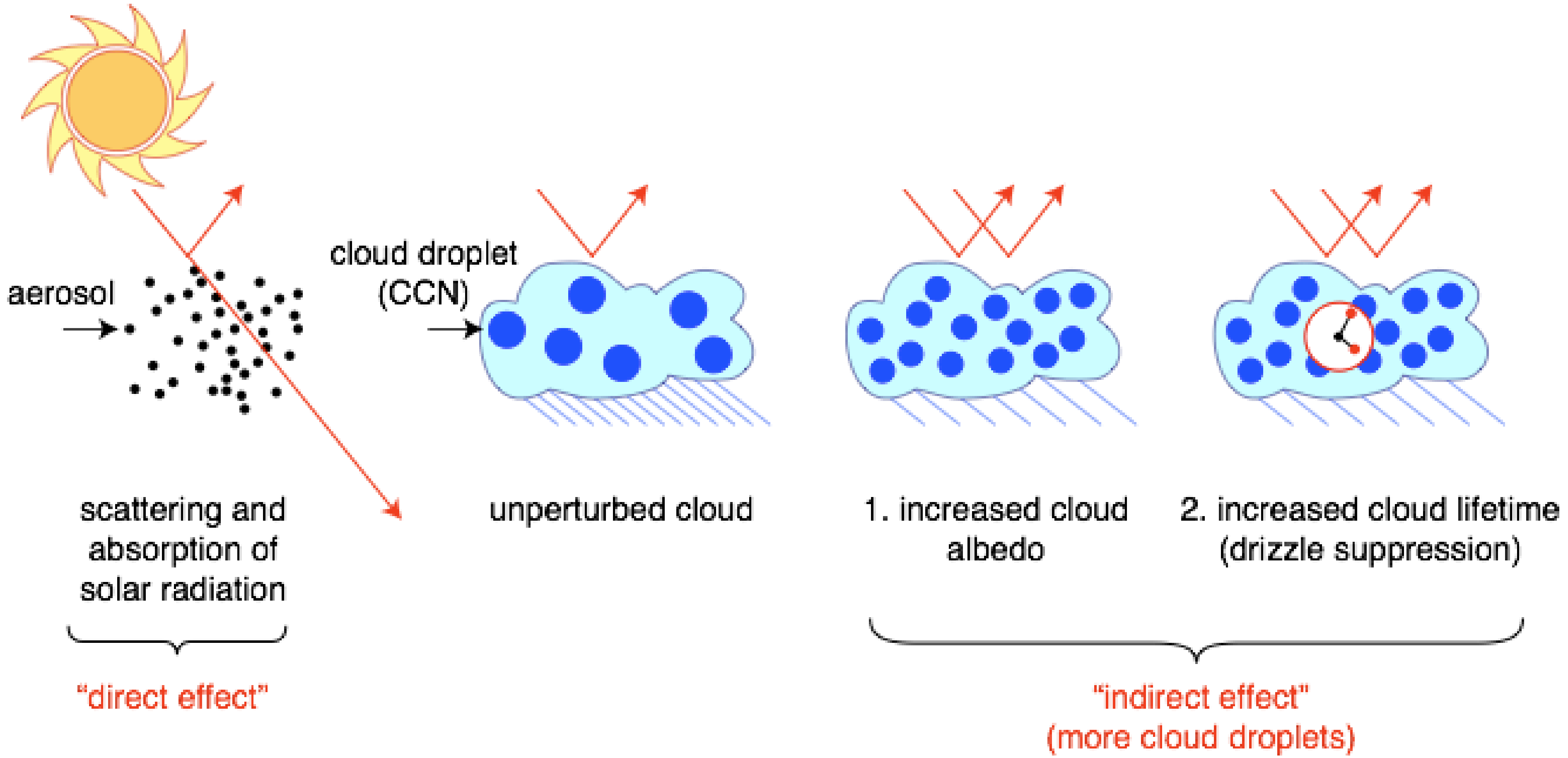
Status and plans of the CLOUD experiment

SPSC open session, CERN 26.11.2024

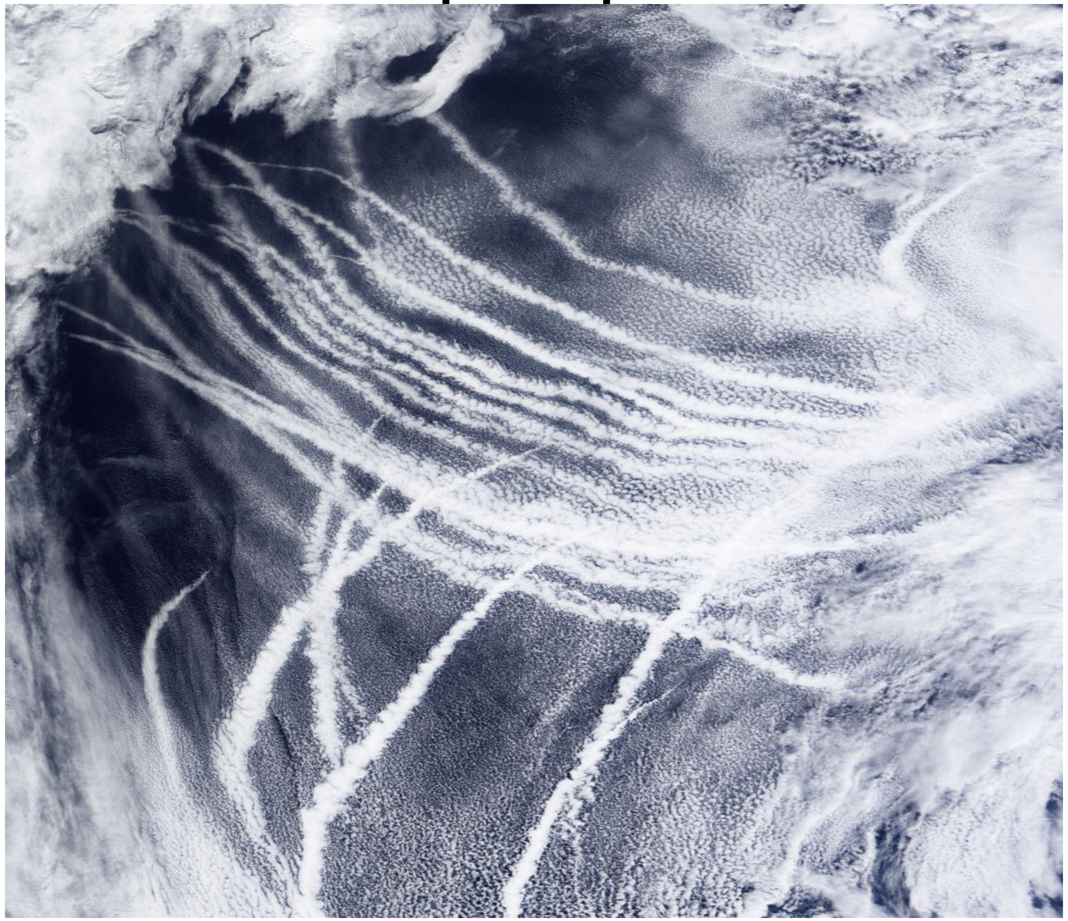
Prof. Katrianne Lehtipalo, on behalf of the CLOUD collaboration:

***Aerodyne Research Inc.**, USA; **California Institute of Technology**, USA ; **Carnegie Mellon University**, USA ; **CERN**, Switzerland ; **The Cyprus Institute**, Cyprus ; **Finnish Meteorological Institute**, Finland ; **Goethe University Frankfurt**, Germany ; **Helsinki Institute of Physics**, Finland ; **Karlsruhe Institute of Technology**, Germany ; **Leibniz Institute for Tropospheric Research**, Germany ; **Max Planck Institute for Chemistry**, Germany; **Paul Scherrer Institute**, Switzerland ; **University of Beira Interior**, Portugal ; **University of Colorado Boulder**, USA ; **University of Eastern Finland**, Finland ; **University of Helsinki**, Finland ; **University of Innsbruck**, Austria ; **University of Lisbon**, Portugal ; **University of Stockholm**, Sweden ; **University of Tartu**, Estonia ; **University of Vienna**, Austria*

Atmospheric aerosol particles affect climate through direct and indirect mechanisms



Ship tracks demonstrate how particles affect the cloud properties and reflectivity



Terra — MODIS, 4.3.2009

NASA images by Robert Simmon and Jesse Allen

https://earthobservatory.nasa.gov/images/37455/ship-tracks-south-of-alaska

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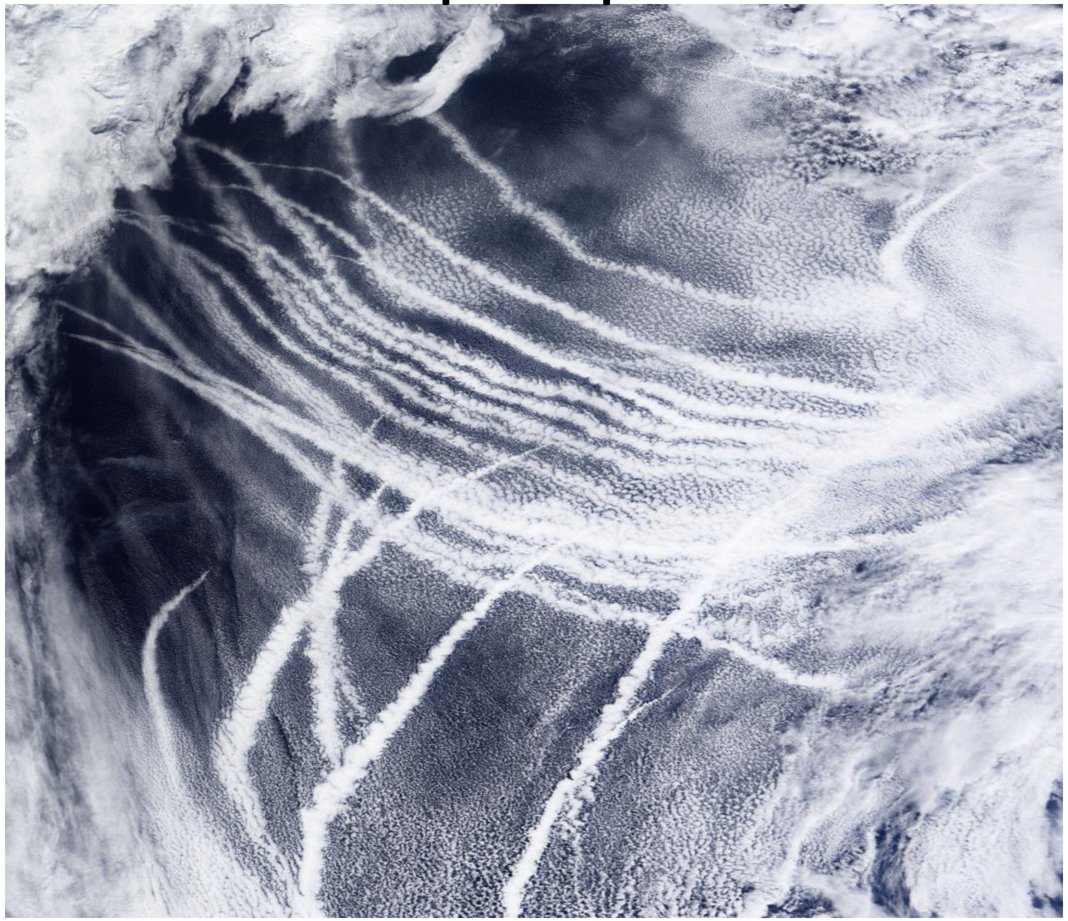

