From Molecules to droplets- learning the formation of Clouds using the CLOUD Chamber at CERN. Development of a charged Cloud Condensation Nuclei (CCN) Generator.

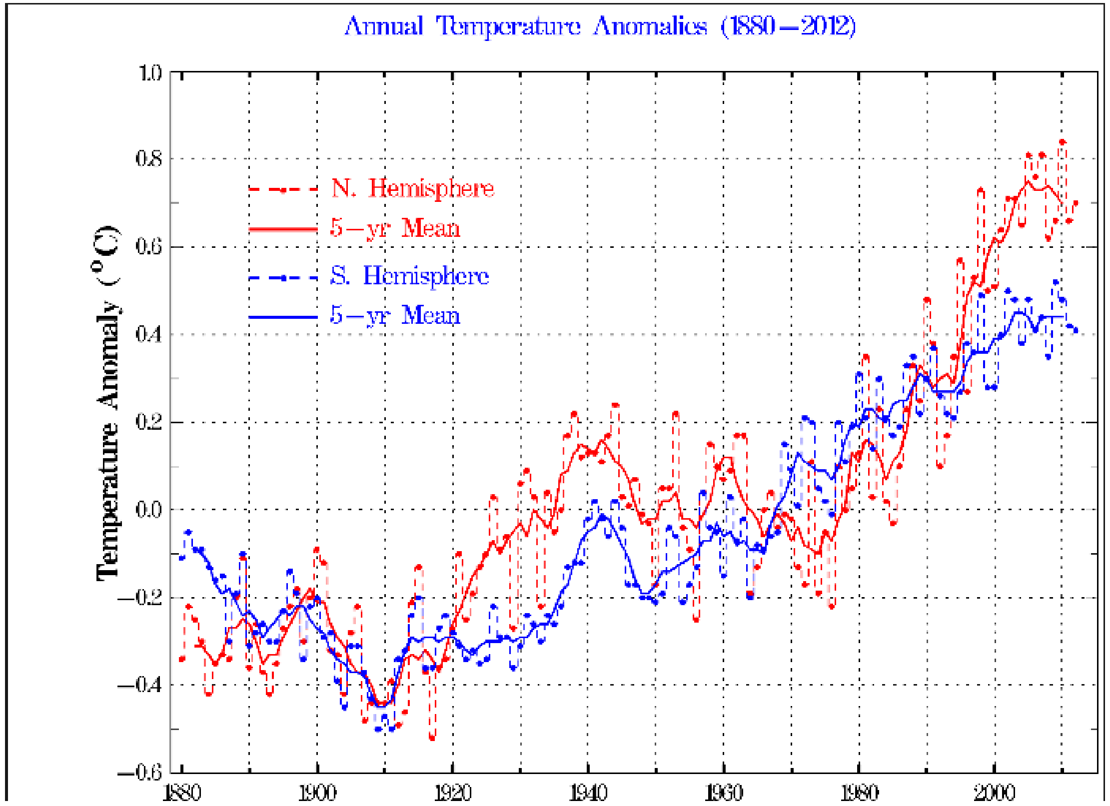
Joschka Pfeifer (CLOUD Experiment, CERN)

The cloud collaboration:

Aerodyne Research Inc., Billerica, Massachusetts 01821, USA
California Institute of Technology, Div. of Chemistry & Chemical Engineering, Pasadena, California 91125, USA
Carnegie Mellon University, Center for Atmospheric Particle Studies, Pittsburgh PA 15213-3890, USA
CERN, CH-1211 Geneva, Switzerland
Finnish Meteorological Institute, FI-00101 Helsinki, Finland
Goethe-University of Frankfurt, Institute for Atmospheric and Environmental Sciences, 60438 Frankfurt am Main, Germany
Helsinki Institute of Physics, University of Helsinki, FI-00014 Helsinki, Finland
Karlsruhe Institute of Technology, Institute for Meteorology and Climate Research, 76344 Eggenstein-Leopoldshafen, Germany
Lebedev Physical Institute, Solar and Cosmic Ray Research Laboratory, 119991 Moscow, Russia
Leibniz Institute for Tropospheric Research, 04318 Leipzig, Germany
Paul Scherrer Institute, Laboratory of Atmospheric Chemistry, CH-5232 Villigen, Switzerland
TOFWERK AG, CH-3600 Thun, Switzerland
University of Eastern Finland, Department of Applied Physics, FI-70211 Kuopio, Finland
University of Helsinki, Department of Physics, FI-00014 Helsinki, Finland
University of Innsbruck, Institute for Ion and Applied Physics, 6020 Innsbruck, Austria
University of Leeds, School of Earth and Environment, LS2-9JT Leeds, UK
University of Lisbon and University of Beira Interior, 1749-016 Lisbon, Portugal
University of Manchester, School of Earth, Atmospheric and Environmental Sciences, Manchester M13 9PL, UK
University of Stockholm, Department of Applied Environmental Science, 10691 Stockholm, Sweden
University of Vienna, Faculty of Physics, 1090 Vienna, Austria

EUROPEAN COMMISSION   CERN   cloud

Motivation: Understanding the earths climate to understand i.e. the links regarding climate change



