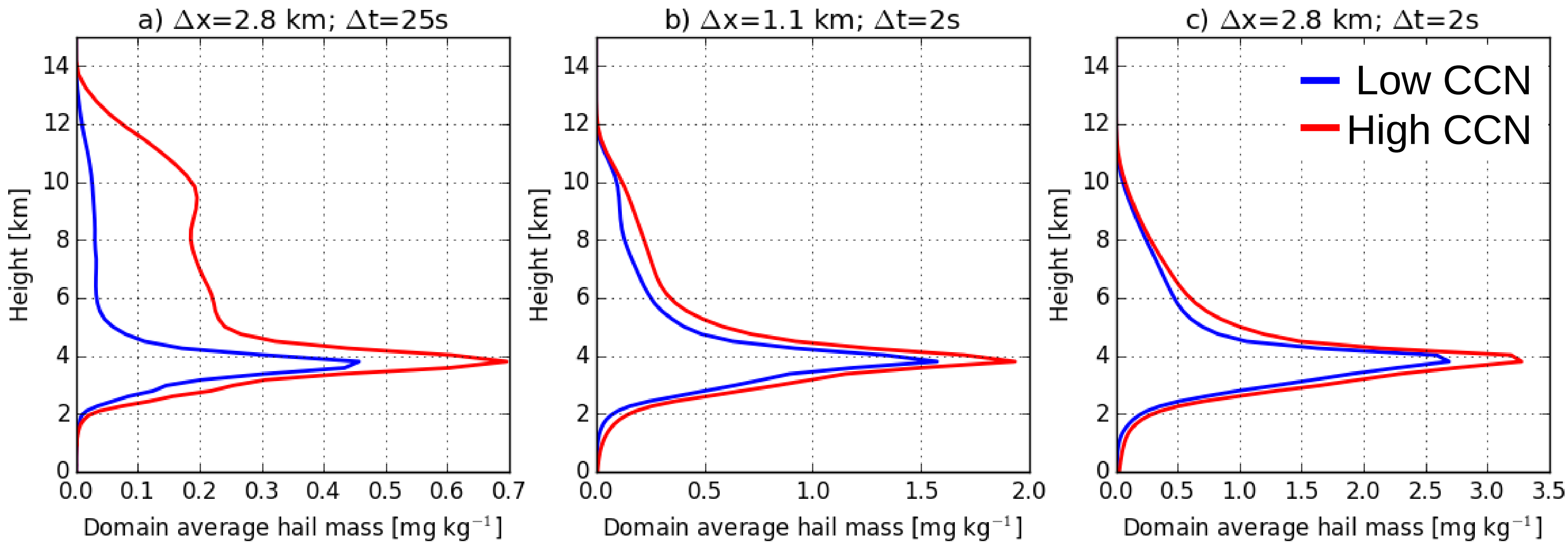

(a)
20° N
10° N
0°
10° S
20° S
10° W
0°
10° E
20° E
(b)
12° N
10° N
8° N
6° N
4° N
2° N
8° W
4° W
0°
4° E
8° E
Lake Volta
Oshogbo Hills
Savè
Ile−Ife
Kumasi
Lagos
Abidjan
Accra
Lomé
Port Harcourt
Mampong Range
Atakora Mountains
Niger Delta
Gulf of Guinea
1000
800
600
400
200
0 m

Comparison to observations



Additional material time spitting

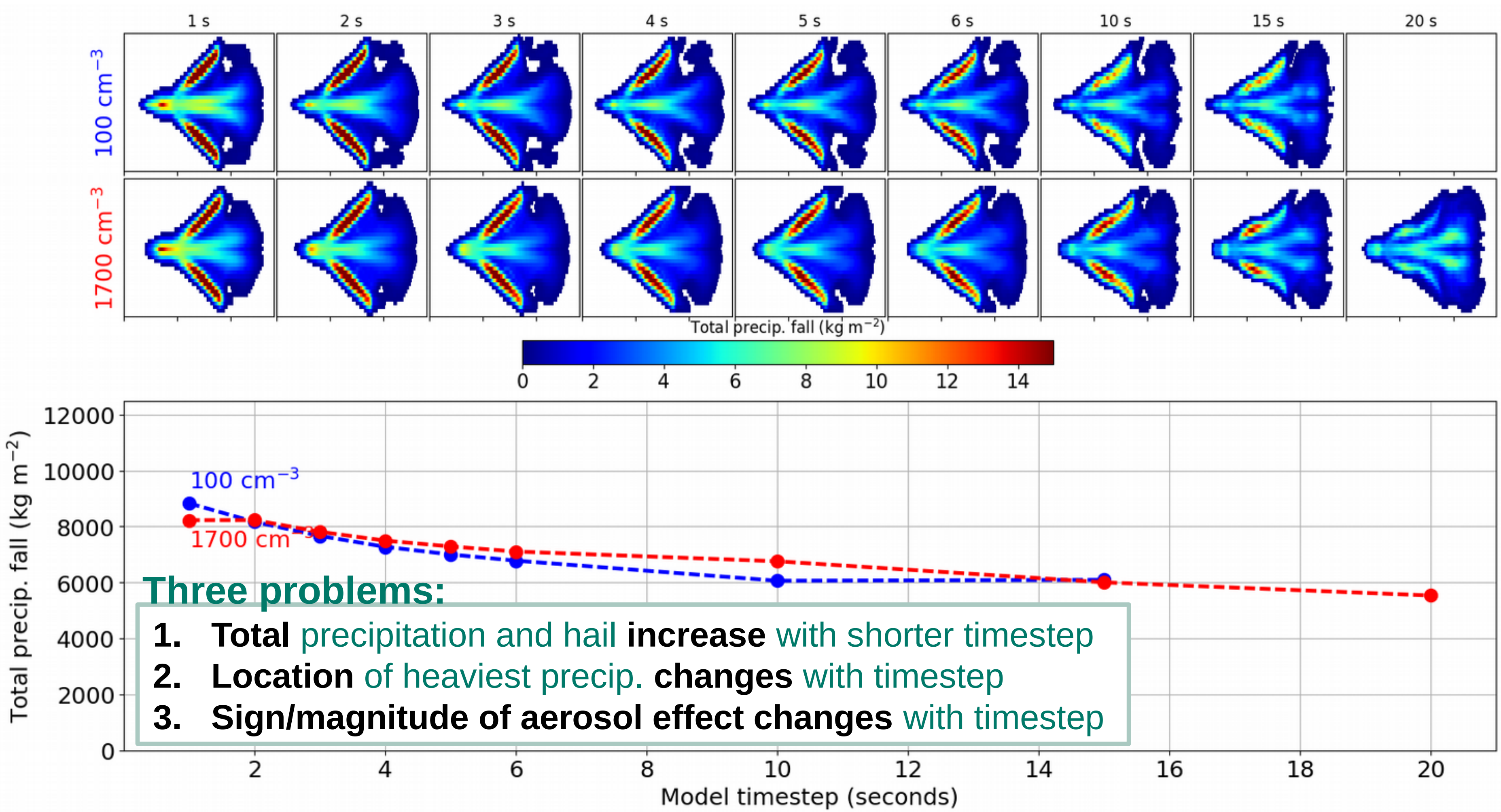
Microphysics sensitivity to timestep



<u>Model setup</u>

- Idealised 2-hour simulation using COSMO v5.3
- 1-km resolution; 64 vertical levels; timestep 1-20 s
  - Weisman-Klemp thermodynamic profile; 2K warm bubble; linear shear
- Seifert & Beheng 2-moment microphysics – Segal & Khain CCN activation
  - Two different aerosol settings:
    - clean = 100 CCN cm^{-3}; continental = 1700 CCN cm^{-3}

Total precipitation: aerosol and timestep effects

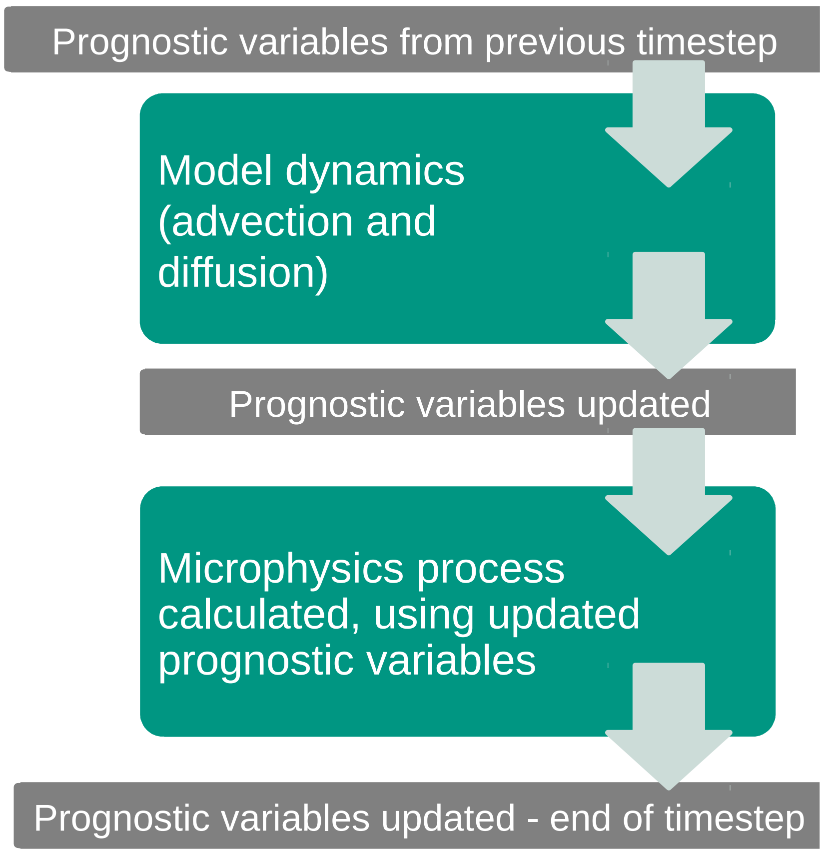


Three problems:

1. **Total** precipitation and hail **increase** with shorter timestep
2. **Location** of heaviest precip. **changes** with timestep
3. **Sign/magnitude of aerosol effect changes** with timestep

Why? Numerics!

- Model dynamics calculated before microphysics



- Storm updraft -> adiabatic cooling
- cooling -> supersaturation

- Cooling = rate x Δt
- Supersaturation depends on timestep

- Microphysical processes now calculated using timestep-dependent supersaturation

- Many processes affected
- Timestep-dependent results

Operator Splitting: Consecutive vs Simultaneous

Karlsruhe Institute of Technology

Process splitting in COSMO:

Prognostic variables from previous timestep

↓

Model dynamics (advection and diffusion)

↓

Prognostic variables updated

↓

Microphysics process calculated, using updated prognostic variables

↓

Prognostic variables updated - end of timestep

“Operator Splitting” or “Additive Splitting”

A different option:

Prognostic variables from previous timestep

↓ ↓

Model dynamics (advection and diffusion) | Microphysics process calculated

↓ ↓

Prognostic variables updated - end of timestep

“Additive Splitting”

Timestep dependence in a simple model

$$\frac{dq_c}{dt} = \underline{C} - \underline{Aq_c^2}$$

$$q_c = \sqrt{\frac{C}{A}}$$

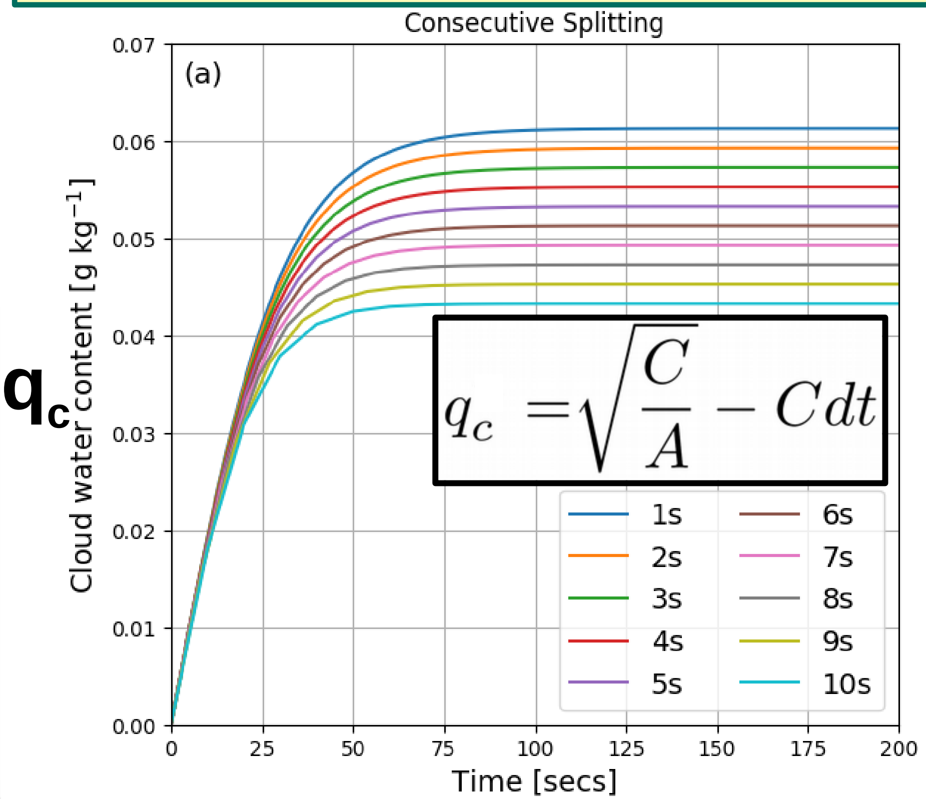
Condensation

Autoconversion (microphysics)