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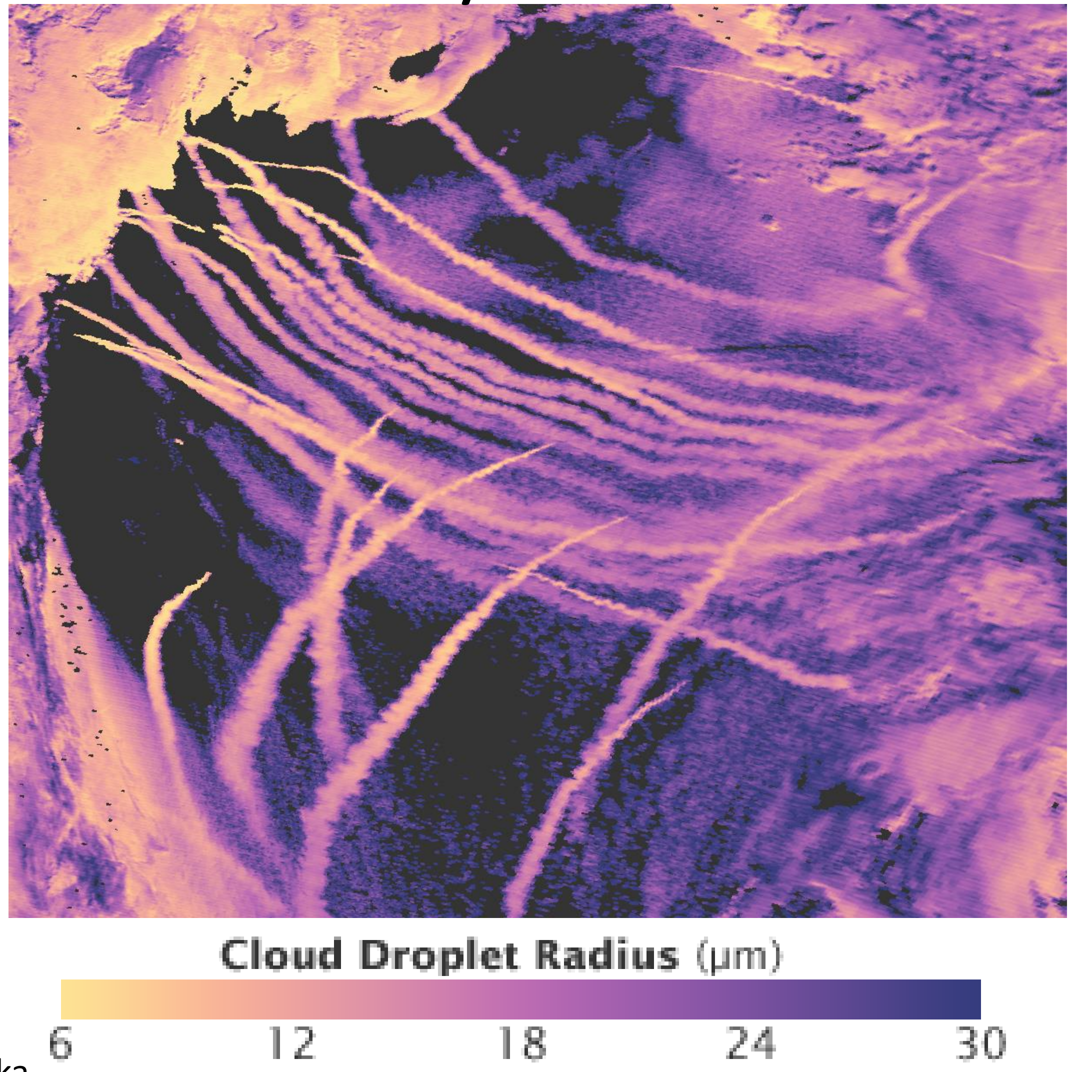
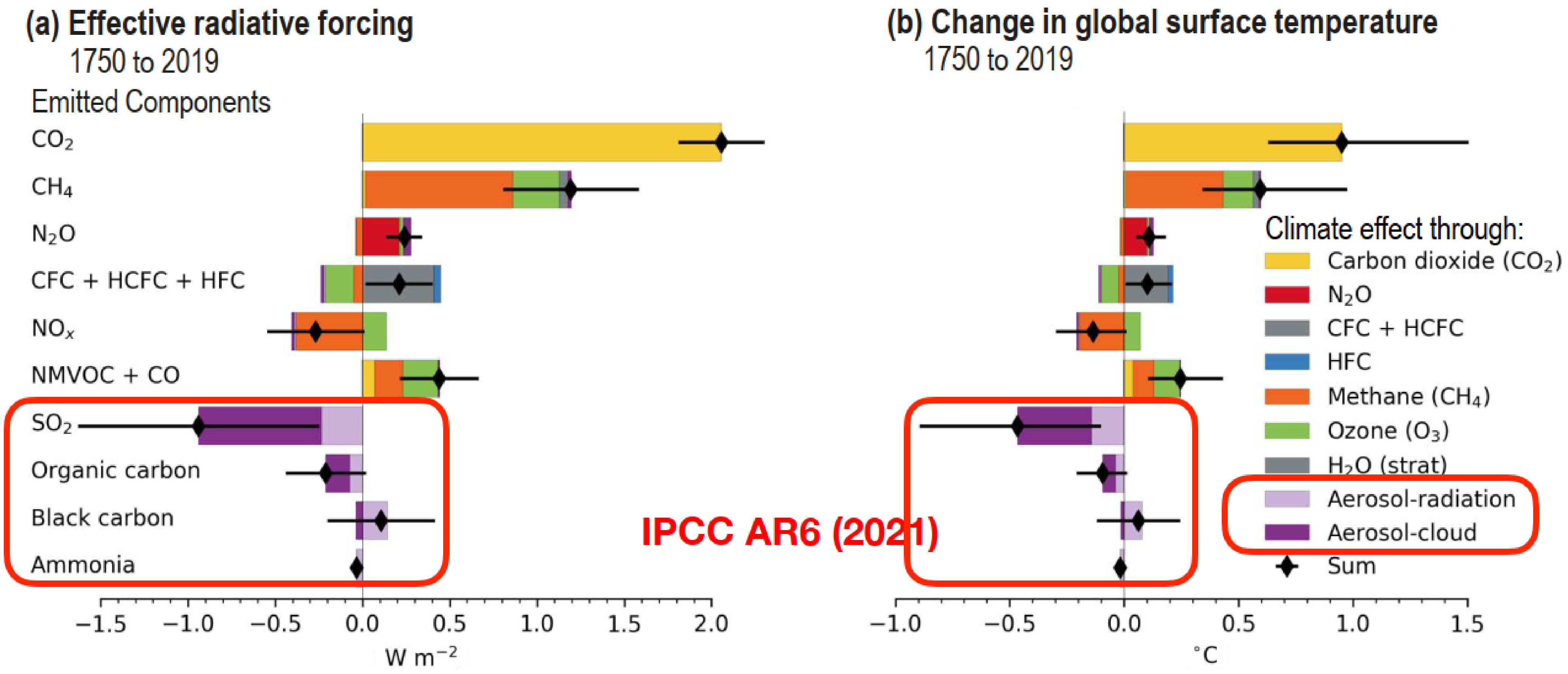


However, aerosols are still the biggest uncertainty in climate models



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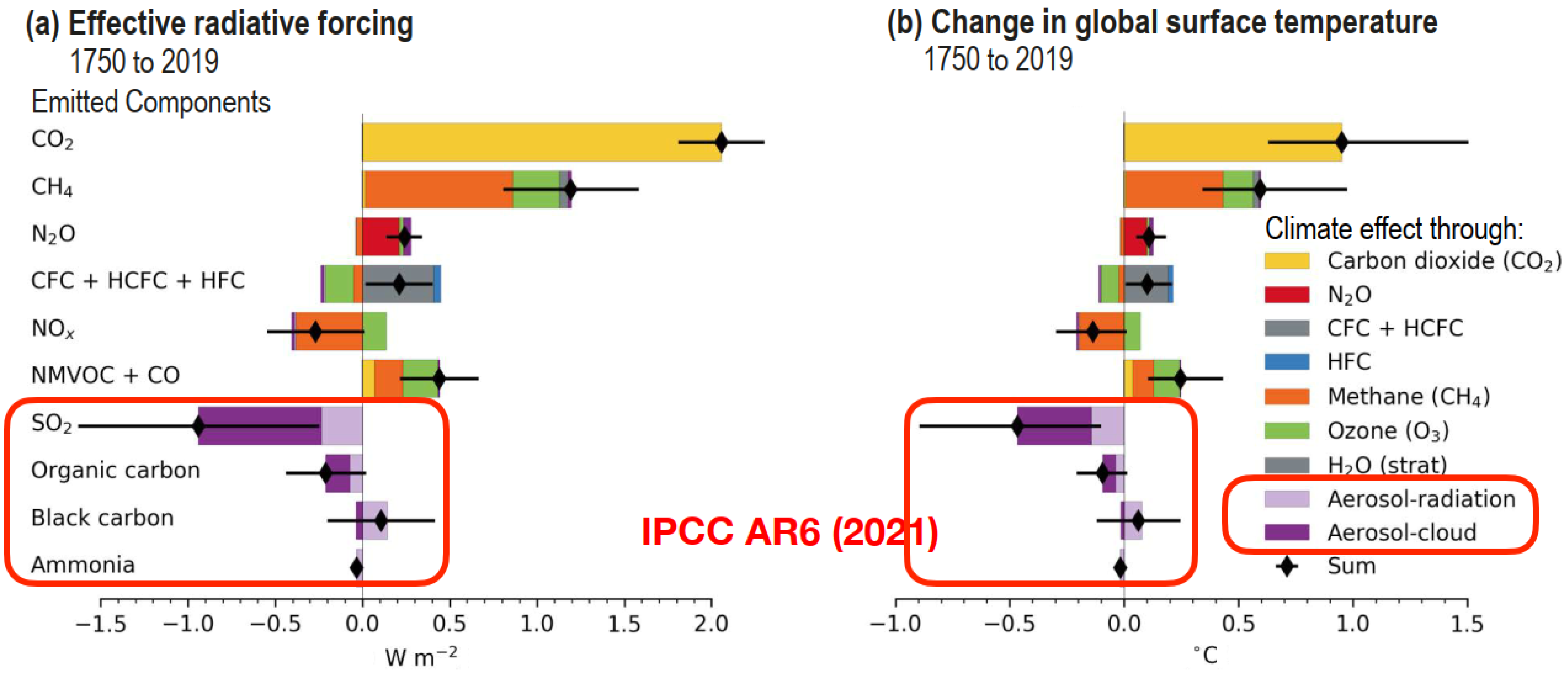
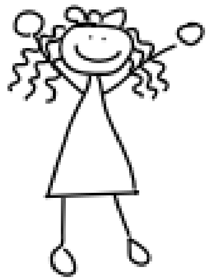


