CLOUD Status and Long-Term Plans

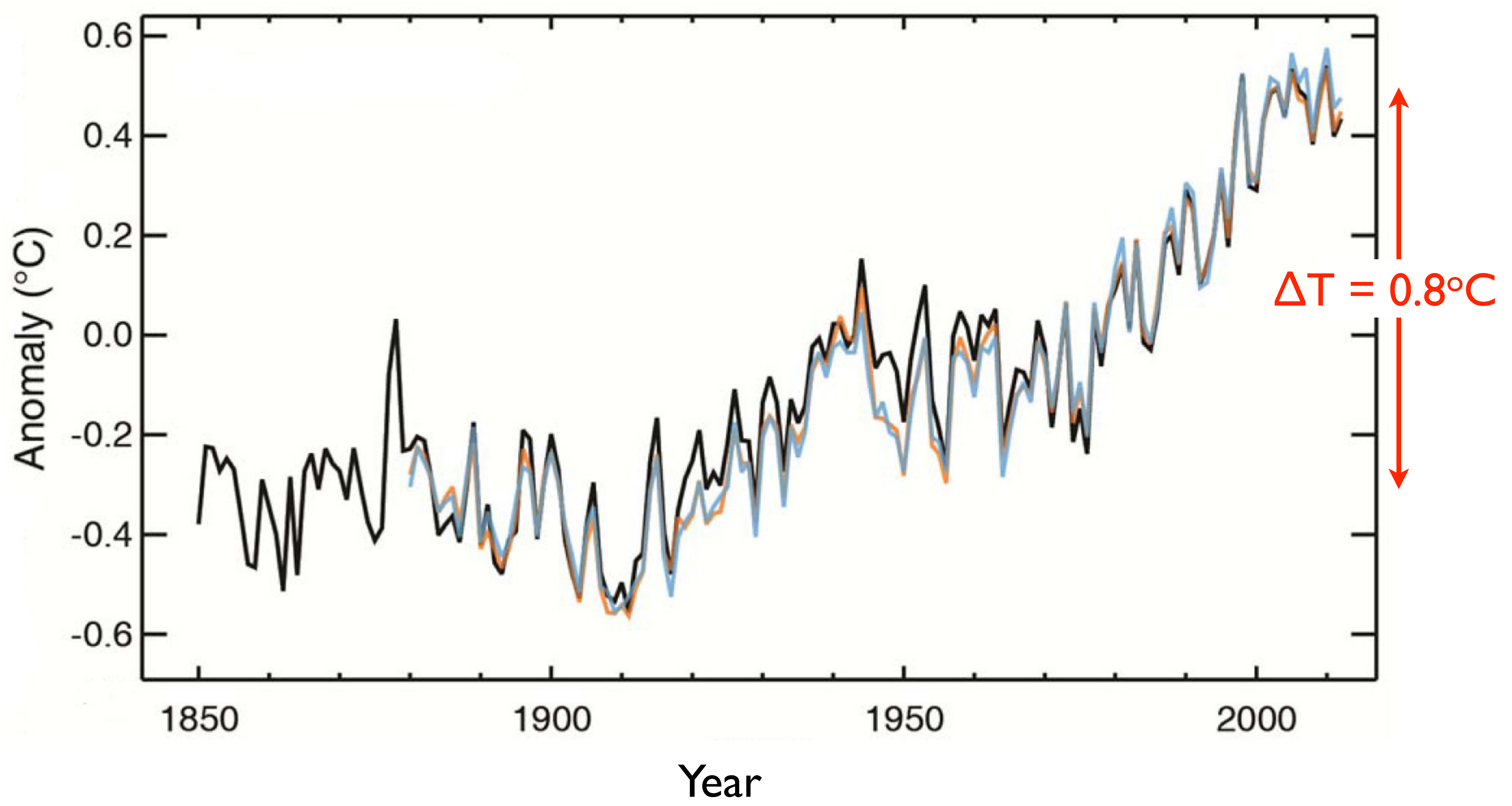
Austria:	University of Innsbruck
	University of Vienna
Finland:	Finnish Meteorological Institute
	Helsinki Institute of Physics
	University of Eastern Finland
	University of Helsinki
Germany:	Johann Wolfgang Goethe University Frankfurt
	Karlsruhe Institute of Technology
	Leibniz Institute for Tropospheric Research
Portugal:	University of Beira Interior
	University of Lisbon
Russia:	Lebedev Physical Institute
Sweden:	University of Stockholm
Switzerland:	CERN
	Paul Scherrer Institute
	TOFWERK
United Kingdom:	University of Manchester
	University of Leeds
USA:	Aerodyne Research
	California Institute of Technology
	Carnegie Mellon University