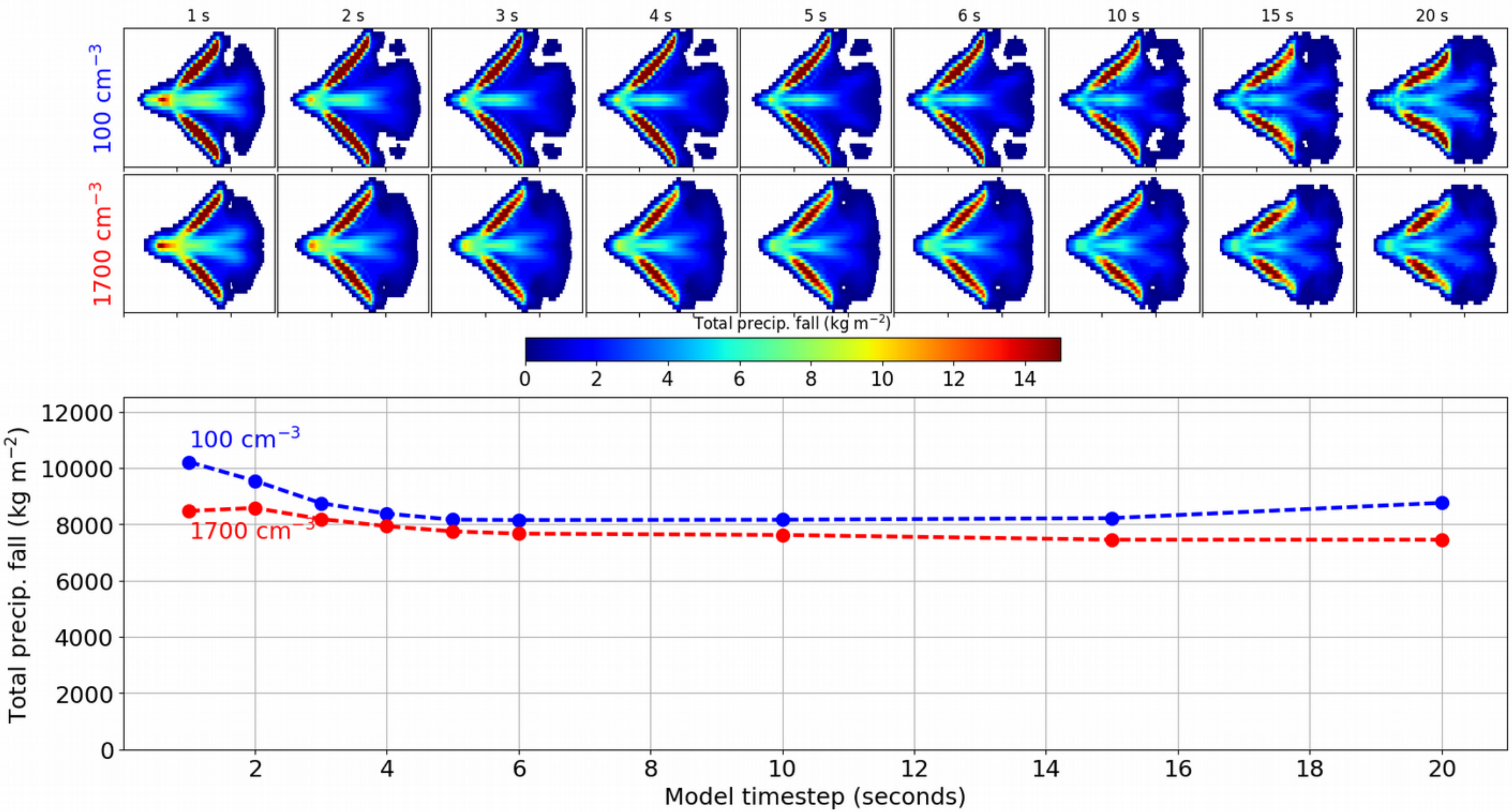
C = “Dynamics”

- Updraft
- □ cooling
- □ condensation

Aq_c^2 = “simplified microphysics”

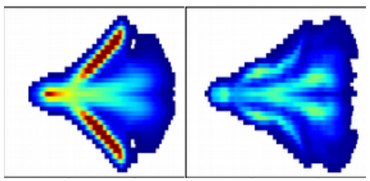


COSMO with Simultaneous Splitting



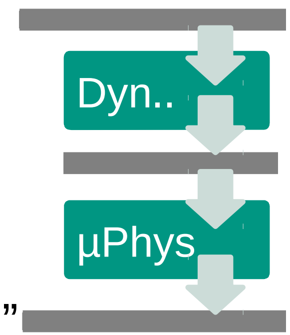
Summary

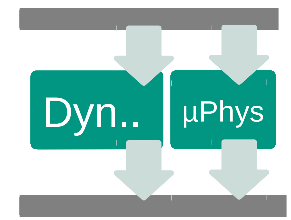
- Large and systematic effect of model timestep on convection-permitting simulations



↑	50%	increase in precipitation
↔	50km	change of maximum precipitation
?		changing sign of aerosol impact

- Caused by “Consecutive Splitting”
  - Dynamics calculated first, then microphysics
    - Supersaturation (or q_c) scales with timestep
  - Results much better with “Simultaneous Splitting”



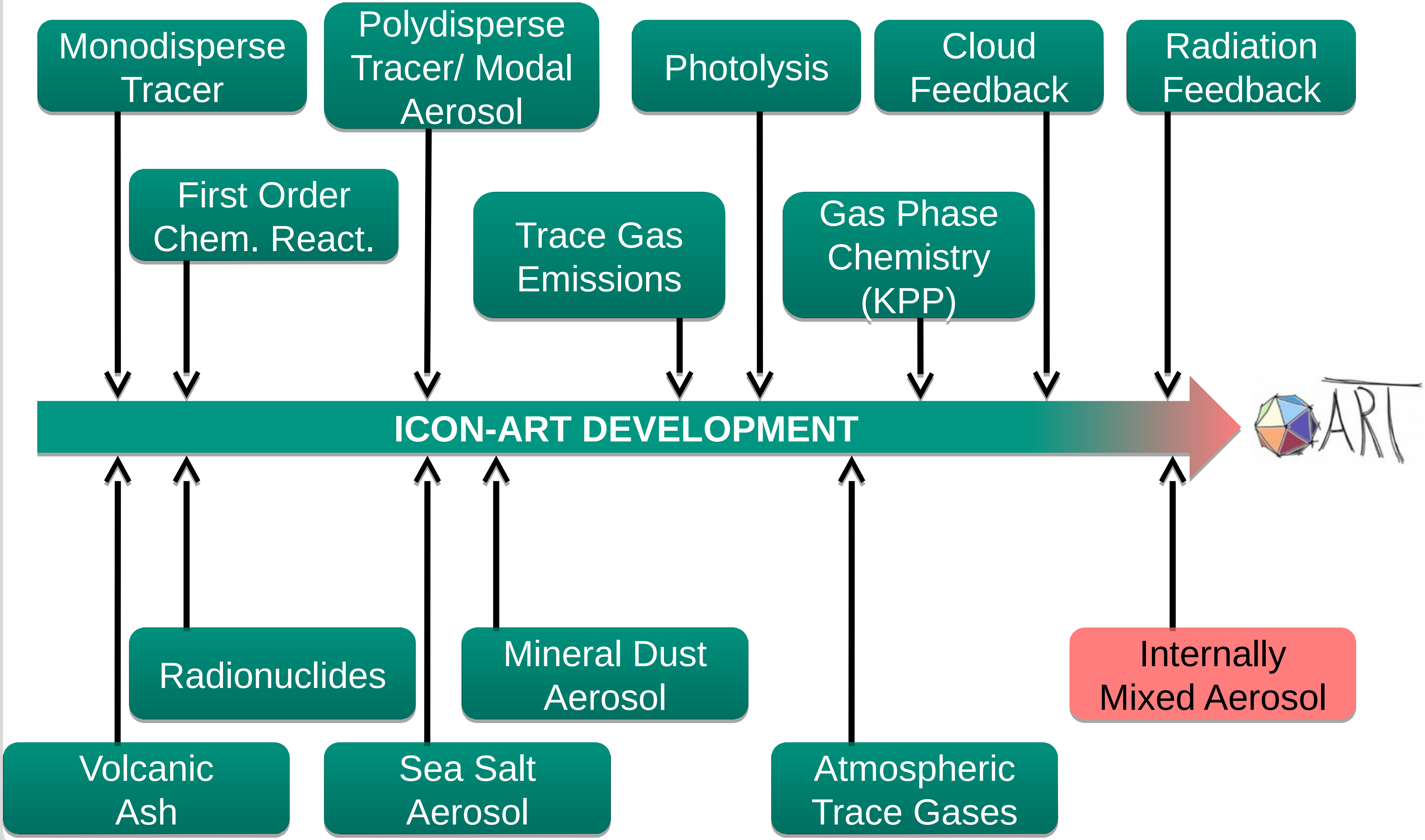


- Affecting convection-permitting simulations … in most (all?) models
  - Also affects NWP and process-studies

- Solution: Changing input for microphysics – easy to change in model

Additional material aerosol module

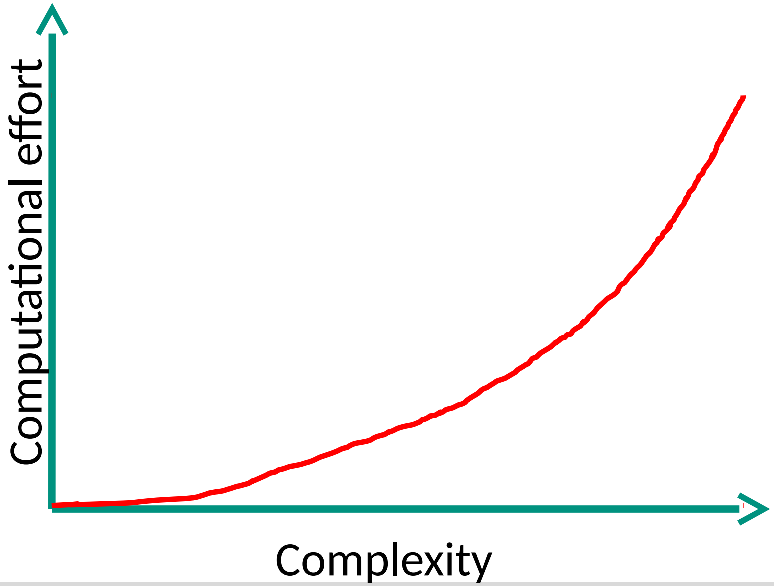
Milestones



Monodisperse Tracer
Polydisperse Tracer/ Modal Aerosol
Photolysis
Cloud Feedback
Radiation Feedback
First Order Chem. React.
Trace Gas Emissions
Gas Phase Chemistry (KPP)
ICON-ART DEVELOPMENT
ART
Radionuclides
Mineral Dust Aerosol
Internally Mixed Aerosol
Volcanic Ash
Sea Salt Aerosol
Atmospheric Trace Gases

Requirements of the aerosol model

- **Aerosol, radiation and cloud physics**
- **Convective uplift**
- **Chemistry-climate feedbacks**



The basic equation

$$\frac{\partial n(v_P)}{\partial t} = \underbrace{-\nabla \cdot \mathbf{v}\, \mathrm{n}(\mathrm{v_P})}_{Advection} - \underbrace{\nabla \cdot \mathbf{c_P}(\mathrm{v_P})\, \mathrm{n}(\mathrm{v_P})}_{External\ forces} + \underbrace{\nabla \cdot D_{PAR}(v_P) \nabla n(v_P)}_{Diffusion}$$

$$+ \underbrace{\frac{1}{2}\int_0^{v_P} \beta(v_P - \tilde{v}_P, \tilde{v}_P) n(v_P - \tilde{v}_P) n(\tilde{v}_P) d\tilde{v}_P - \int_0^{\infty} \beta(v_P, \tilde{v}_P) n(v_P) n(\tilde{v}_P) d\tilde{v}_P}_{Coagulation}$$

$$+ \underbrace{\left[\frac{\partial}{\partial t} n(v_P)\right]_g}_{Particle\ growth} + \underbrace{\dot{n}_S(v_P)}_{Sources/\sin}$$