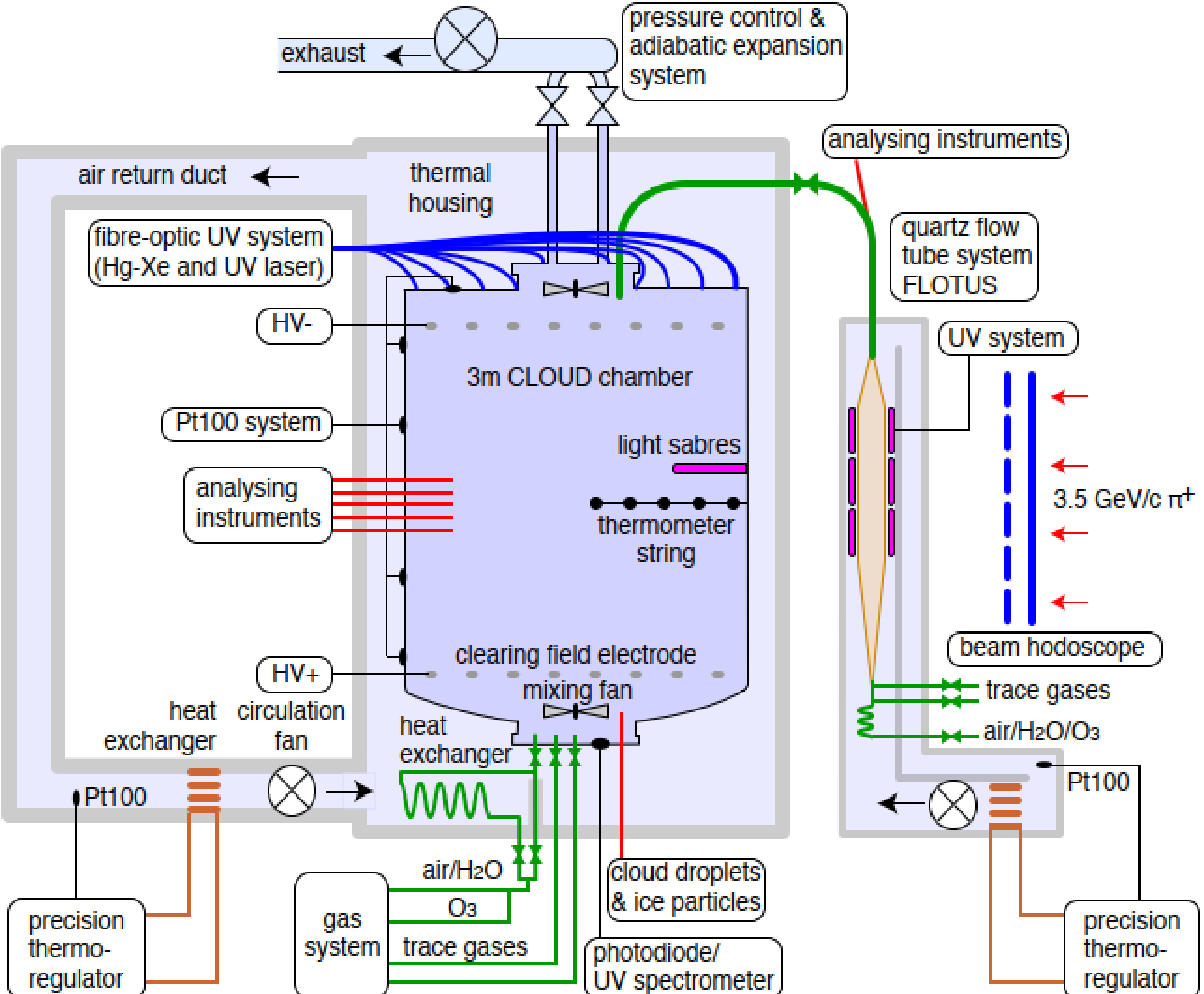
→ We need climate models that include the underlying atmospheric chemical and physical mechanisms to predict: a) pre-industrial aerosol and clouds (Earth's climate sensitivity) & b) Earth's future climate.

CLOUD chamber

- Key features::
  - Ultra-low contaminants
  - Atmospheric concentrations
  - Precise and steady control of all conditions over long periods:
    - vapours
    - T, UV
    - ionisation (n, gcr, π)
  - Comprehensive analysis instruments
  - FLOTUS
    (FLOw TUbe System)