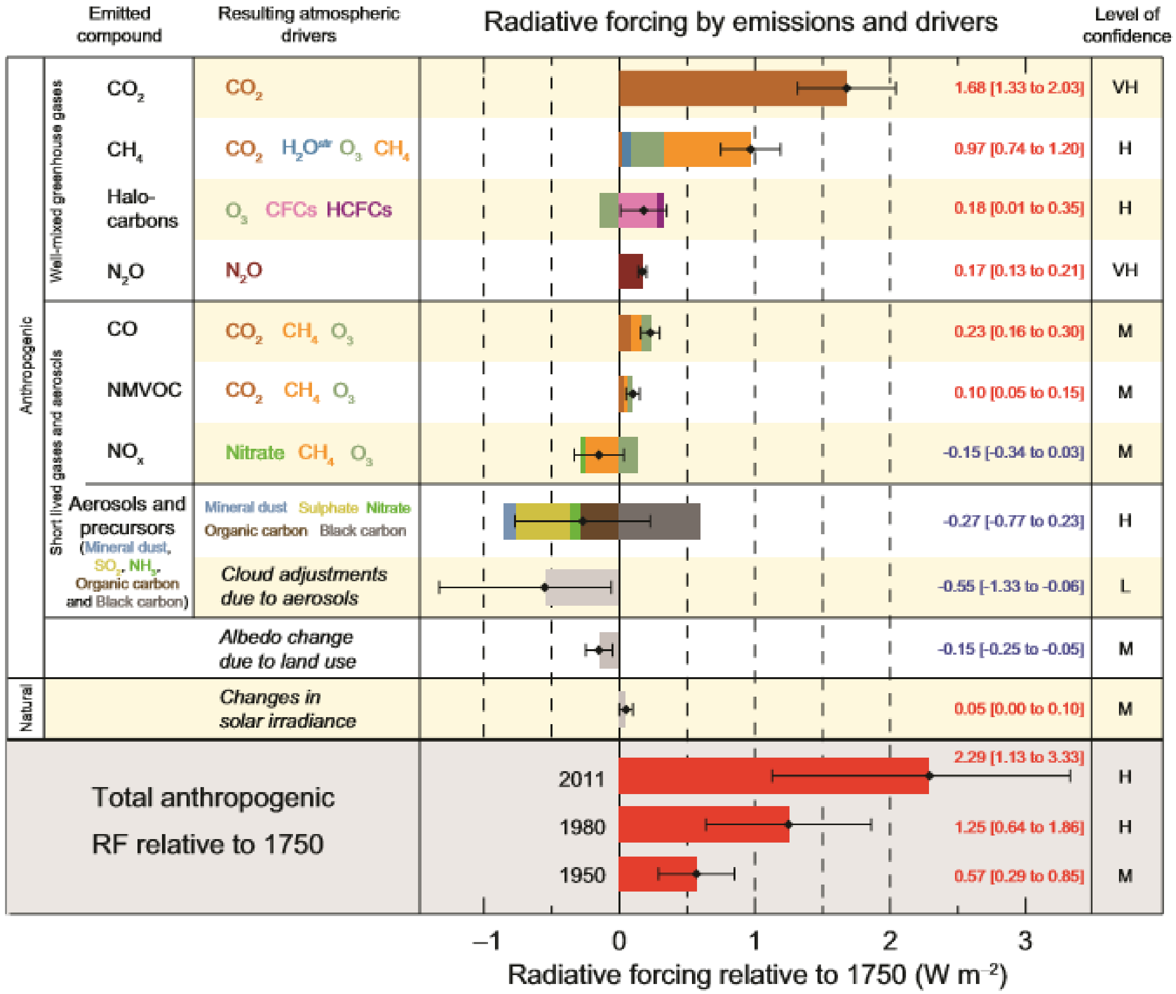
J.E. Hansen, NASA Goddard Institute for Space Studies (2012)

Key questions:

- How did our climate look like before industrial revolution?
- How do ions, i.e. produced by galactic cosmic rays, affect our climate?
- How will our climate look like in the future, based on what we learn from the past?
- Implementing the results of CLOUD into climate models that predict future climate change.

EUROPEAN COMMISSION

Radiative forcing of main components of the atmosphere

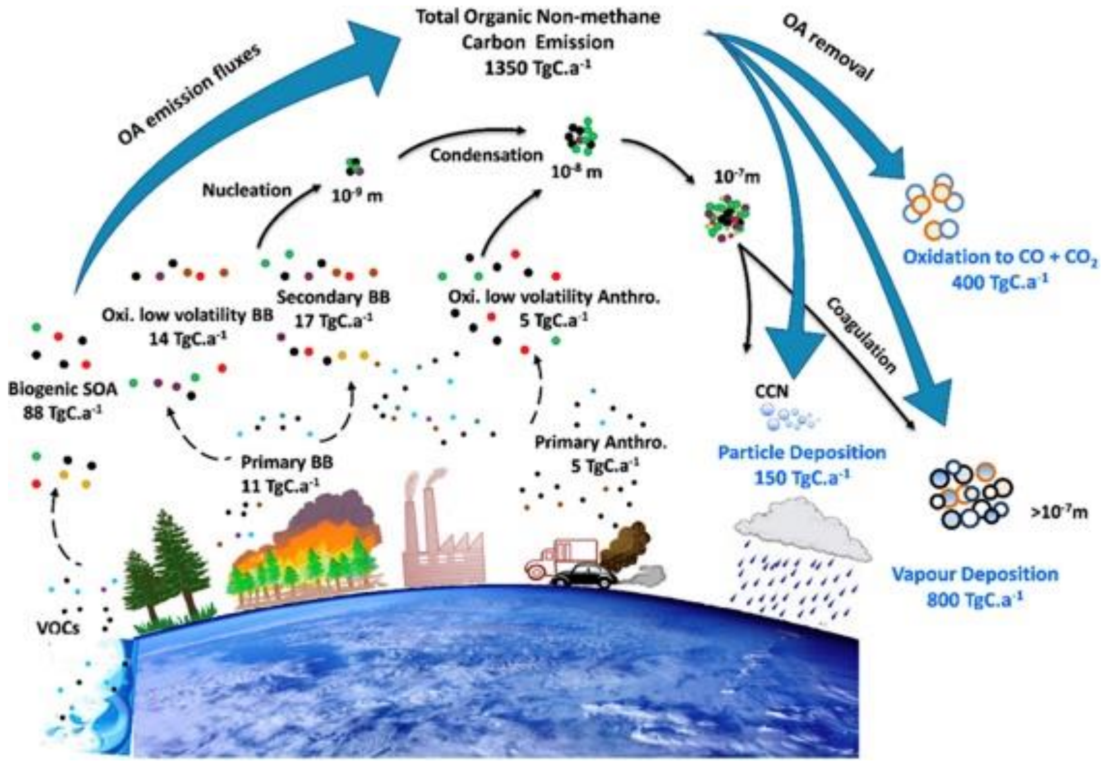


- There are still a lot of uncertainties regarding the substances that *reduce* the radiative budget of the earths surface.
- These compounds (Aerosols) *can* possibly cool down the troposphere by i.e. further growing until they act as *Cloud Condensation Nuclei (CCN).*

IPCC 2013, F. Stocker et al. (2013), *Climate change 2013*, The Physical Science Basis - Working Group1 Technical summary, p.12