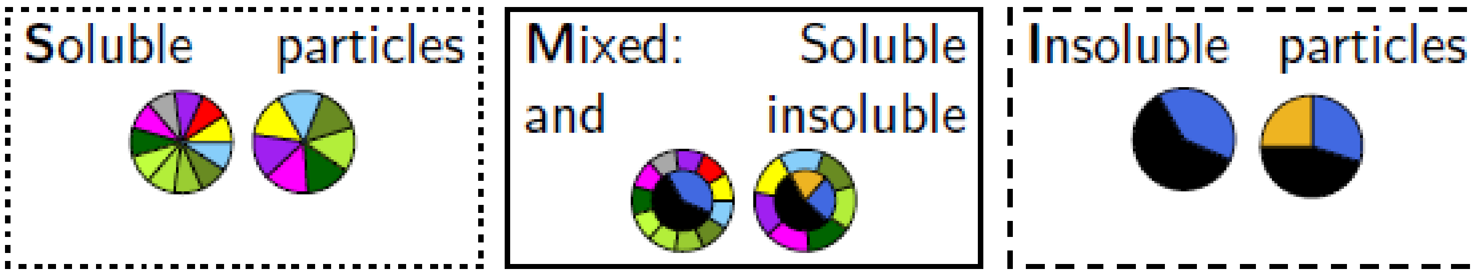
Friedlander (1977)

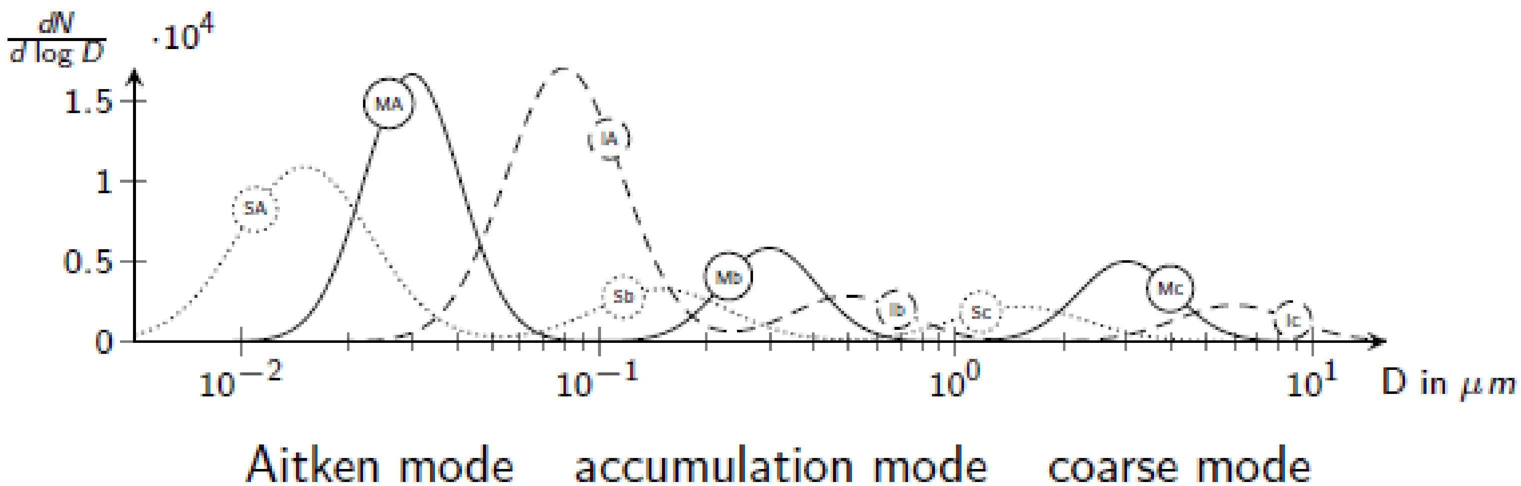
MADE-ART

SO_4 | NH_4 | NO_3 | Na | Cl | POM | SOA1 | SOA2 | SOA3 | SOA4 | H_2O

BC | DU | VA

Pol





Already realized processes

- **Atmospheric transport**
  (advection, convection, turbulent diffusion)
- **Sedimentation**
- **Washout**
- **Emission**
  (sea salt, mineral dust, volcanic ash, pollen, radioactive material)
- **Optical properties**
- **Activation**

Processes currently tested

- Coagulation
- Condensation (explicit of H_2SO_4)
- Nucleation
- Gas-aerosol partitioning

Coagulation

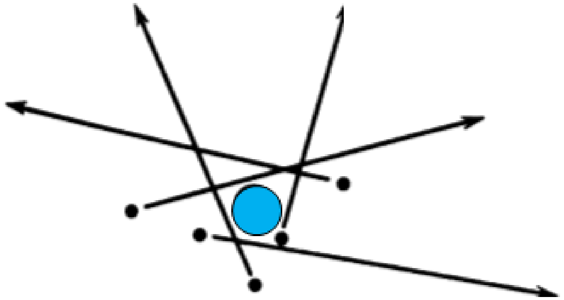
	SA	IA	MA	Sa	Ia	Ma	Sc	Ic	Mc
SA	SA	MA	MA	Sa	Ma	Ma	Sc	Mc	Mc
IA		IA	MA	Ma	Ia	Ma	Mc	Ic	Mc
MA			MA	Ma	Ma	Ma	Mc	Mc	Mc
Sa				Sa	Ma	Ma	Sc	Mc	Mc
Ia					Ia	Ma	Mc	Ic	Mc
Ma						Ma	Mc	Mc	Mc
Sc							Sc	Mc	Mc
Ic								Ic	Mc
Mc									Mc

e.g. intermodal coagulation:

$$\mathrm{Ca}_{0,ij} = \int_0^\infty \int_0^\infty \beta(d_1, d_2) n_i(d_1) n_j(d_2)\,\mathrm{d}d_1 \mathrm{d}d_2$$

Coagulation

free molecular regime:



$$\mathrm{Ca}^{\mathrm{fm}}_{0,ij} = \int_0^\infty \int_0^\infty \beta_{\mathrm{fm}}(d_1, d_2) n_i(d_1) n_j(d_2)\, \mathrm{d}d_1 \mathrm{d}d_2$$

$$= M_{0,i} M_{0,j} K_{\mathrm{fm}} b_0^{(1)} \sqrt{d_{gi}} \Bigg[e^{\frac{1}{8} ln^2(\sigma_{gi})} + \sqrt{\frac{d_{gj}}{d_{gi}}} e^{\frac{1}{8} ln^2(\sigma_{gj})}$$

$$+ 2 \frac{d_{gj}}{d_{gi}} e^{\frac{1}{8} ln^2(\sigma_{gi})} e^{\frac{4}{8} ln^2(\sigma_{gj})} + \frac{{d_{gj}}^2}{{d_{gi}}^2} e^{\frac{9}{8} ln^2(\sigma_{gi})} e^{\frac{16}{8} ln^2(\sigma_{gj})}$$

$$+ \left(\sqrt{\frac{d_{gi}}{d_{gj}}} \right)^3 e^{\frac{16}{8} ln^2(\sigma_{gi})} e^{\frac{9}{8} ln^2(\sigma_{gj})} + 2 \sqrt{\frac{d_{gi}}{d_{gj}}} e^{\frac{4}{8} ln^2(\sigma_{gi})} e^{\frac{1}{8} ln^2(\sigma_{gj})} \Bigg]$$

Condensation

$$\frac{\partial C_{SO_4,l}}{\partial t} = \frac{\pi}{6} \cdot G_l^3 \cdot C_{H_2SO_4}(t)$$

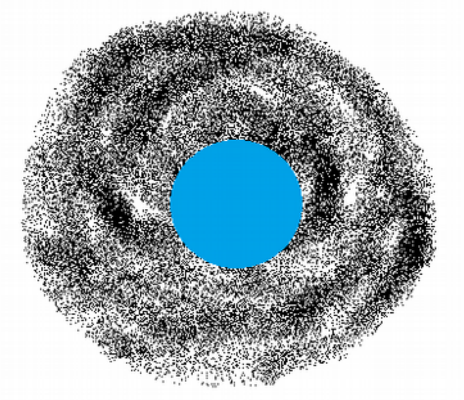
$$G_l^3 = \frac{G_{l,fm}^3 \cdot G_{l,nc}^3}{G_{l,fm}^3 + G_{l,nc}^3}$$

$$G_{l,fm}^3 = \frac{6}{\pi}\frac{\pi\alpha\bar{c}}{4}M_l^2$$

$$G_{l,nc}^3 = \frac{6}{\pi}2\pi D_v M_l^1$$

Coagulation

near continuum regime:



$$\begin{aligned}
\mathrm{Ca}^{\mathrm{nc}}_{0,ij} &= \int_0^\infty \int_0^\infty \beta_{\mathrm{nc}}(d_1, d_2) n_i(d_1) n_j(d_2) \mathrm{d}d_1 \mathrm{d}d_2 \\
&= M_{0,i} M_{0,j} K_{\mathrm{nc}} \left[2 + A_i \mathrm{Kn}_{g_i} \left(e^{\frac{4}{8}\ln^2(\sigma_{gi})} + \frac{d_{gj}}{d_{gi}} e^{\frac{16}{8}\ln^2(\sigma_{gi})} e^{\frac{4}{8}\ln^2(\sigma_{gj})} \right) \right. \\
&\quad + A_j \mathrm{Kn}_{g_j} \left(e^{\frac{4}{8}\ln^2(\sigma_{gj})} + \frac{d_{gi}}{d_{gj}} e^{\frac{16}{8}\ln^2(\sigma_{gj})} e^{\frac{4}{8}\ln^2(\sigma_{gi})} \right) \\
&\quad \left. + \left(\frac{d_{gi}}{d_{gj}} + \frac{d_{gj}}{d_{gi}} \right) \left(e^{\frac{4}{8}\ln^2(\sigma_{gj})} \right) \left(e^{\frac{4}{8}\ln^2(\sigma_{gi})} \right) \right]
\end{aligned}$$

Nucleation

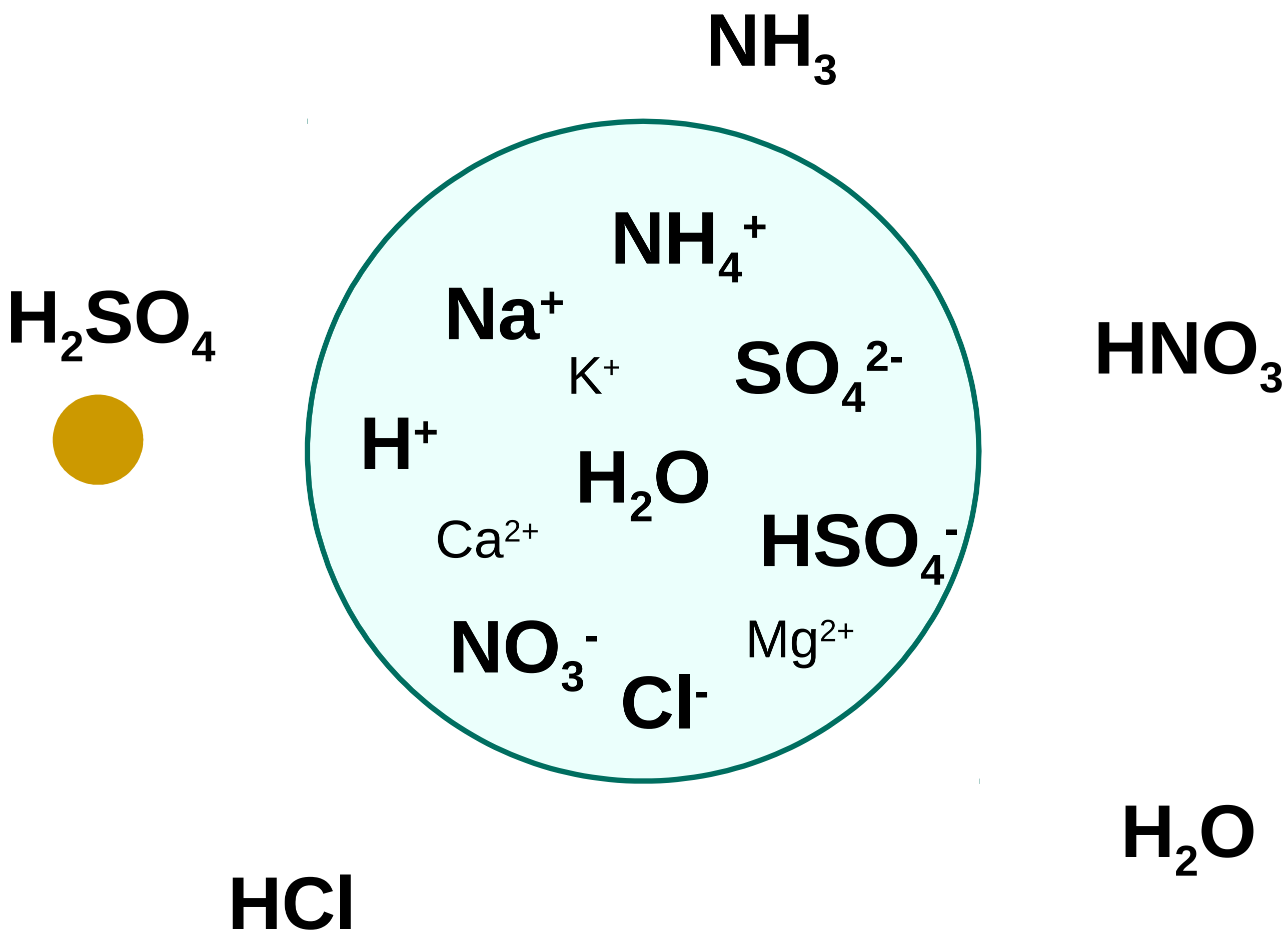
- **Calculation of the loss of sulfuric acid on already existing particles**