typical CLOUD scientist



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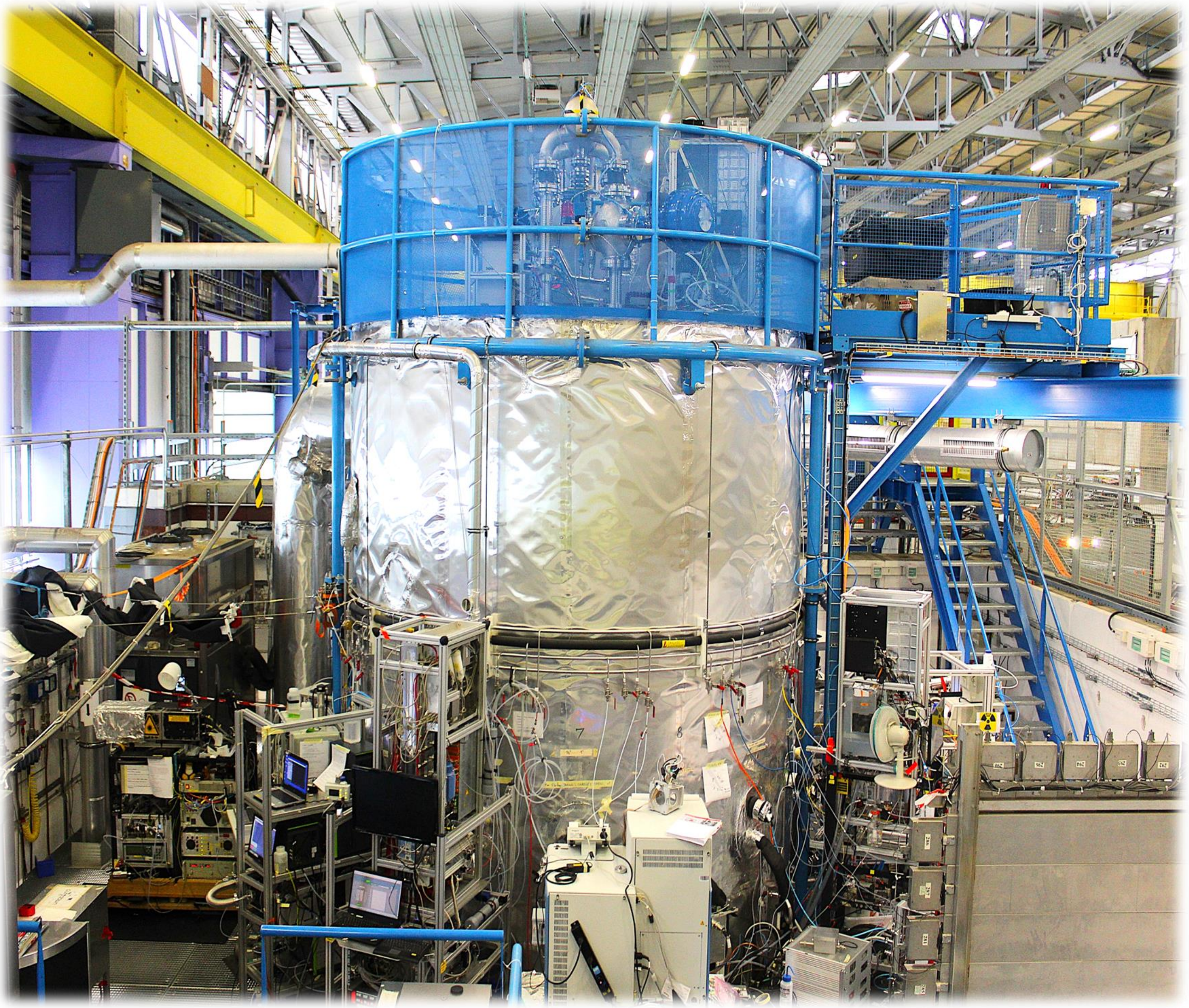
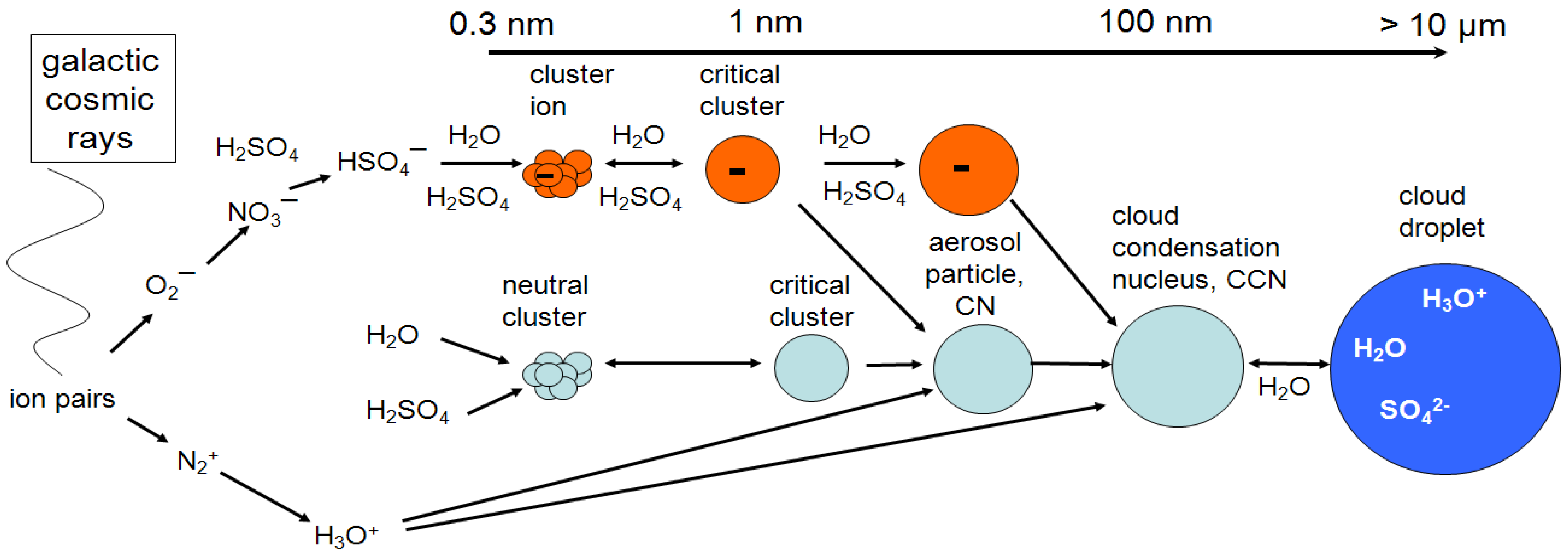
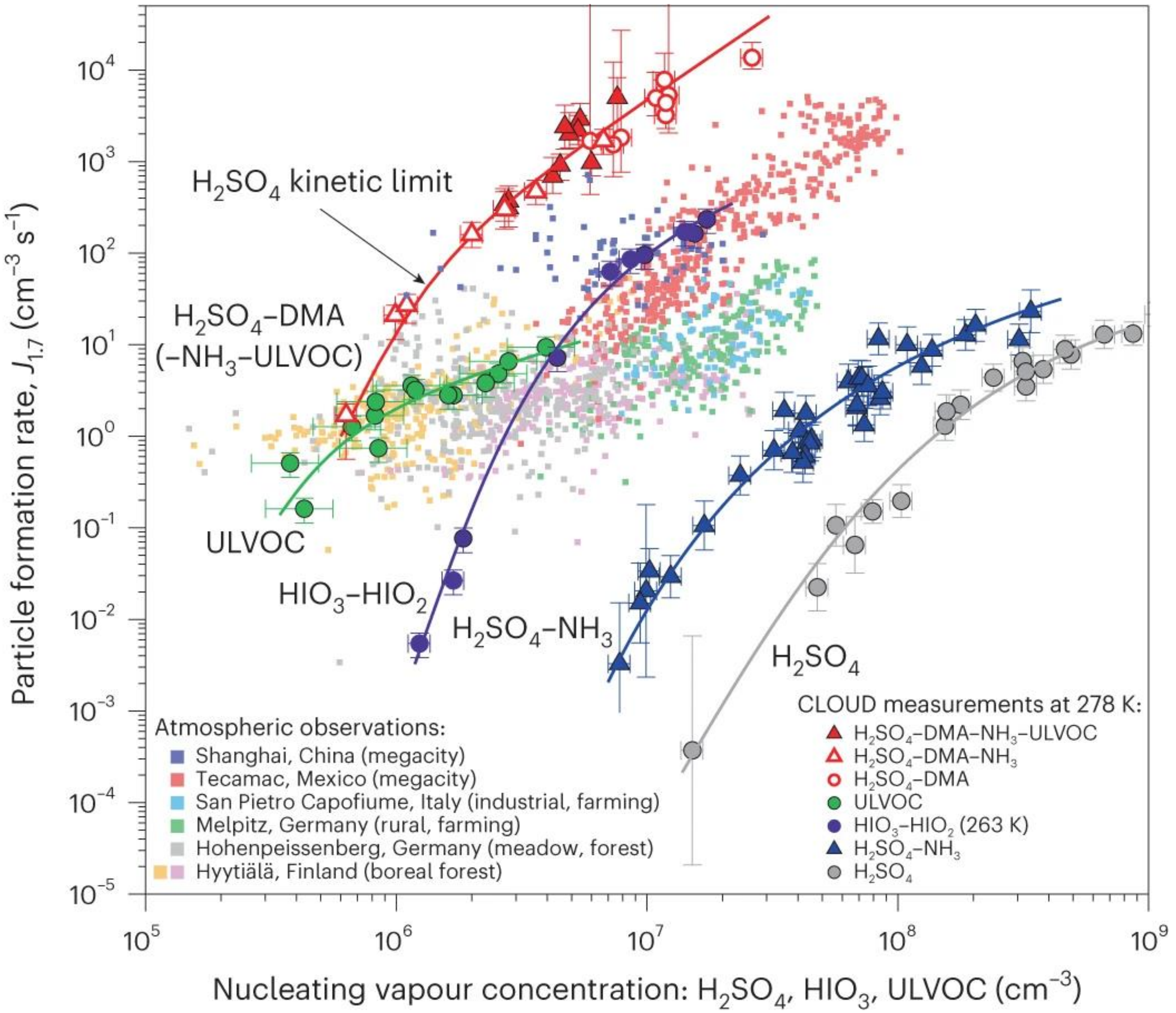