EUROPEAN COMMISSION

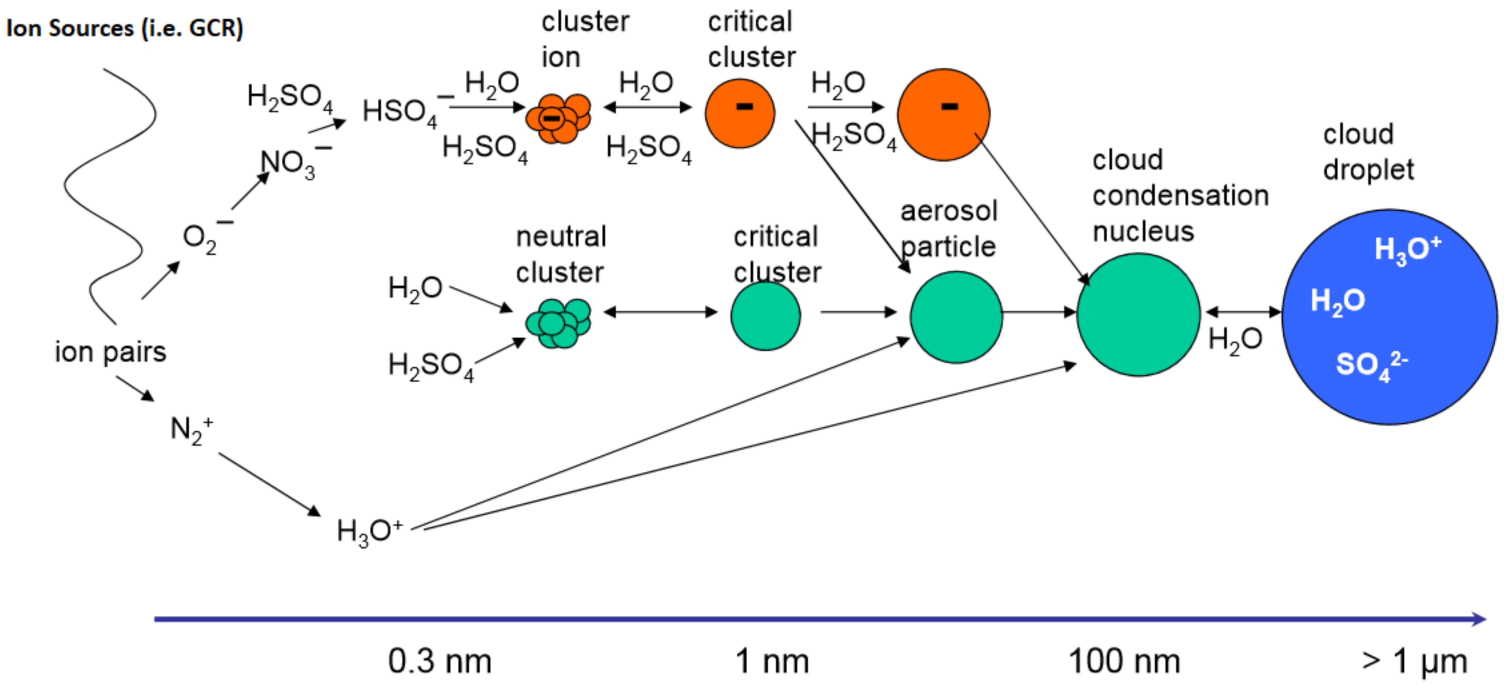
Possible ways of aerosols in the atmosphere



Singh et al., Atmospheric Environment, 2017

- Primary Aerosols are in particle phase *before* they are emitted to the atmosphere.
- Secondary aerosols are formed by nucleation and growth from the gas phase.
- Further atmospheric processes (Coagulation, Condensation, Evaporation, chemical reactions) define their lifetime and if they grow to CCN.

Nucleation and growth (a concept)

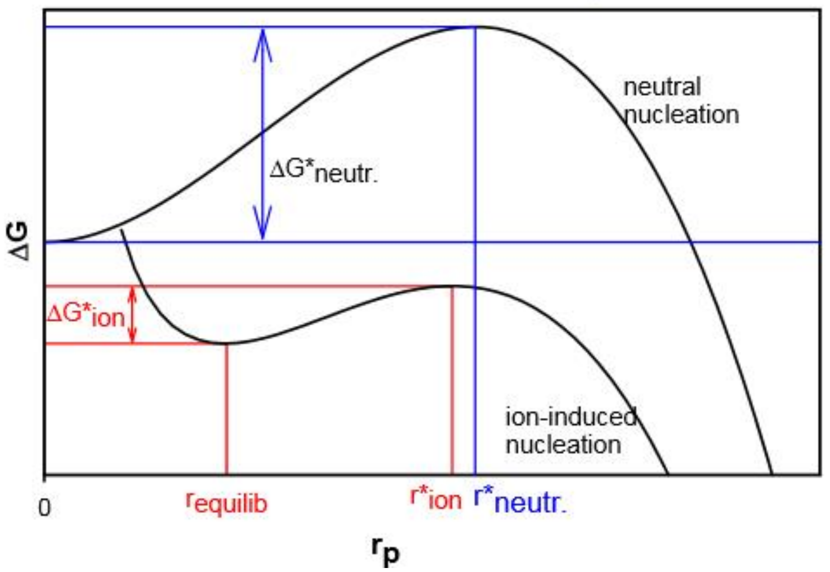


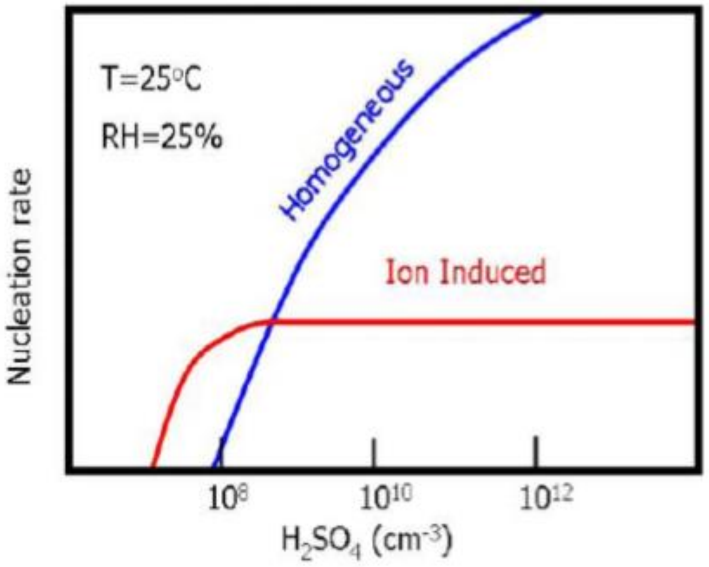
Joachim Curtius (University of Frankfurt, CLOUD, 2017)

- As soon as clusters get *stable,* they will grow to aerosol particles.
- Ions stabilize the critical cluster.
- The collision rate is higher when there are more ions.
- Galactic Cosmic Rays (GCR) are an important source for ions in the upper troposphere.