- **Calculation of a critical concentration according to Wexler (1994).**

$$c_{crit} = 0.16 \cdot \exp\left(0.1 \cdot T - 3.5 \frac{RH}{100} - 27.7\right)$$

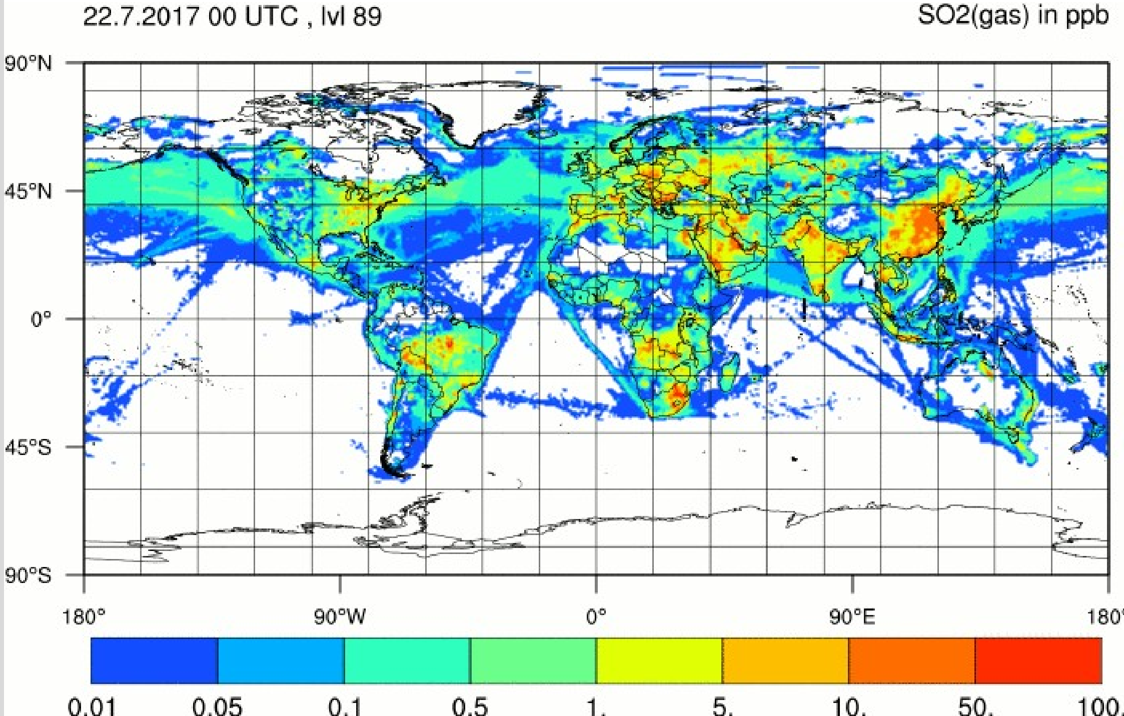
- **Remaining mass above c_{crit} nucleates and forms new particles**