Comprehensive set of instrumentation to measure ultra-low vapor concentrations and particles from 1 nm to >10 μm



CLOUD has provided quantification of the particle production from different precursor vapors



Key questions for each system of precursor vapours and ambient conditions (T, relative humidity...):

- *What is the aerosol particle formation rate vs vapour concentrations?*
- *What is the influence of ions from galactic cosmic rays between 0 and 10 km altitude?*
- *How fast do the particles grow from molecular (~1 nm) to CCN sizes (~50 nm)?*
- *Which chemical compounds are involved in a) particle formation and b) growth?*
- *What are the chemical pathways transforming volatile precursor vapours into ultra-low-volatility nucleating vapours?*

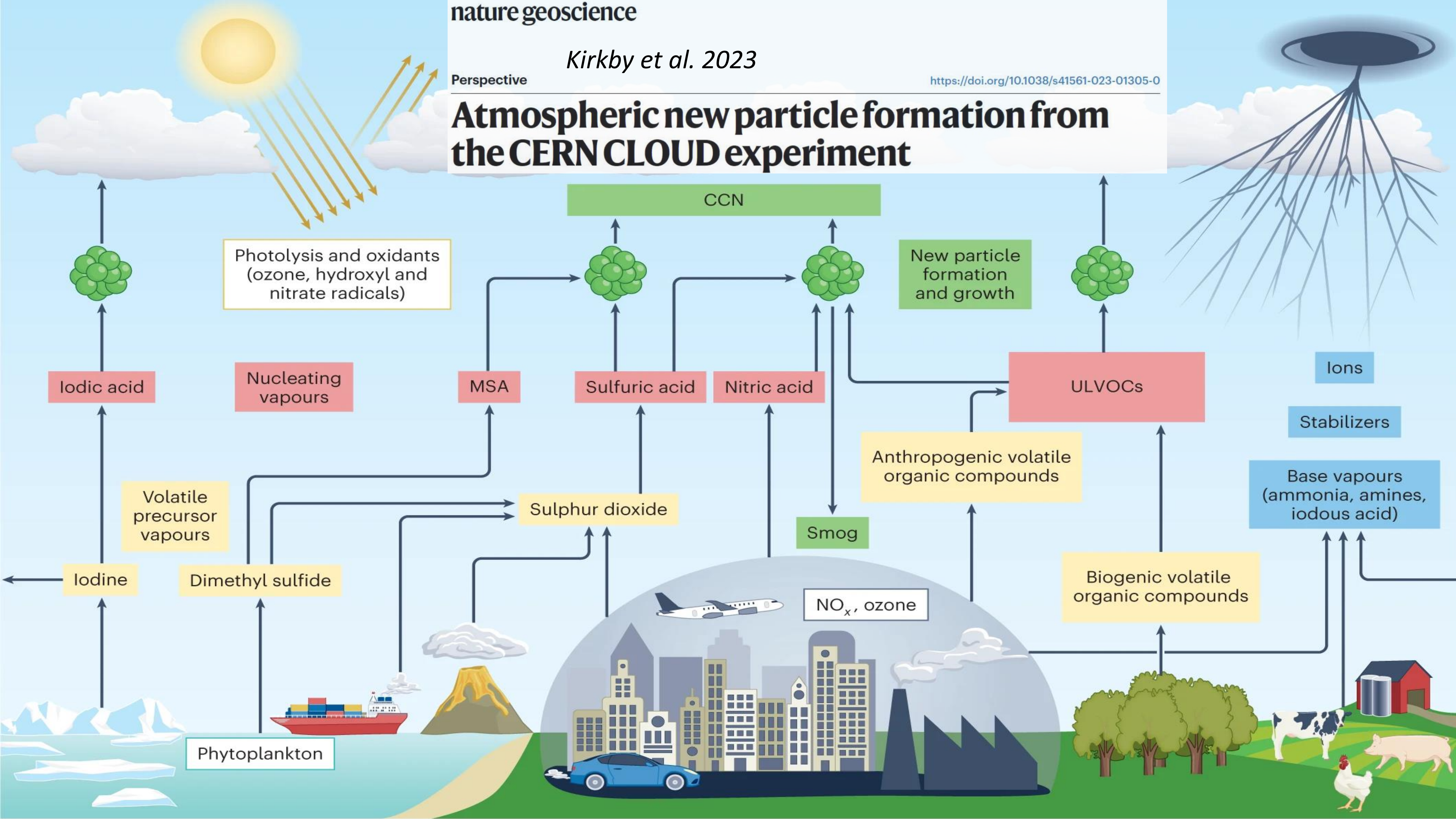
nature geoscience

Kirkby et al. 2023

Perspective

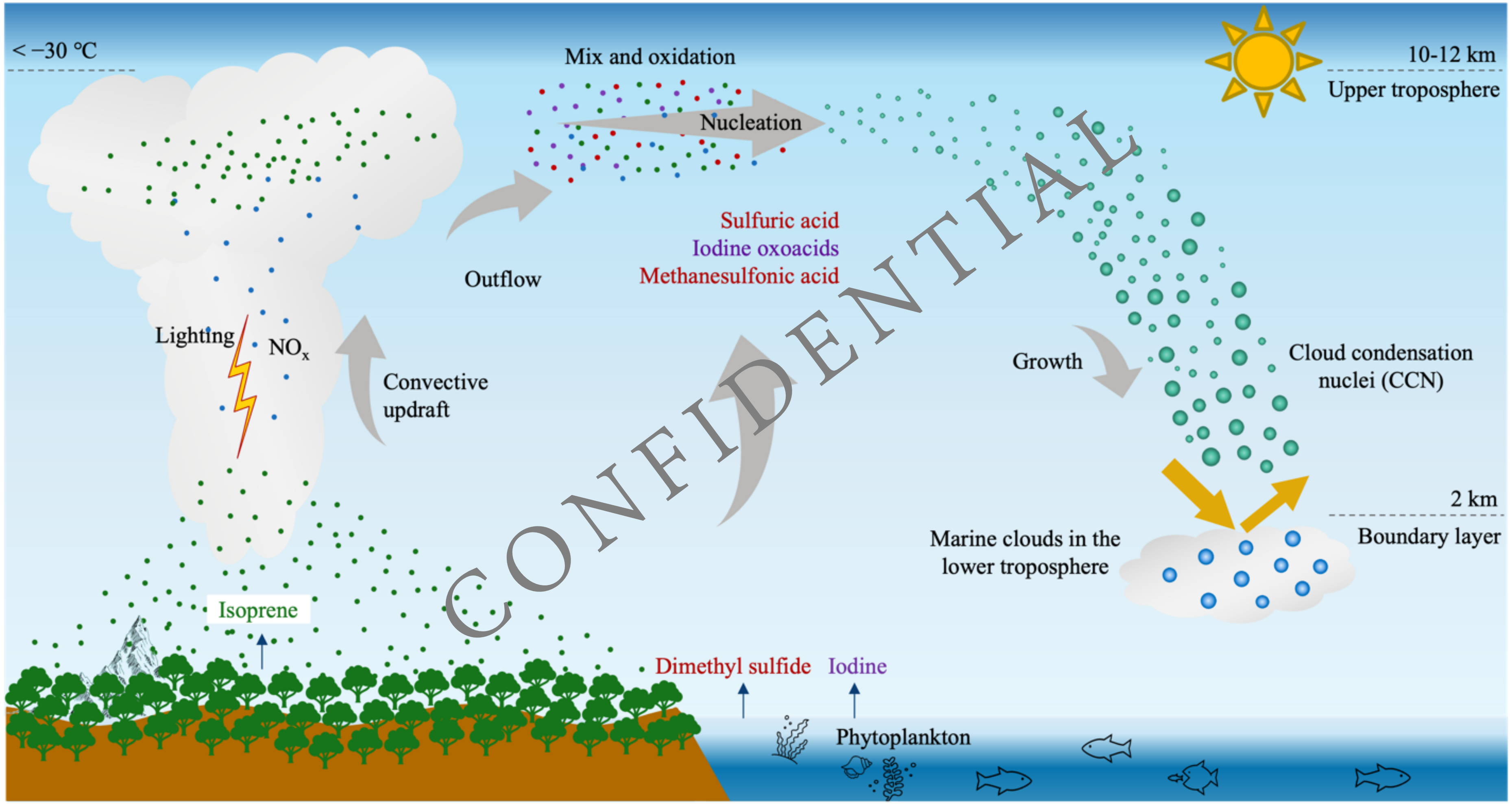
https://doi.org/10.1038/s41561-023-01305-0