EUROPEAN COMMISSION
cloud

When is a cluster thermodynamic stable?





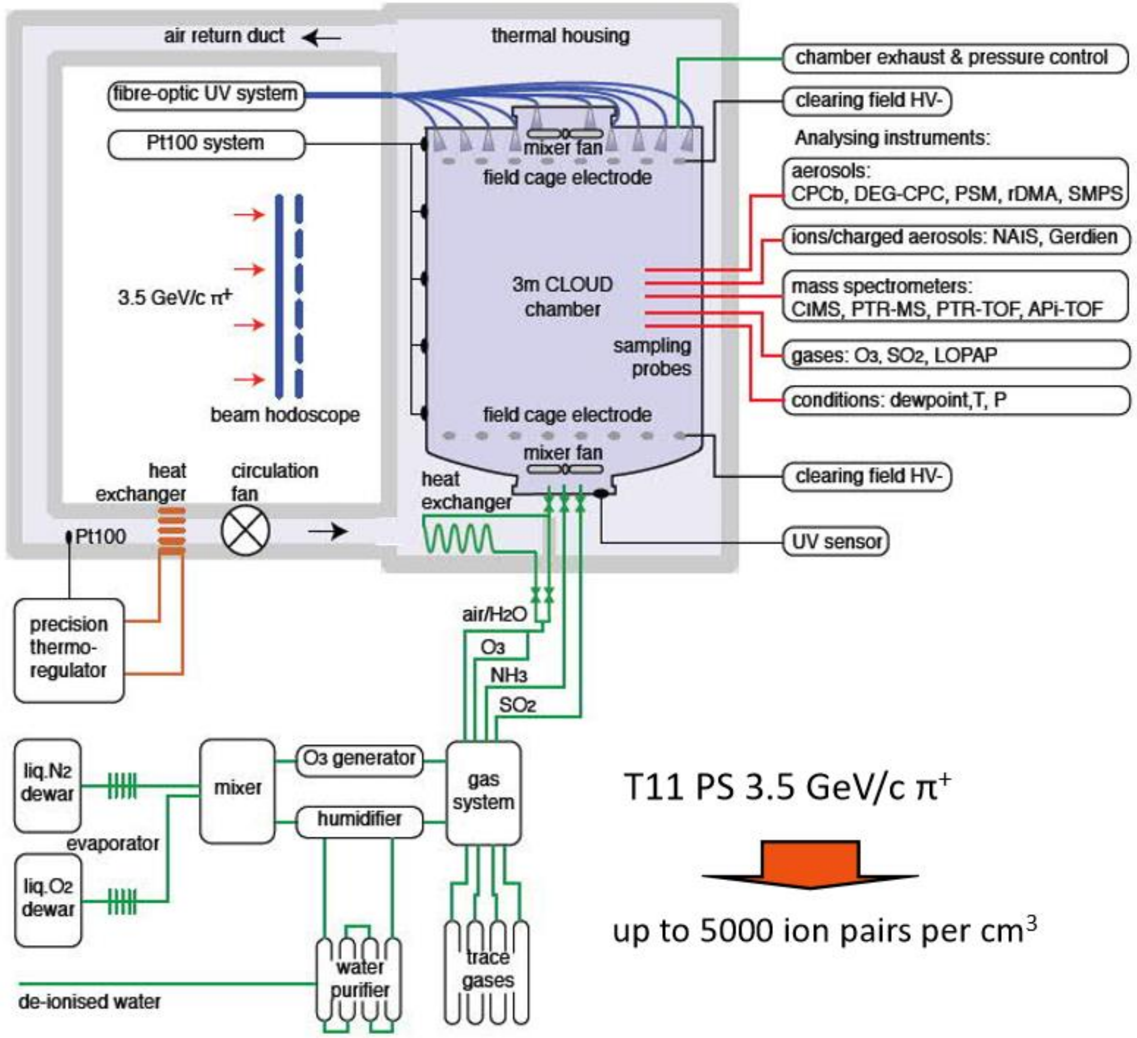
Joachim Curtius (University of Frankfurt, CLOUD, 2017)

$$\Delta G = -n(r_p^3)kT\ln(S) + 4\pi r_p^2\sigma + \frac{q^2}{2}\left(1-\frac{1}{\varepsilon}\right)\left(\frac{1}{r_p}-\frac{1}{r_0}\right)$$

This strongly depends on:

- Surface tension
- Vapor pressure
- Solution of the particle
- Particle radius
- Charge
- Ion-Ion recombination
- …

EUROPEAN COMMISSION



T11 PS 3.5 GeV/c π^+

up to 5000 ion pairs per cm^3

CERN's CLOUD chamber

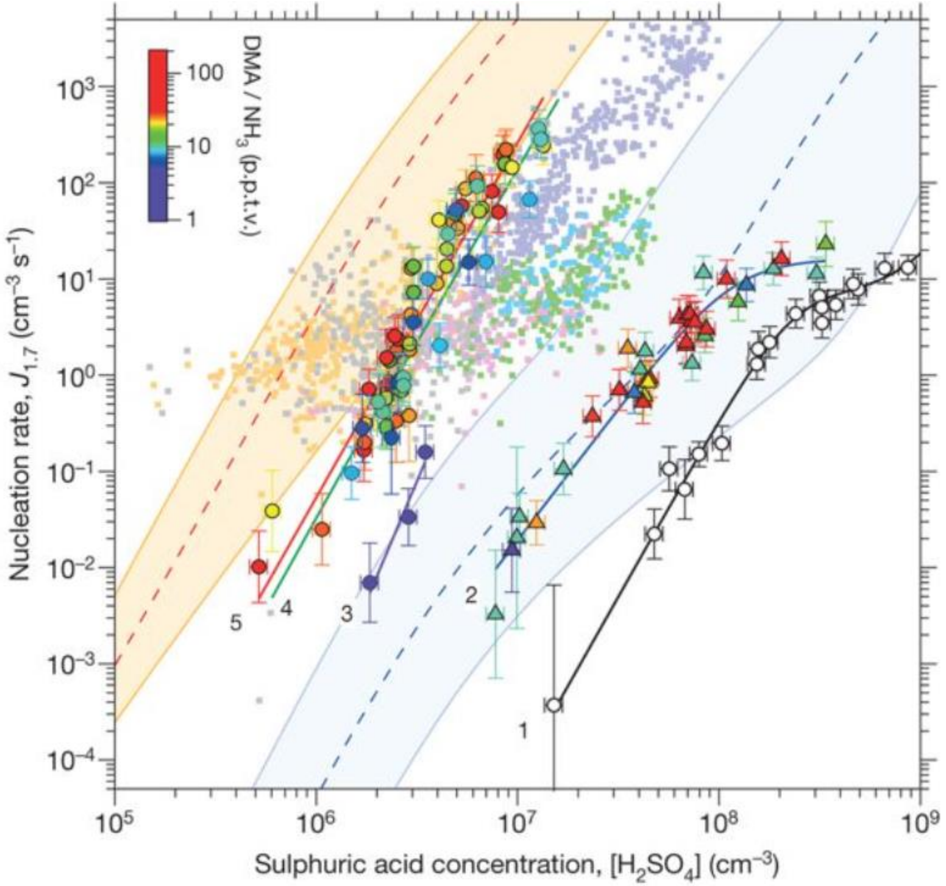
To understand aerosol formation with ions in the chamber:

- Need low concentrations (ppt) of sticky (non-volatile) gases
- Strong effects from sub-ppt contaminants and temperature
- Need large volume to avoid high wall losses

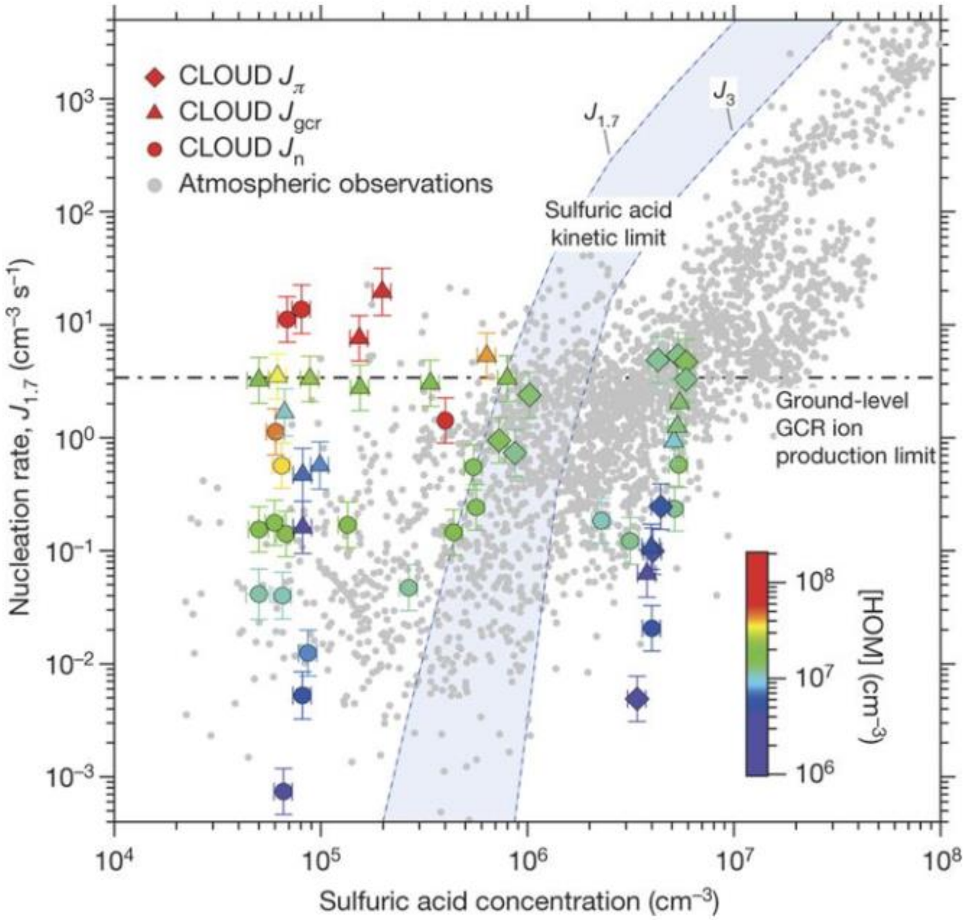
Kirkby et al., Nature 2011; 2016

EUROPEAN COMMISSION

CLOUD simulates atmospheric nucleation and growth for various regions of the world and compares the results with atmospheric measurements:



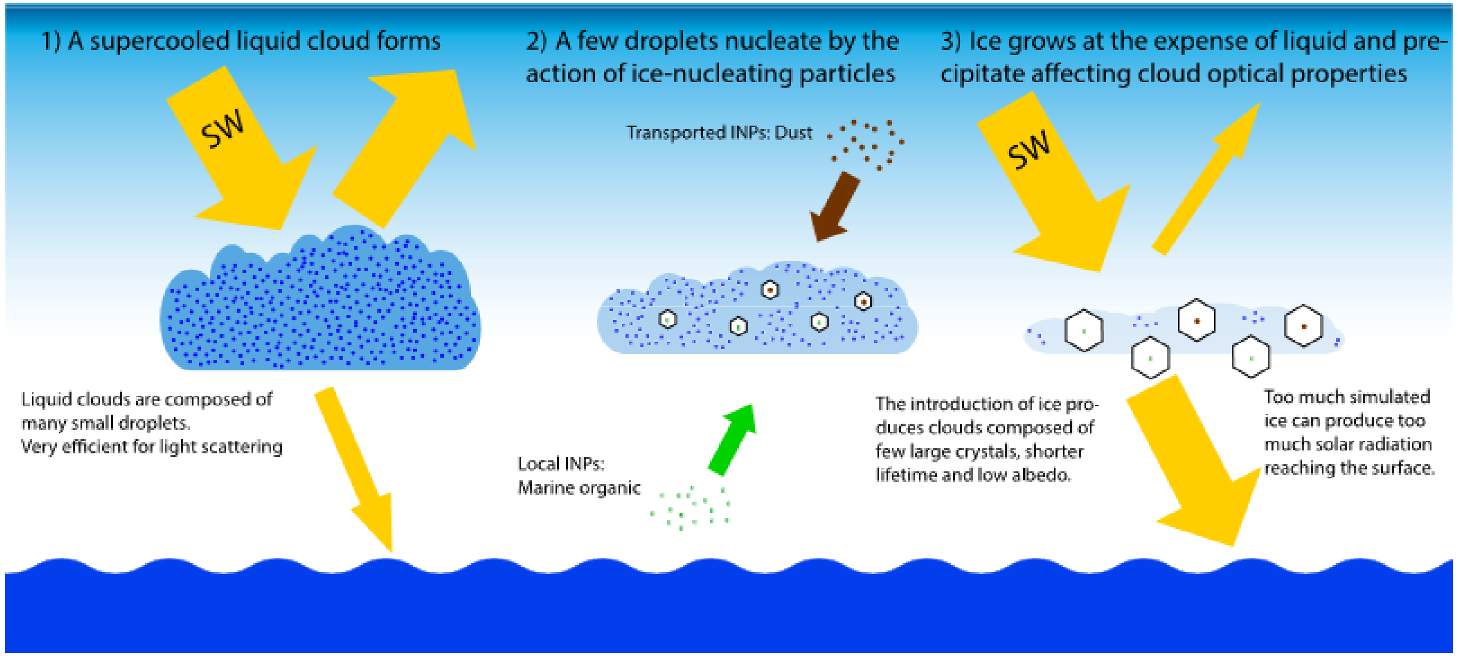
Almeida et al., Nature, 2013



Kirkby et al., Nature, 2016

EUROPEAN COMMISSION

The role of CCN in cloud formation



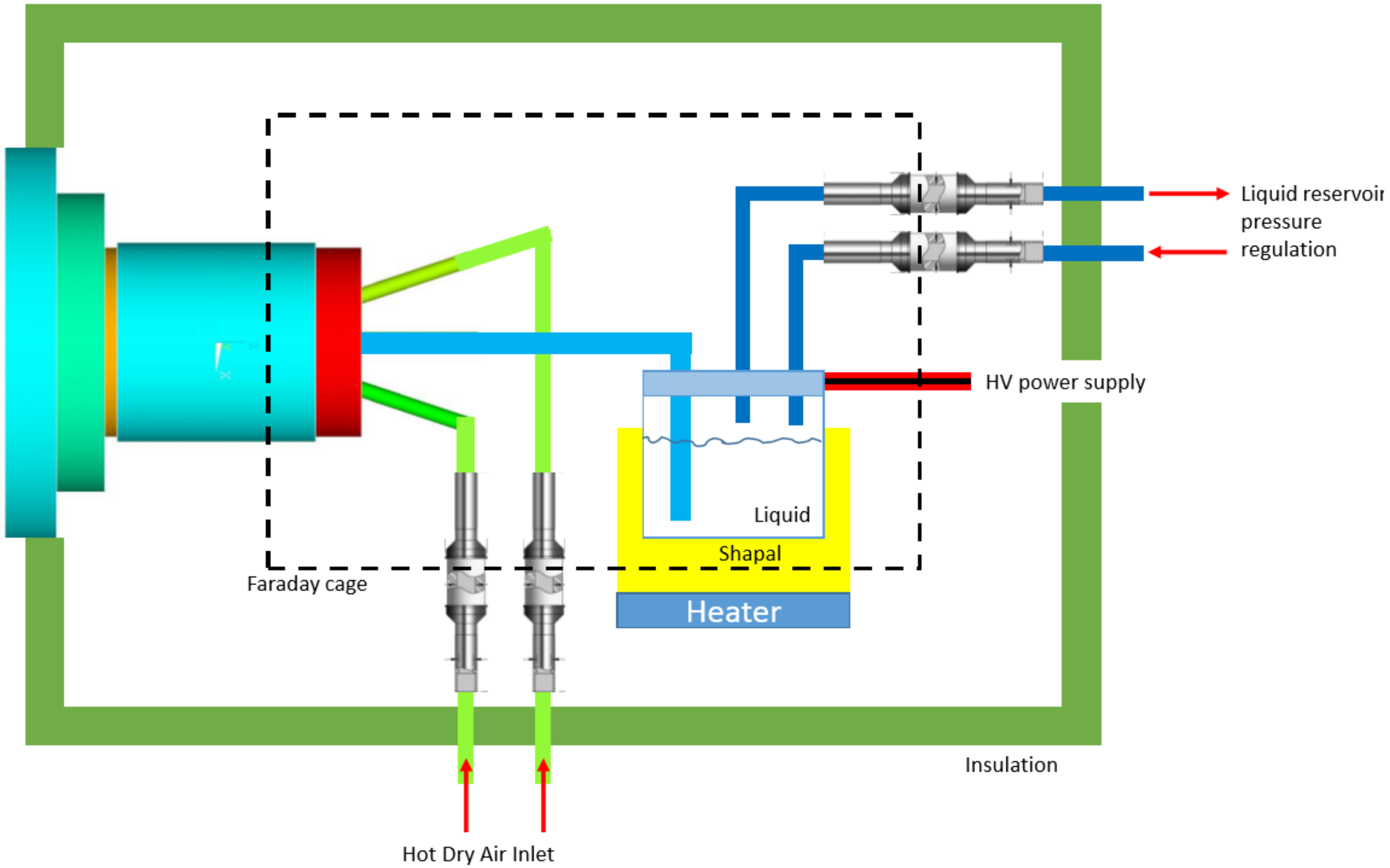
Vergara-Tempradoa et al., PNAS, 2018

- A higher number concentration of CCN at constant liquid water content leads to a higher Cloud albedo. In addition, the lifetime of the cloud increases with CCN number concentration.

- Inside clouds, charge distribution will appear, where most negative charged CCN are on bottom and positively charged CCN on top of the cloud.

- For now, we don't know exactly, how charged CCNs affect clouds.

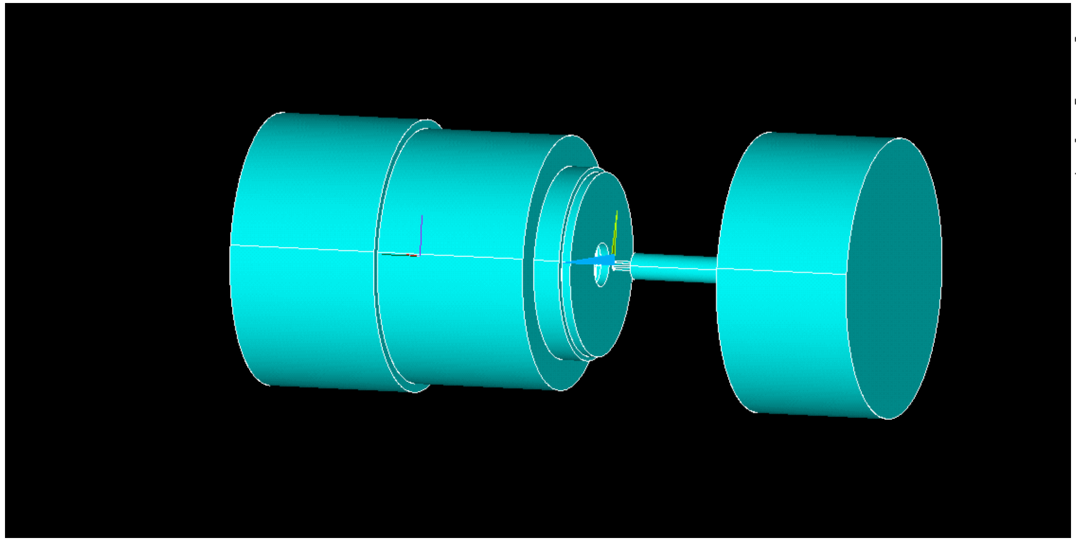
Project for CLOUD14 (2019): Development of a highly charged CCN generator.