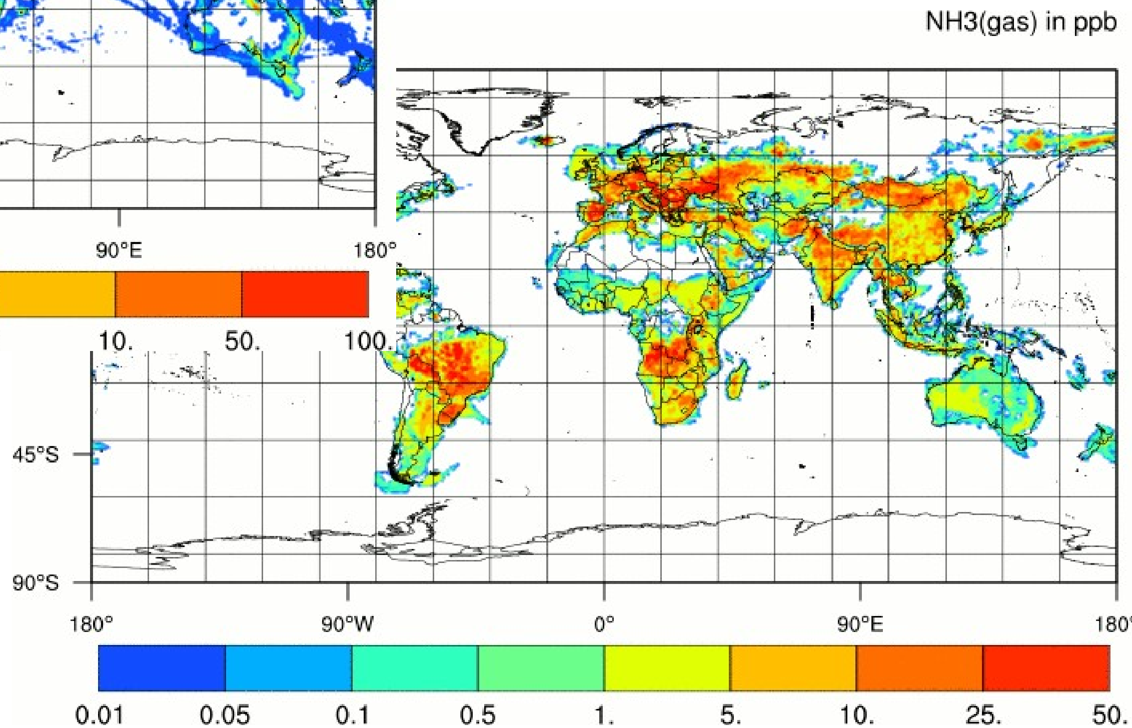
Gas-aerosol partitioning



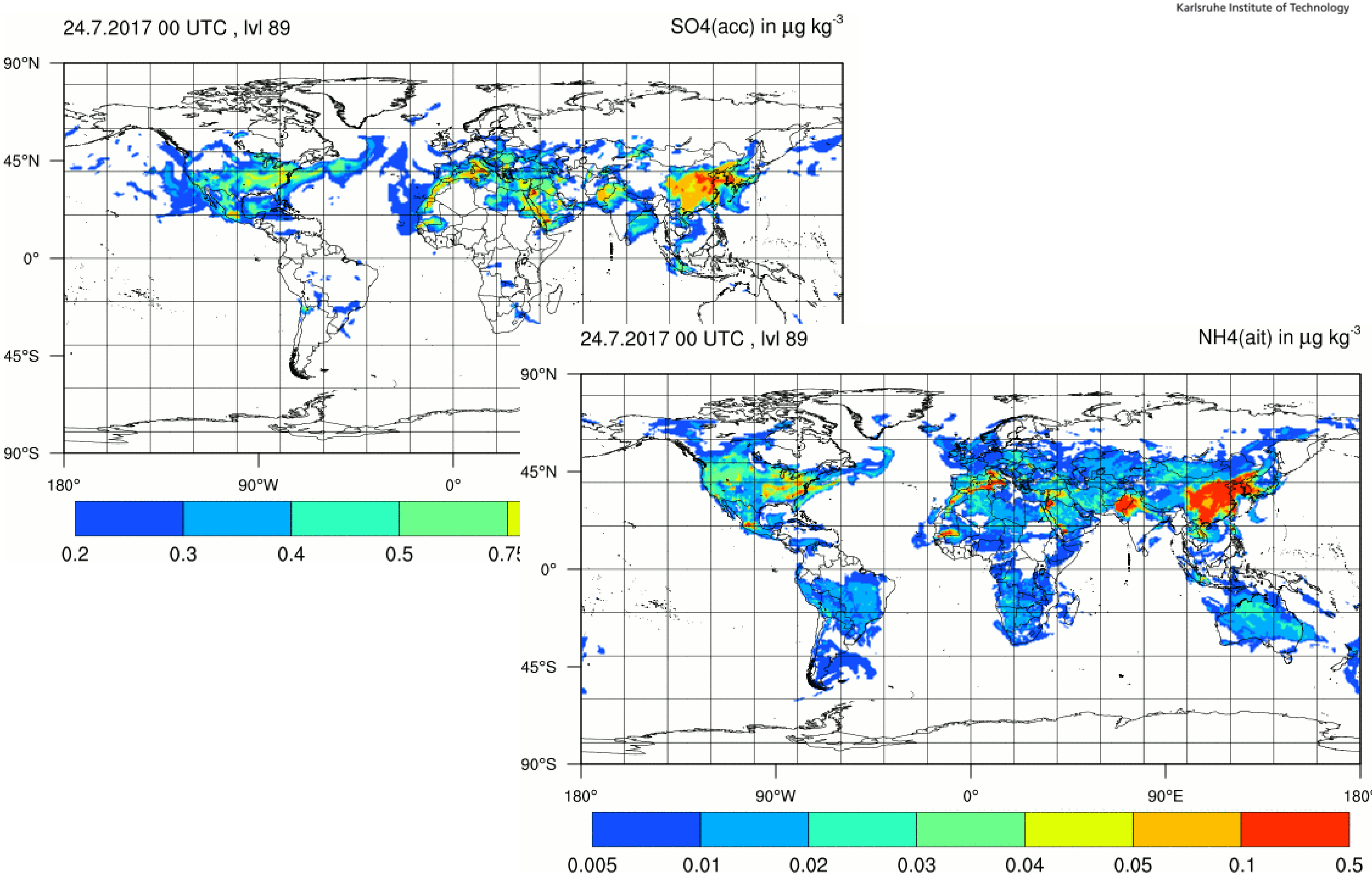
ISORROPIA, Nenes, Fountoukis

Simulated SO_2 and NH_3 concentration

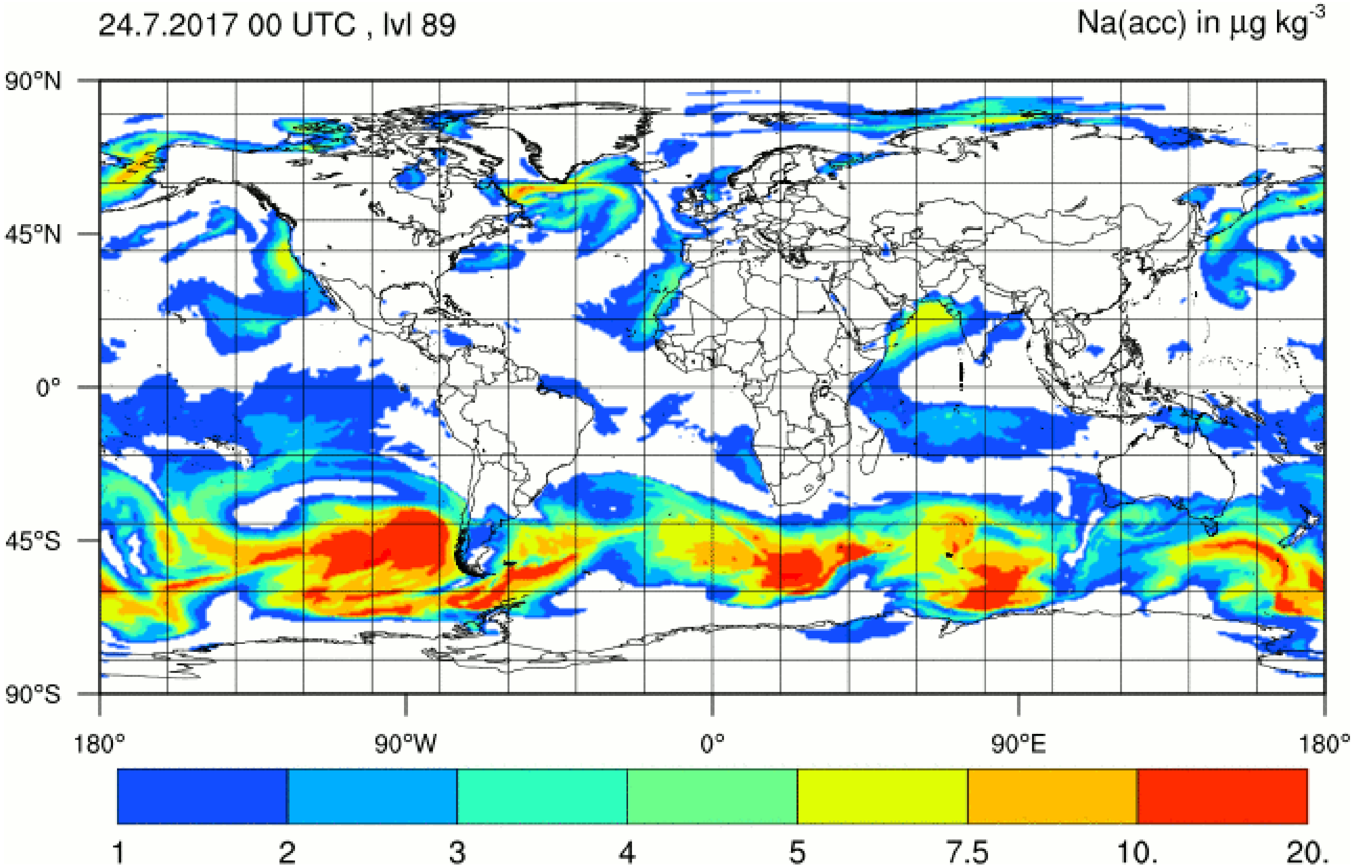




Sulfate and ammonia concentration



Sea salt concentration



Summary

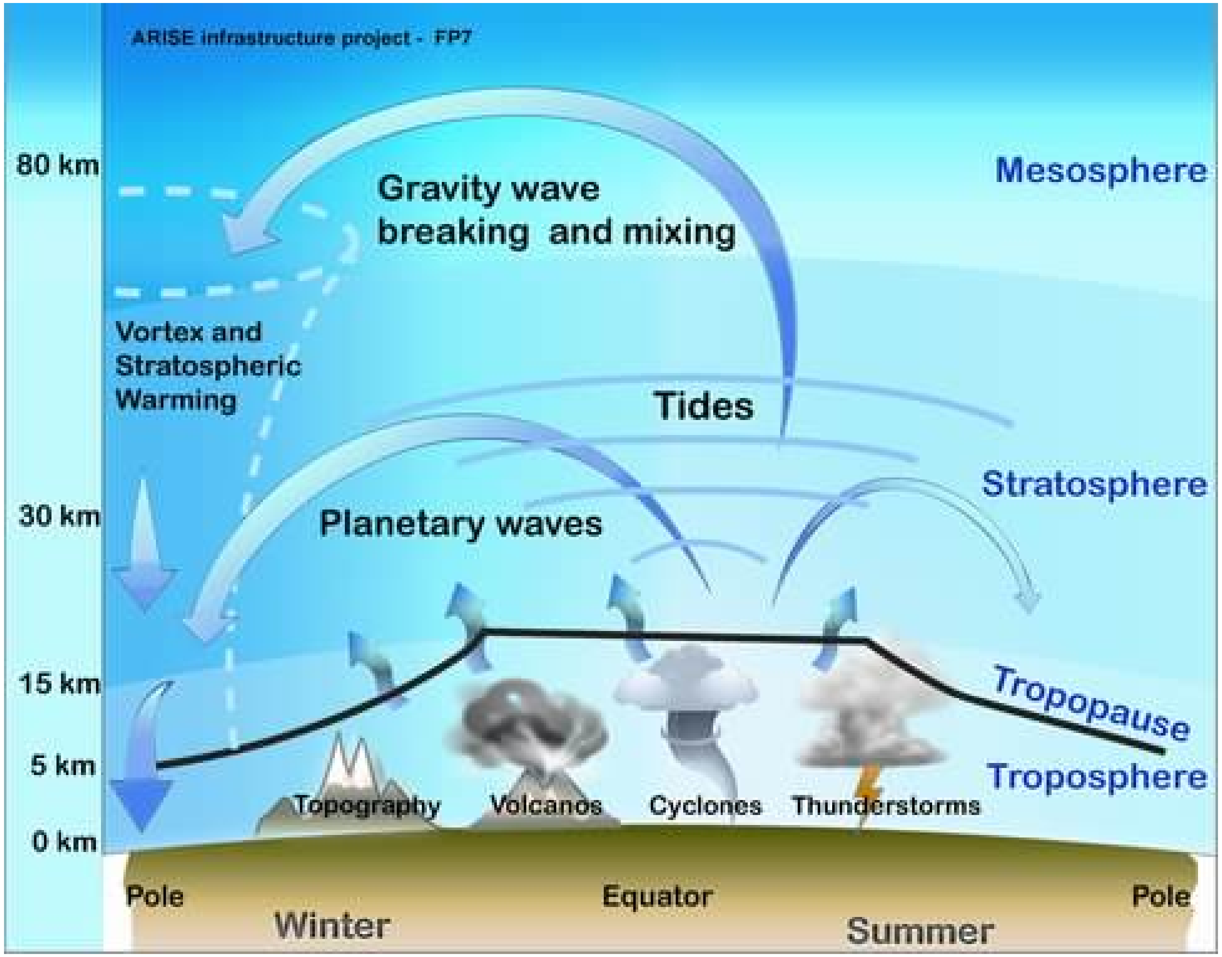
Karlsruhe Institute of Technology

- New aerosol module for ICON-ART developed and realized (testing phase)

- Mode structure allows large range of complexity:

  → reduced aerosol module for NWP-applications
  detailed aerosol module for research

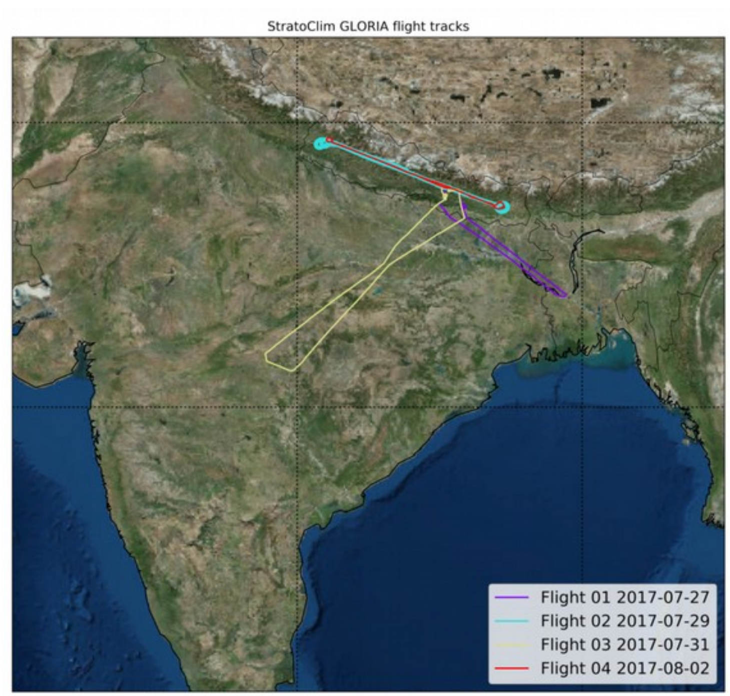
Seamless in the vertical direction

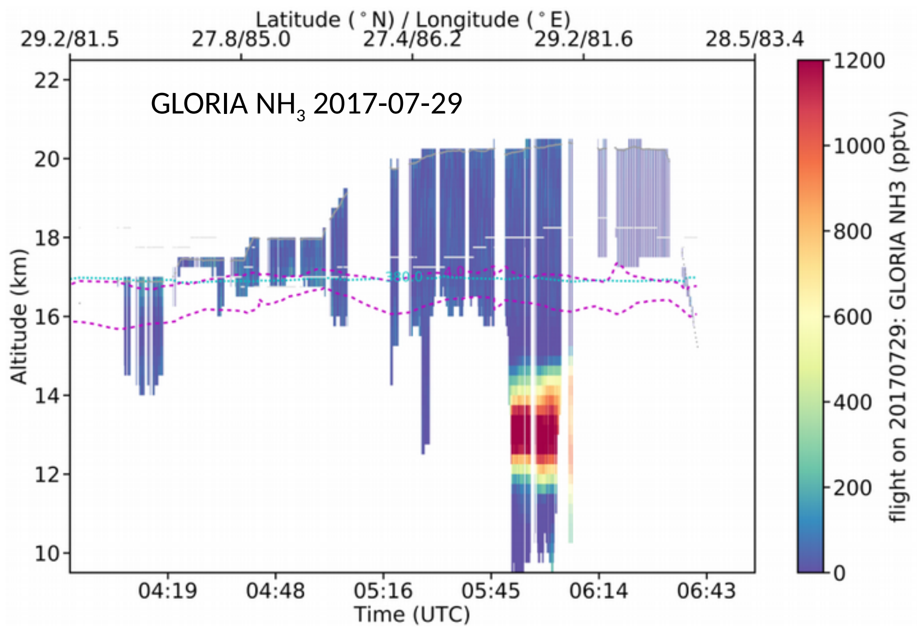


ARISE
Atmospheric dynamics Research
InfraStructure in Europe

Observations in the Asian Monsoon July 2017

- Very high values (**> 1 ppbv**) of NH_3 measured (12 km - 14 km)
- ~40 times higher than maximum NH_3 values measured by MIPAS-Envisat
- Inhomogeneous horizontal distribution



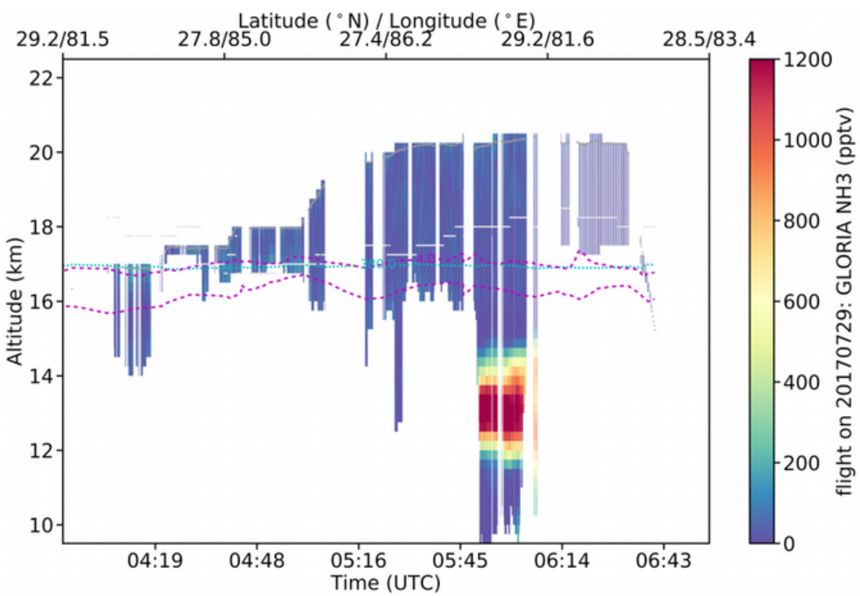


Sören Johansson for the GLORIA Team

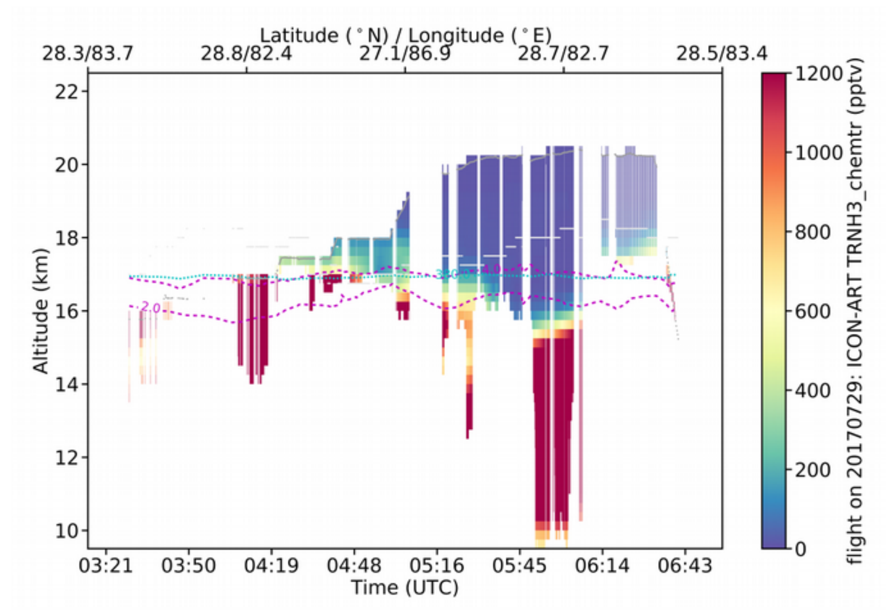
Institute of Meteorology and Climate Research -
Atmospheric Trace Gases and Remote Sensing

Comparison with observations

GLORIA NH_3 2017-07-29



ICON-ART NH_3 2017-07-29



Sören Johannson & Michael Höpfner

Poster: Carmen Ullwer et al., Investigation of the distribution of aerosol-forming trace gases in the UTLS region with ICON-ART