Atmospheric new particle formation from the CERN CLOUD experiment



Isoprene released from tropical rainforests explains particle formation in the upper troposphere

Jiali Shen et al. New particle formation from isoprene under upper tropospheric conditions. *Nature*, in press

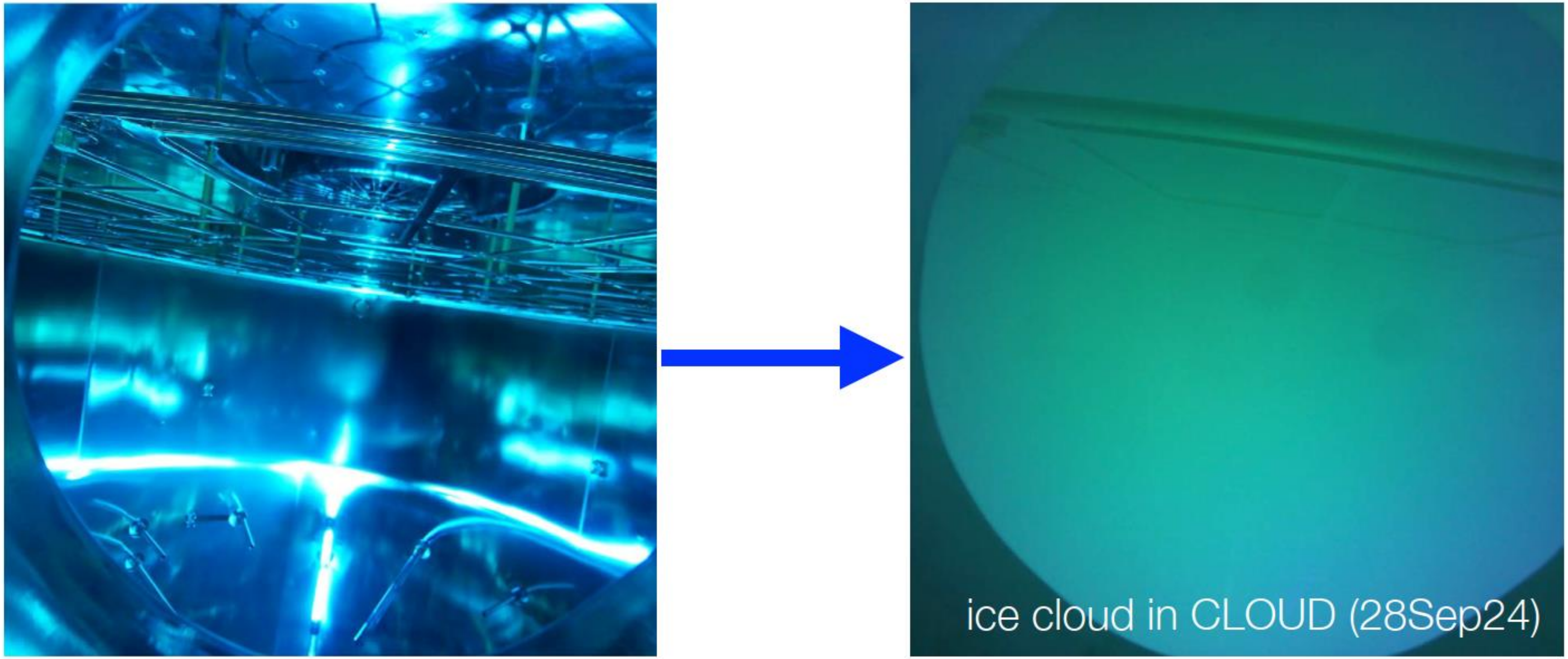


This will be the 11th Nature/Science paper from CLOUD since 2011 (6 Nature, 4 Science)

April-May 2024 CLOUD17T; testing new capabilities at CLOUD

- CHarged AeRosol GEnerator, CHARGE2: an electrospray charged aerosol generator with a ^{241}Am neutraliser for generating multiply-charged aerosol of either polarity inside the CLOUD chamber.
- Condensation Nuclei (CCN) generation in FLOTUS: growing CCN-sized (50-150 nm) particles from the gas phase in FLOTUS of any chosen chemical composition.
- Generation of continuous liquid- or ice-clouds in the CLOUD chamber by injecting humid air and cloud condensation nuclei from FLOTUS.