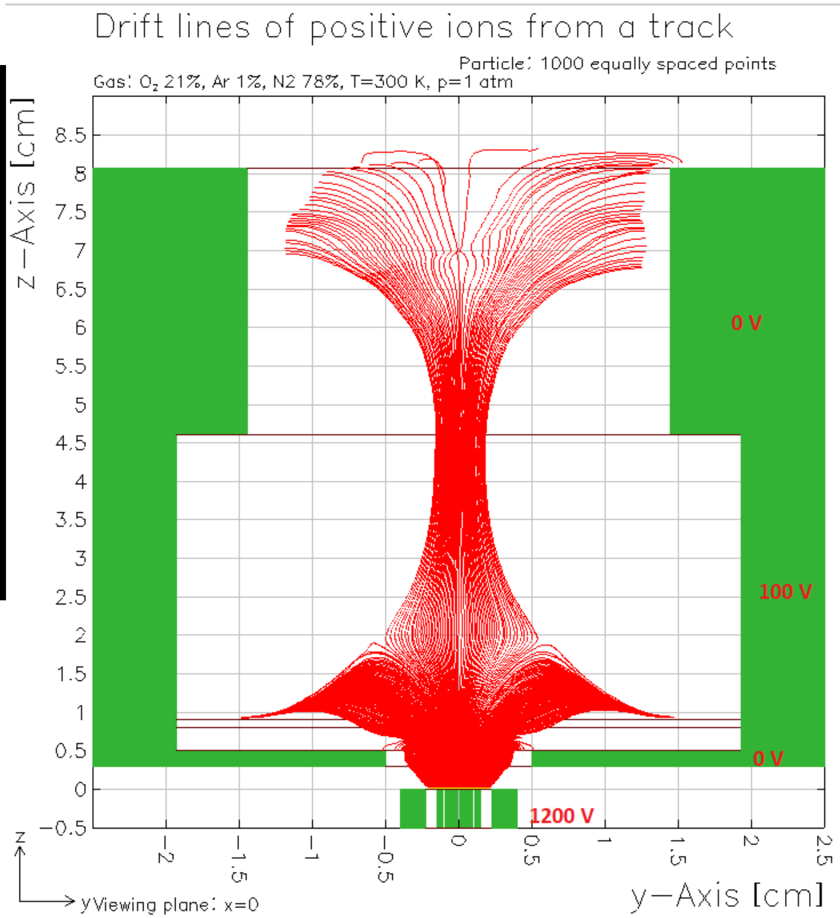
Serge Mathot, CLOUD, 2018

- Injecting highly charged CCN (diameter: 100nm) into the CLOUD chamber.
- Creating space charge inside the chamber.
- Varying the composition of these particles, as well as their charge.

First simulations using GARFIELD developed by Rob Veenhof.



Joschka Pfeifer, CLOUD, 2018



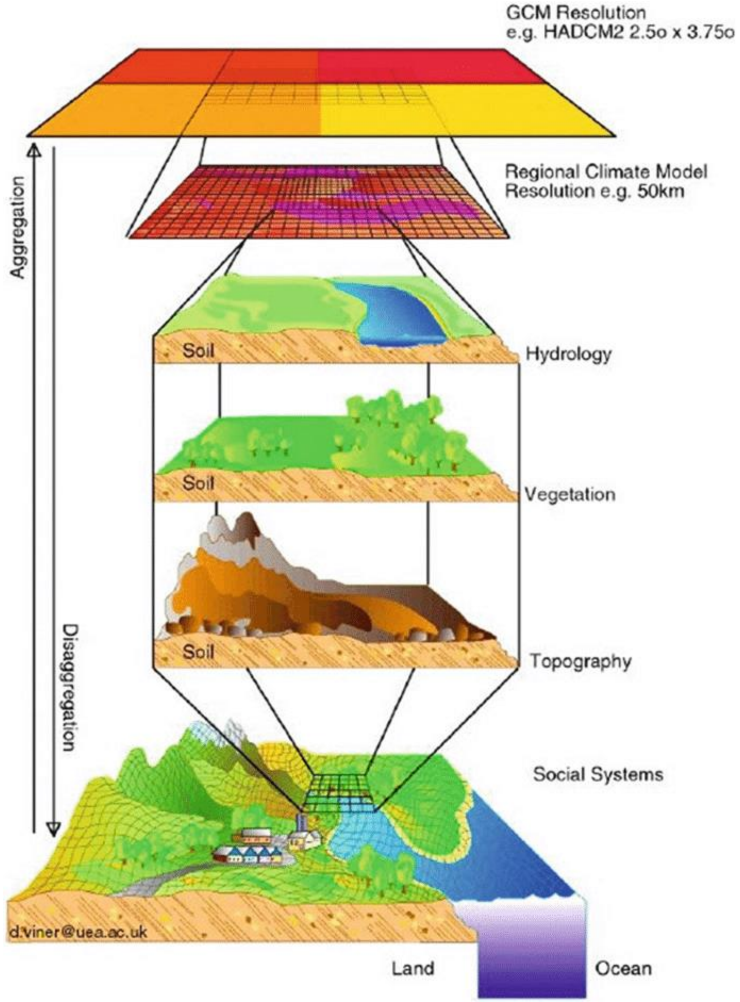
- Small voltages next to the chamber to avoid an electric field inside the chamber caused by the generator.

Next to this:

- Simulate the evaporation of charged droplets using GARFIELD (in collaboration with Rob Veenhof).
- Compare the results with measurement results from the CCN Generator.
- Afterwards: Improve the model.

- this could be the first step to simulate evaporating, charged droplets and CCN inside of clouds.