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Johannes Eckstein[2]
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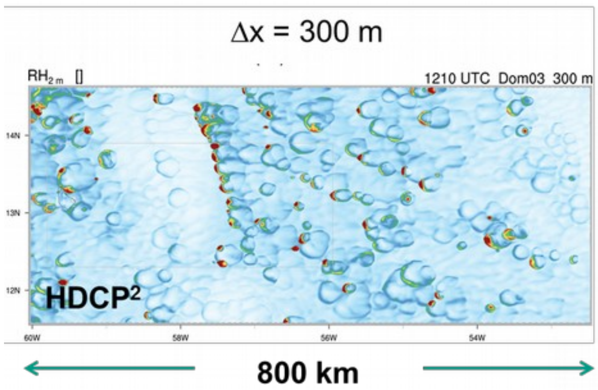
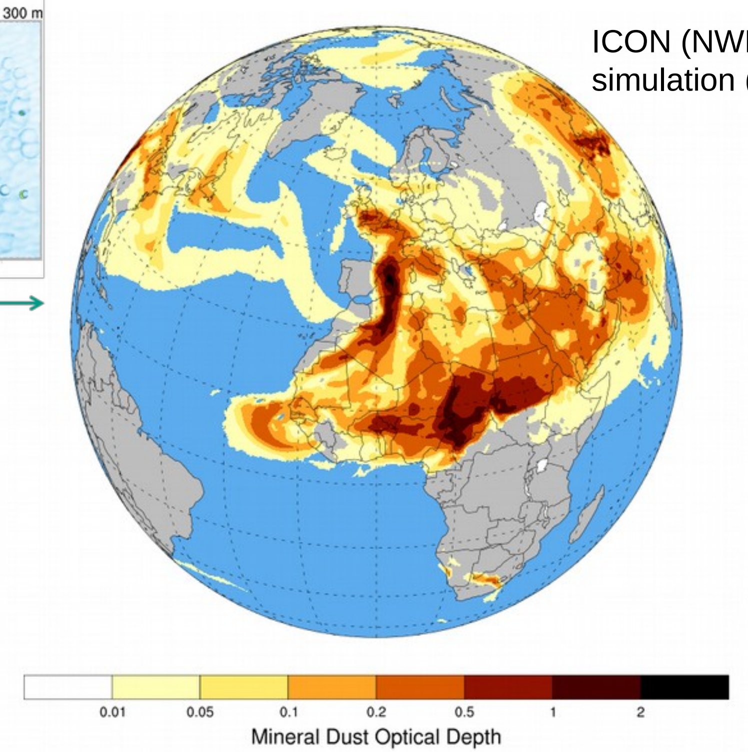
[4] KIT, Steinbuch Centre for Computing

What makes ICON and ICON-ART unique?

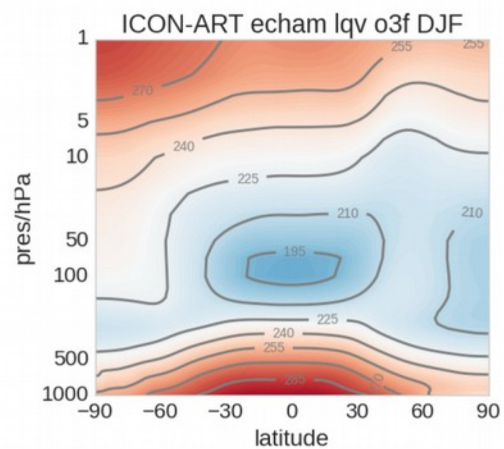
- Seamless in horizontal and vertical scales (troposphere-mesosphere)
- Seamless in time (seconds-decades): (LES) – Weather – Climate



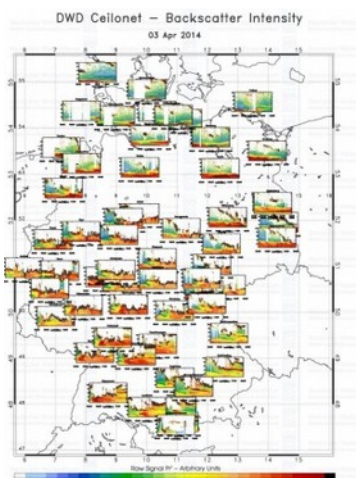
ICON (NWP) mineral dust simulation (case study)



ICON (Climate) temperature structure with interactive ozone



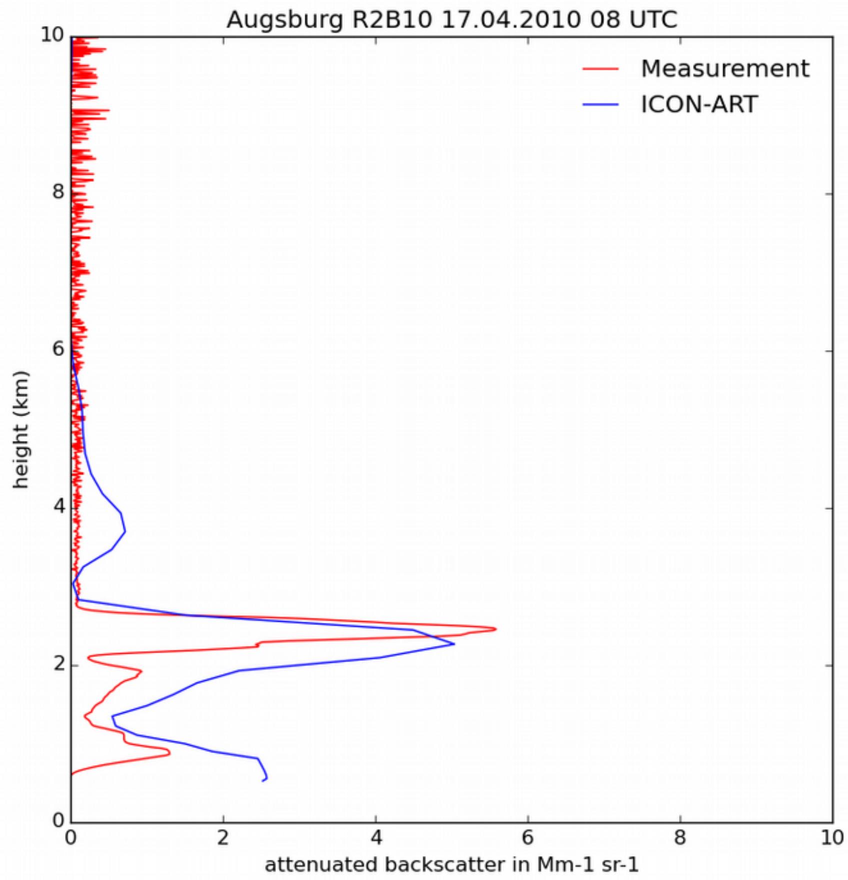
Link between observation and simulation

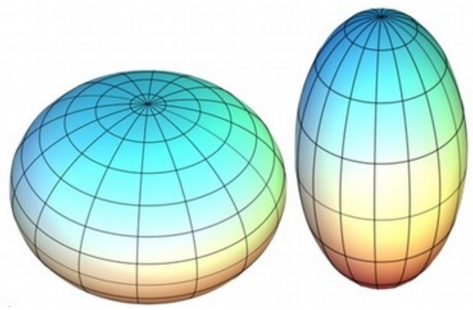


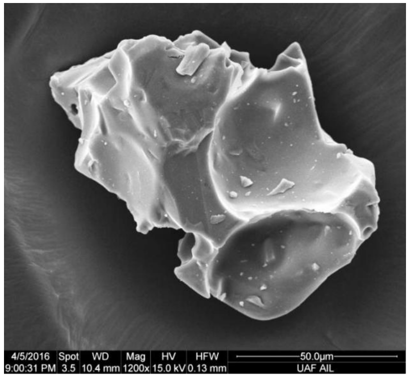
Attenuated backscatter ⟷ Aerosol concentration

➡ Development and implemention of forward operators of natural and anthropogenic aerosol

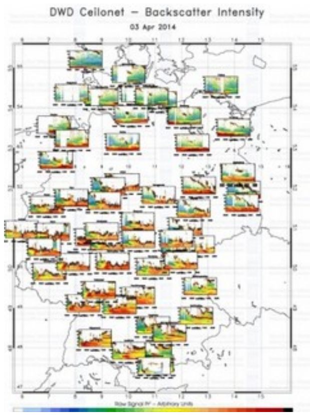
Vertical profile of attenuated backscatter







Link between observation and simulation



Attenuated backscatter ⟷ Aerosol concentration

$$P(z) = C_L \frac{\beta(z)}{z^2} exp\left(-2\int_0^z \alpha(z')dz'\right)$$

Frequently the Lidar ratio S is used to derive the backscatter coefficient

$$\beta(\lambda) = \frac{\alpha(\lambda)}{S}$$

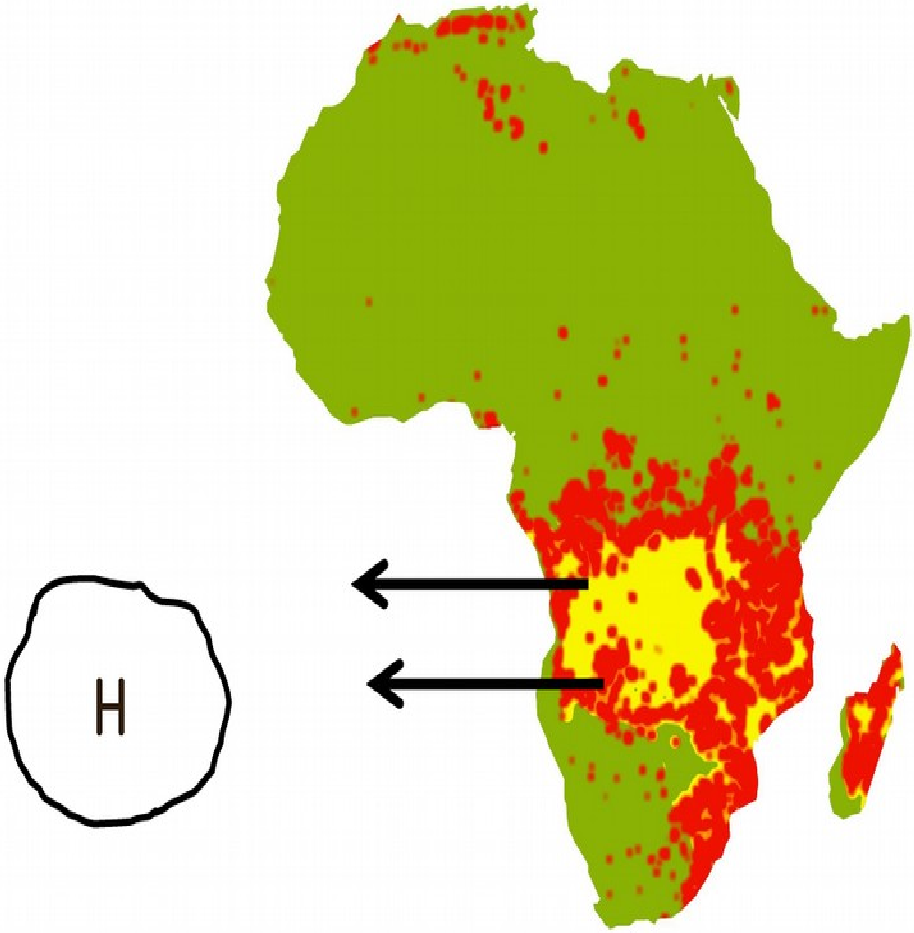
➡ Preferable: Direct calculation of the backscatter coefficient

Some hypothesis and evidence

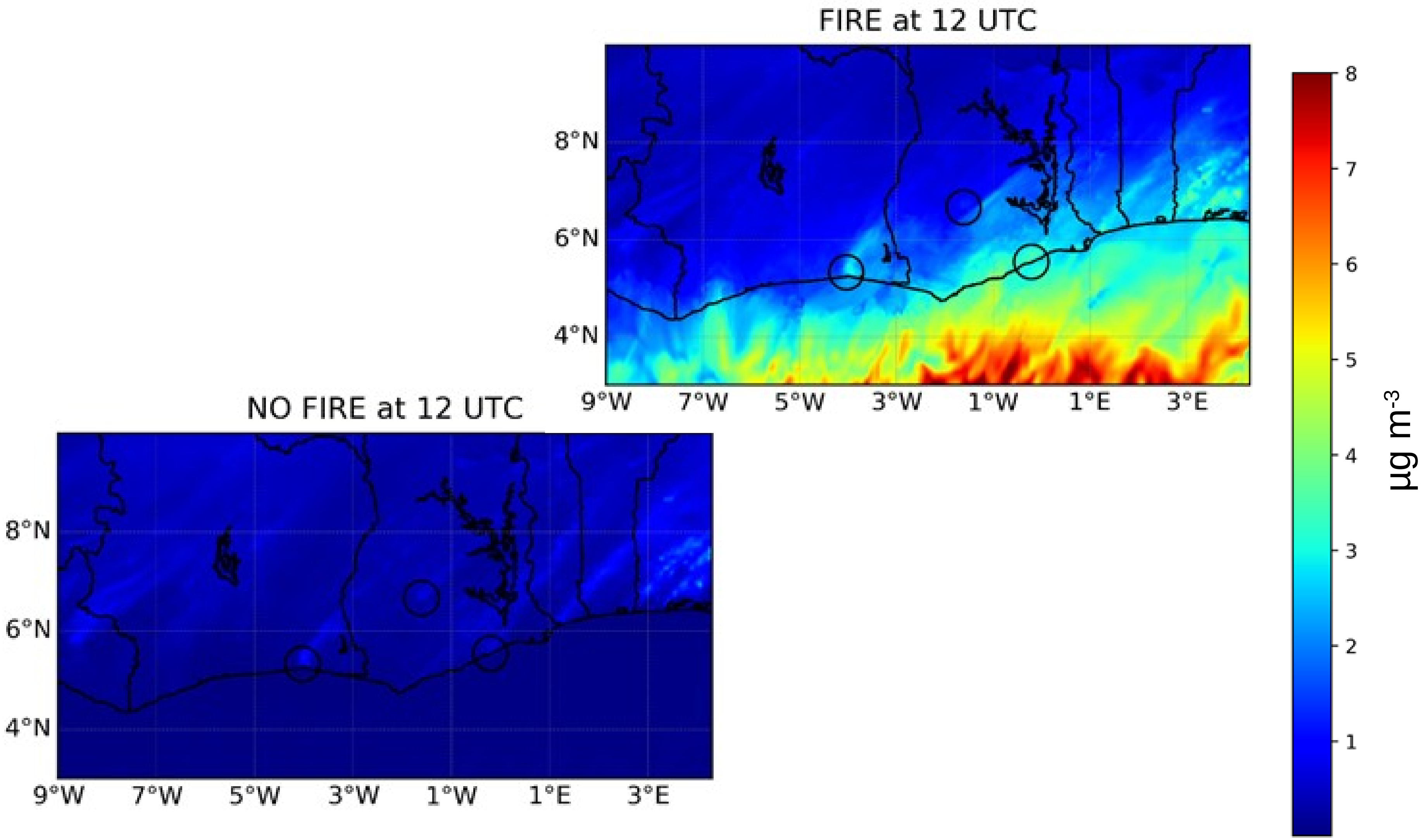
- Evidence of biomass burning plumes in central and south Africa from June to September.