Using FLOTUS to create ice clouds in the CLOUD chamber



CLOUD17 run (Sep-Dec 2024)

Aerosol formation and growth:

- Parameterisation free tropospheric nucleation
- α-pinene and trace sulfuric acid
- Interaction of biogenic and anthropogenic vapours
- Asian tropopause
- Southern Ocean
- Particle evaporation in passing from cold to warm environments

"CLOUDy" experiments:

- Effect of aerosol charge on cloud microphysics (aerosol scavenging)
- Asian monsoon ice nucleation
- Release of NH_3 (and other dissolved vapours) upon supercooled droplet freezing or evaporation

Future plans of CLOUD

- Multi-component chemical systems
- Aerosol-cloud processes using steady-state clouds and cloud condensation nuclei from FLOTUS:
  - Aerosol processing in supercooled liquid droplets or ice particles
  - Transport of vapours in convective clouds and release at cloud tops
  - Evaporation of aerosol at low relative humidity and re-cycling of vapours
  - Influence of charge on aerosol-cloud microphysics

→ Parameterisations to implement new particle formation and growth mechanisms (including effects of charge) from CLOUD into climate models

Initial science goals for CLOUD18 run; 22.9.2025-1.12.2025

1. Parameterisation of sulfuric acid–ammonia–α-pinene OOM new particle formation

2. Ion evolution in the atmosphere. Investigation of the chemical ion chain from the primary N^+ and O^- ions to final stable “small ions”

3. Multicomponent marine and coastal new particle formation, involving mixtures of iodine, dimethylsulfide, dimethylamine, ammonia and organic vapours

4. Isoprene chemistry in the lower troposphere: Isoprene chemistry at -10 ◦C, together with NOx

5. Reactive uptake of organic vapours into particles. Evolution of particle growth to form organic salts such as organosulfate.

6. Aerosol-cloud processing. Include various compounds such as DMS, amines, ammonia, isoprene OOM, α-pinene OOM and surfactants

7. Recycling of vapours from aerosol particles. Role of humidity, temperature and particle size on the evaporation of particles containing various compounds.

8. Release of vapours, such as ammonia and iodine, from freezing cloud droplets

9. Continuing highly-charged aerosol studies.

Impact of P371 on CLOUD

The following assumes that P371 is approved by the SPSC for 2 months operation in T11 in 2025:

- We will temporarily remove the VH hodoscope but the B counters will remain in place in the beam during P371
- The entire P371 run shall take place between 7 July and 29 August 2025 (8 weeks).
  - By "entire run" we mean all installation, data taking and removal work for the infrastructure and detectors.
  - All P371 equipment and support structures shall be cleared from the T11 experimental zone and the T11 control room by 29 August, regardless of how successful the data taking has been and whether or not it has been completed
- All safety requirements for the P371 equipment shall be handled by the proponents in consultation with the appropriate CERN safety officers

The July/August period is important for CLOUD to prepare the facility for our fall run. CLOUD therefore reserves the right to access CLOUD for urgent work if the need arises. This could even imply the need to stop the beam, in especially urgent cases.

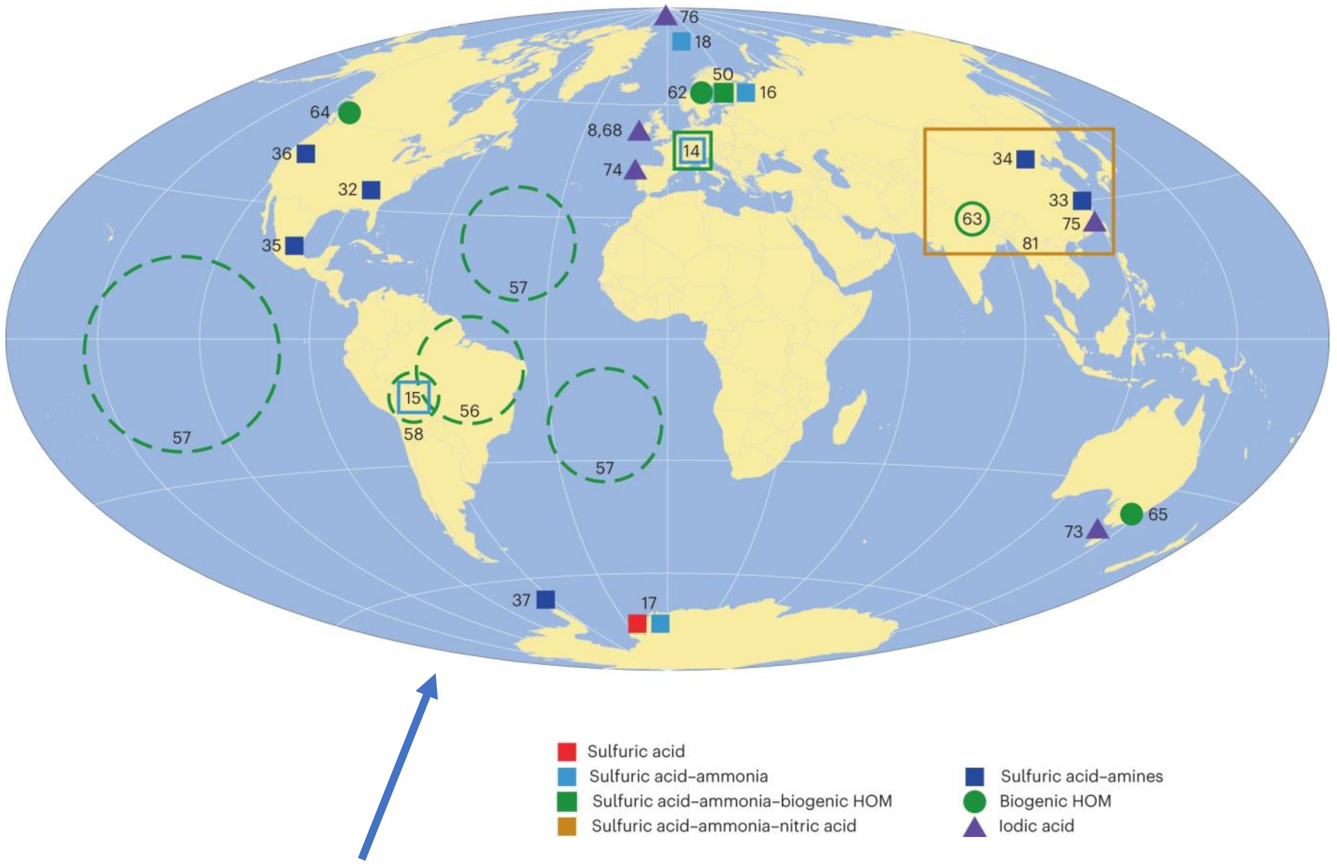
CLOUD Marie Curie Doctoral network

- CLOUD-DOC
  - 1 Sep 22- 31 Aug 26
  - 12 PhD students at different CLOUD institutes
  - 5 private sector partners

- Preparing to apply again in 2025 call for 2026-2030

Summary

- CLOUD is providing a mechanistic understanding of aerosol particle formation and growth starting from molecular level up to cloud droplets
- It has transformed the view of which chemical compounds are relevant for atmospheric new particle formation
- The information is crucial for improving global atmospheric chemistry and climate models



Geographical locations where mechanisms found at CLOUD has been measured in real atmosphere