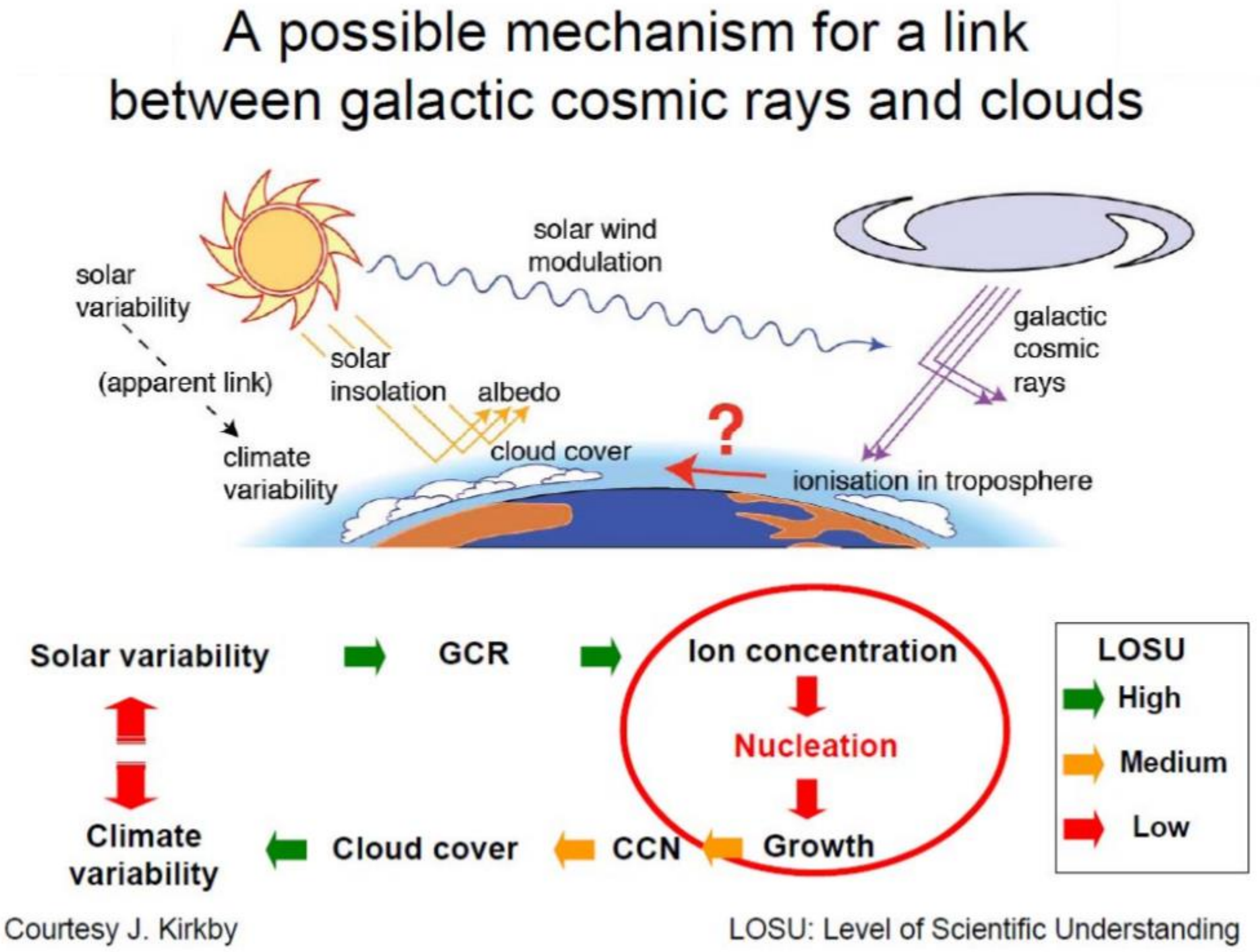
These simulations can be the next grid cell in a model predicting climate change:



Climate Modelling. Concept of downscaling.
David Viner, Climatic Research Unit,
University of East Anglia, UK

- Thank you for your attention!

The Svensmark Hypothesis



Measurement techniques at CLOUD

- There are more than 30 instruments measuring hundreds of components during a campaign.
  - Differential Mobility Analyzer (DMA).
  - Particle counter (CPC).
  - Time-of-Flight Mass Spectrometer (TOF).
  - Lasers, Gas Monitors,…

- Example for an instrument at CLOUD: NH3HTOF.
  - LOD for compounds like Ammonia: <<1 pptv
  - During CLOUD 12 it was able to measure the lowest ammonia value ever measured worldwide until then (0.5pptv).

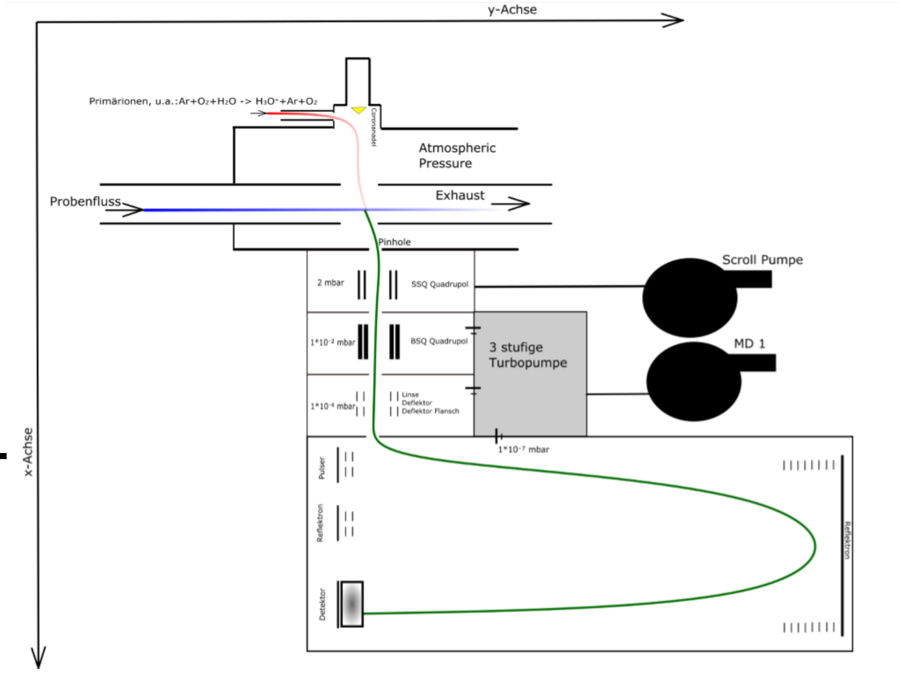


Abbildung 5: Aufbau der vier Kammern des HTOF.

Principle of a Time of Flight Mass Spectrometer (Joschka Pfeifer, CERN).

EUROPEAN COMMISSION

EUROPEAN COMMISSION

cloud