- According to Mari et al, 2008, there is a long-range biomass transport which is carried Westward by a jet at 700 hPa between 2 to 4 km

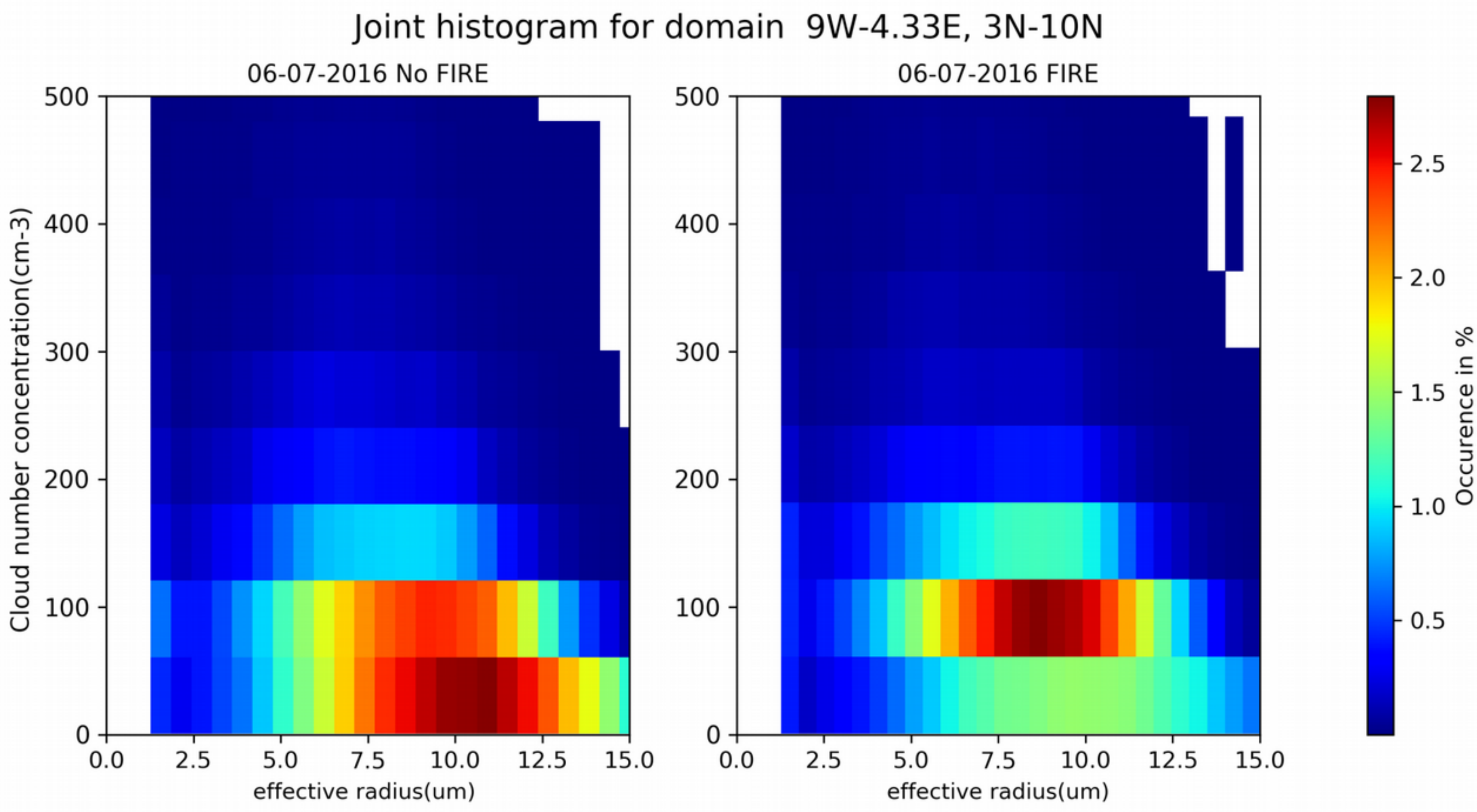
- High-pressure region to the West of African continent might play a role to mix it into the boundary layer. (Haslett, 2017)



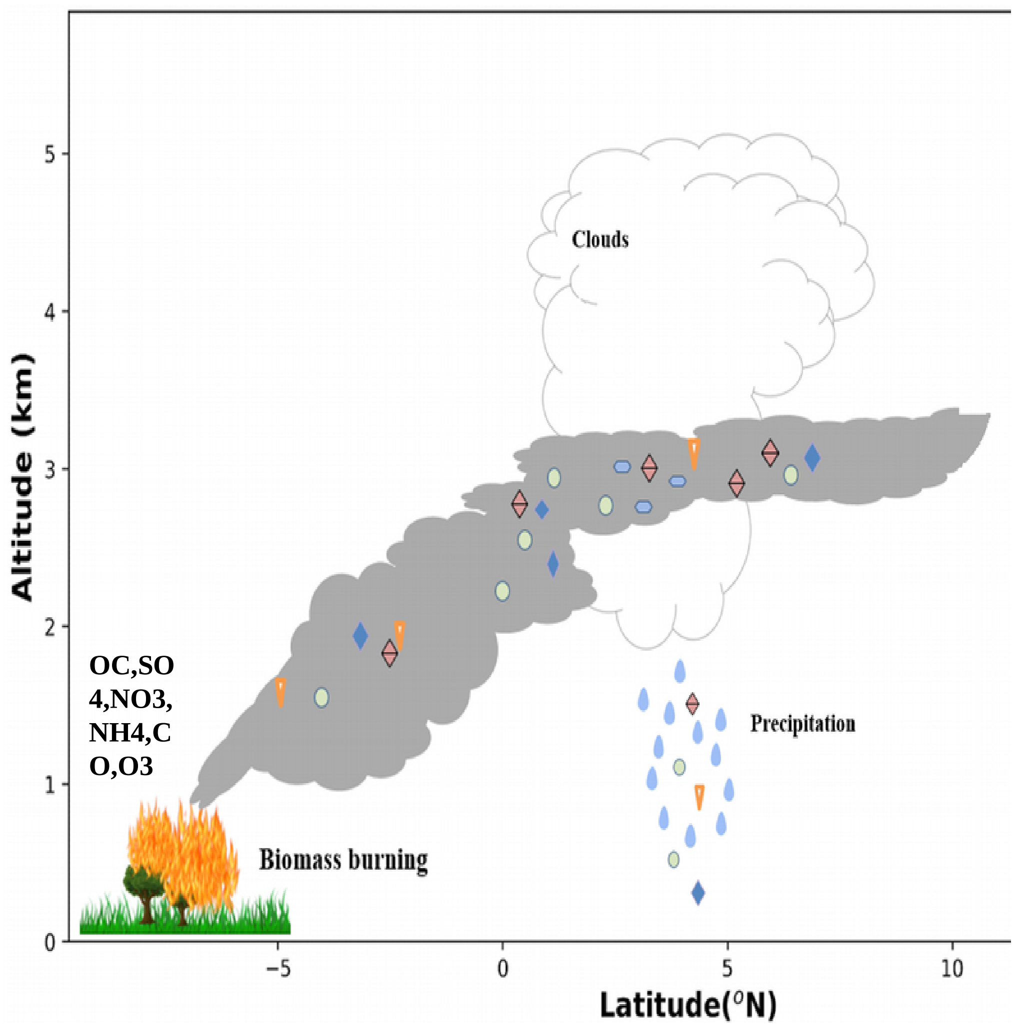
Organic aerosol wo/w vegetation fire



Impact on CDN and r_e



Conceptual model

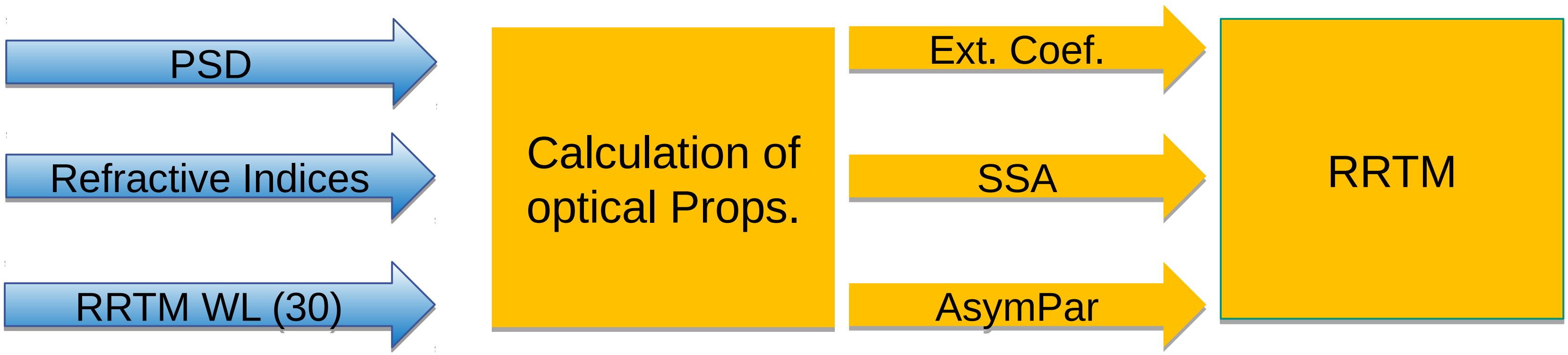


- **Clouds** bring aerosols from aloft into PBL.
- **7.46%** increase of CDNC over the DACCIWA region and **32.92%** over the marine domain.
- **50 w/m2** decrease in direct surface incoming SW radiation
- Mass concentration flux rate can reach **5 µg m-^{2} s^{-1}.**

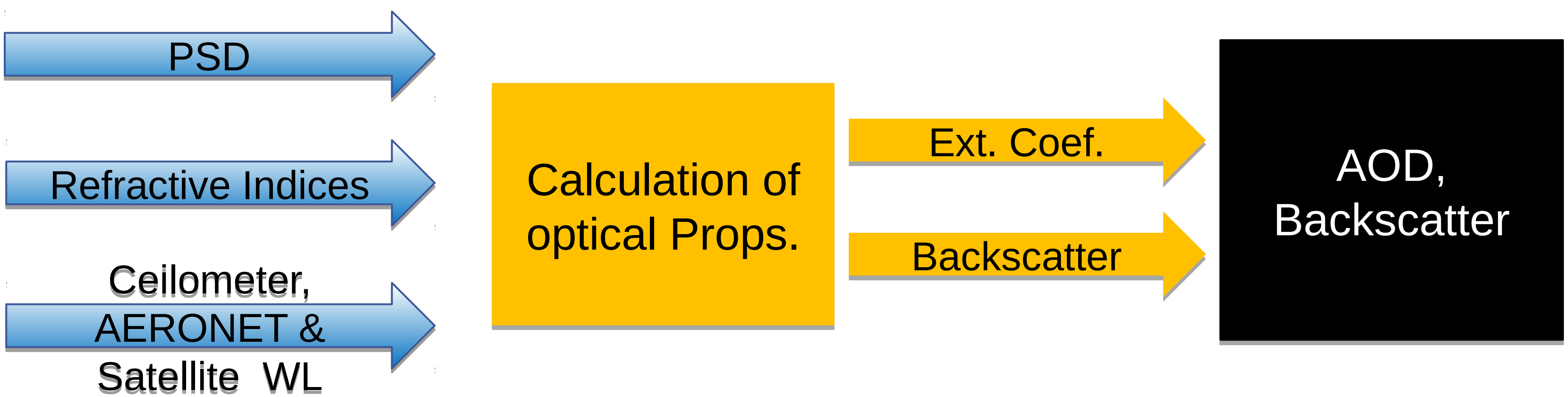
Dust optical properties in ICON-ART

Karlsruhe Institute of Technology

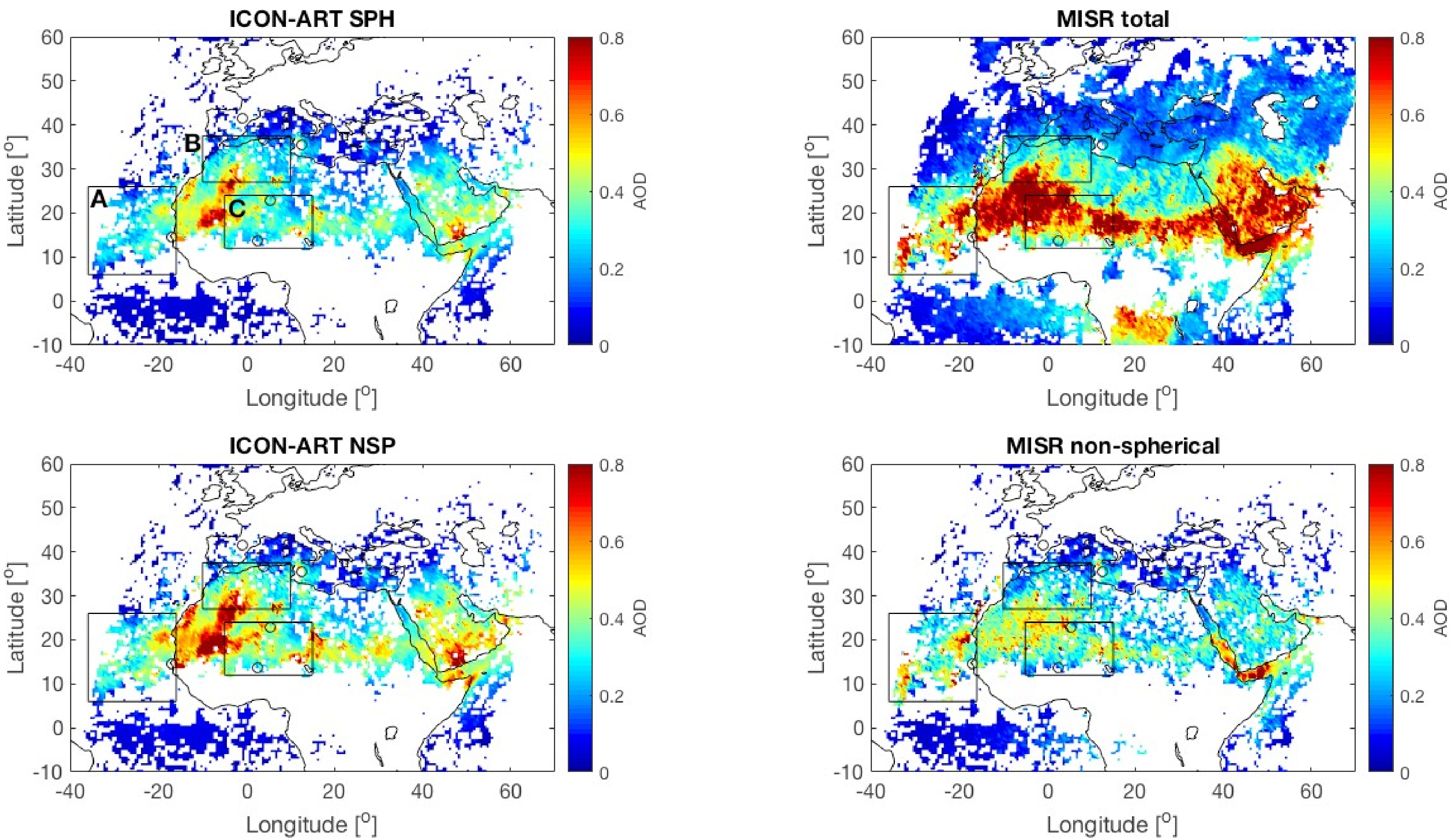
Prognostic (for direct radiative effect):



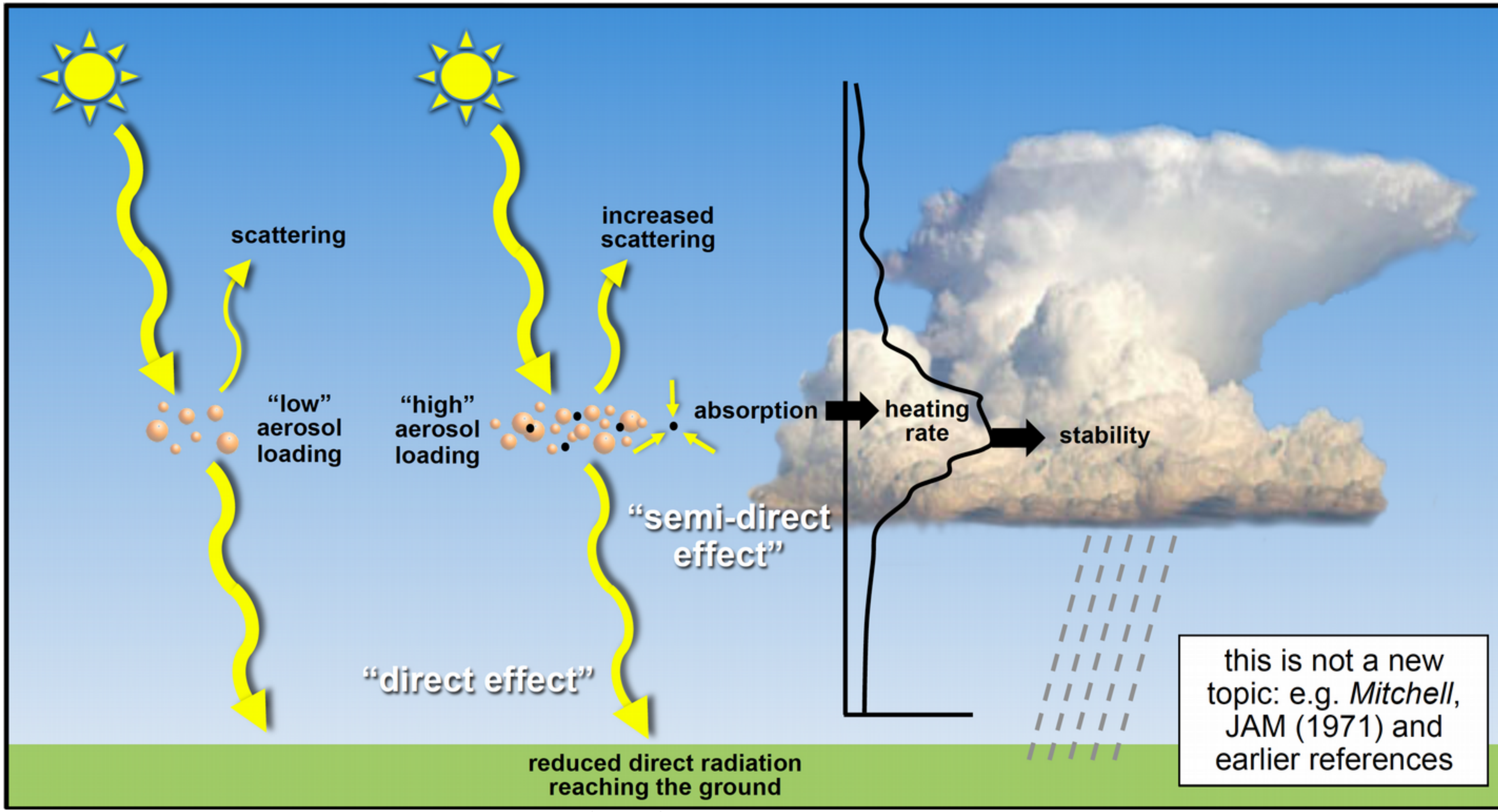
Diagnostics (for AOD and AB):



Verification: Mean AOD July 2017



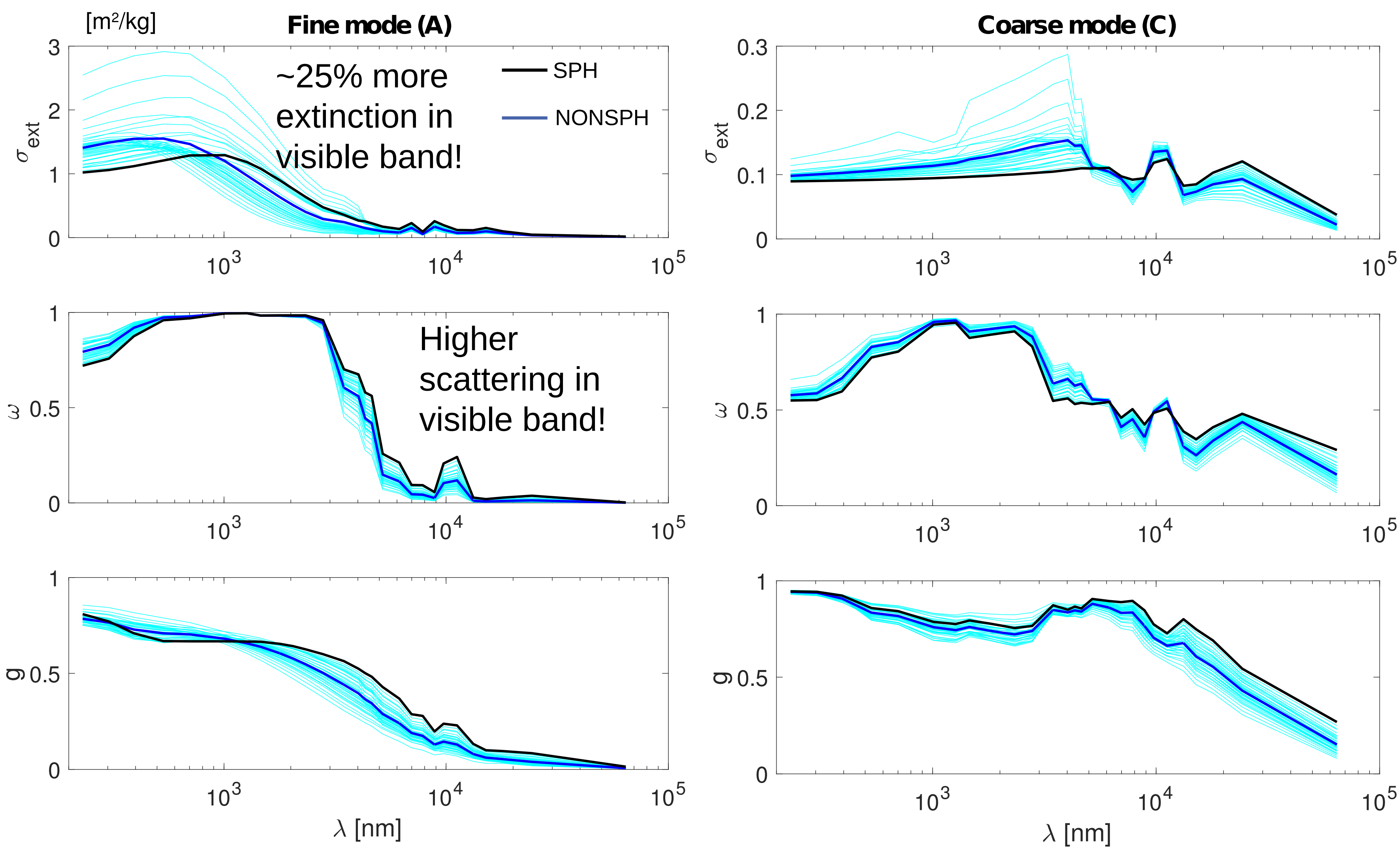
Impact of particles on radiation



Photovoltaic Energy Generation ⇔ **Surface heat and latent heat fluxes**

Source: Alma Hodzic, NCAR

Calculated optical properties



Uncertainties/outlook

- Particle size distribution (emitted and transported)
- Variable median diameter and its impacts on optical props
- Dynamic land surface properties for emissions
- Parameterization of convective dust emission

Hoshyaripour, G., Bachmann, V., Förstner, J., Steiner, A., Vogel, H., Wagner, F. , Vogel, B. Accounting for Particle Non-sphericity in a Dust Forecast System: Impacts on Model-Observation Comparison, submitted to JGR

Further acitivities

- Operational pollen forecast at MeteoSwiss (web page and app!)
- Simulation of air quality in the area of Karlsruhe and comparison with detailed measurements (IMK-AAF)
- EMPA
- Investigation of timestep dependency of aerosol-cloud-convection modelling study results:
  Barrett et al 2018: "One Step at a Time: How Model Timestep Significantly Affects Convection-Permitting Simulations" submitted to Journal of Advances in Modelling Earth Systems (JAMES)