CERN SPSC Open Session, 24Jun14

Jasper Kirkby
Goethe University of Frankfurt & CERN

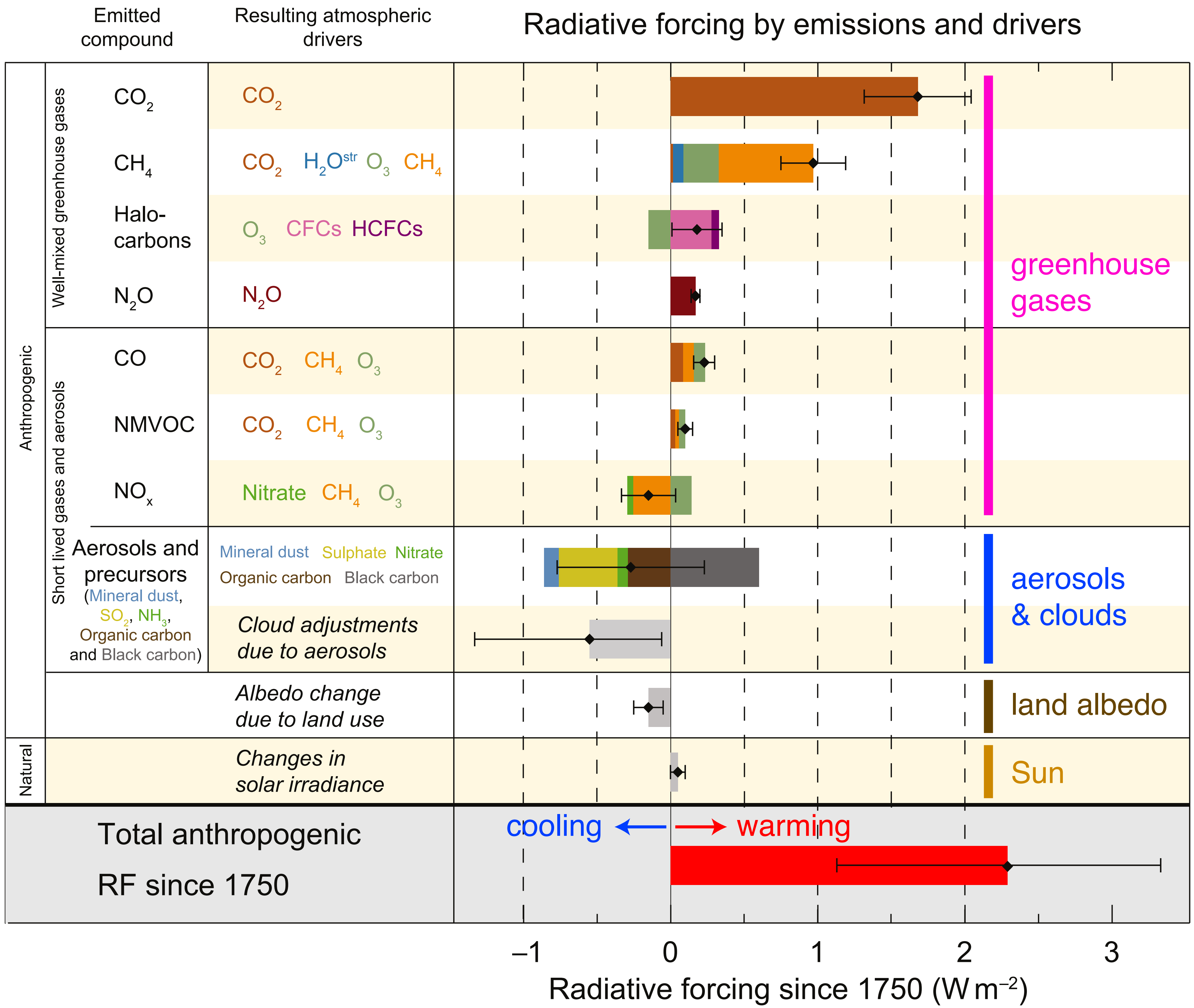
Global surface temperature

Intergovernmental Panel on Climate Change, IPCC, AR5, 2013



Climate radiative forcings

IPCC AR5 Summary for Policymakers, 27 September 2013

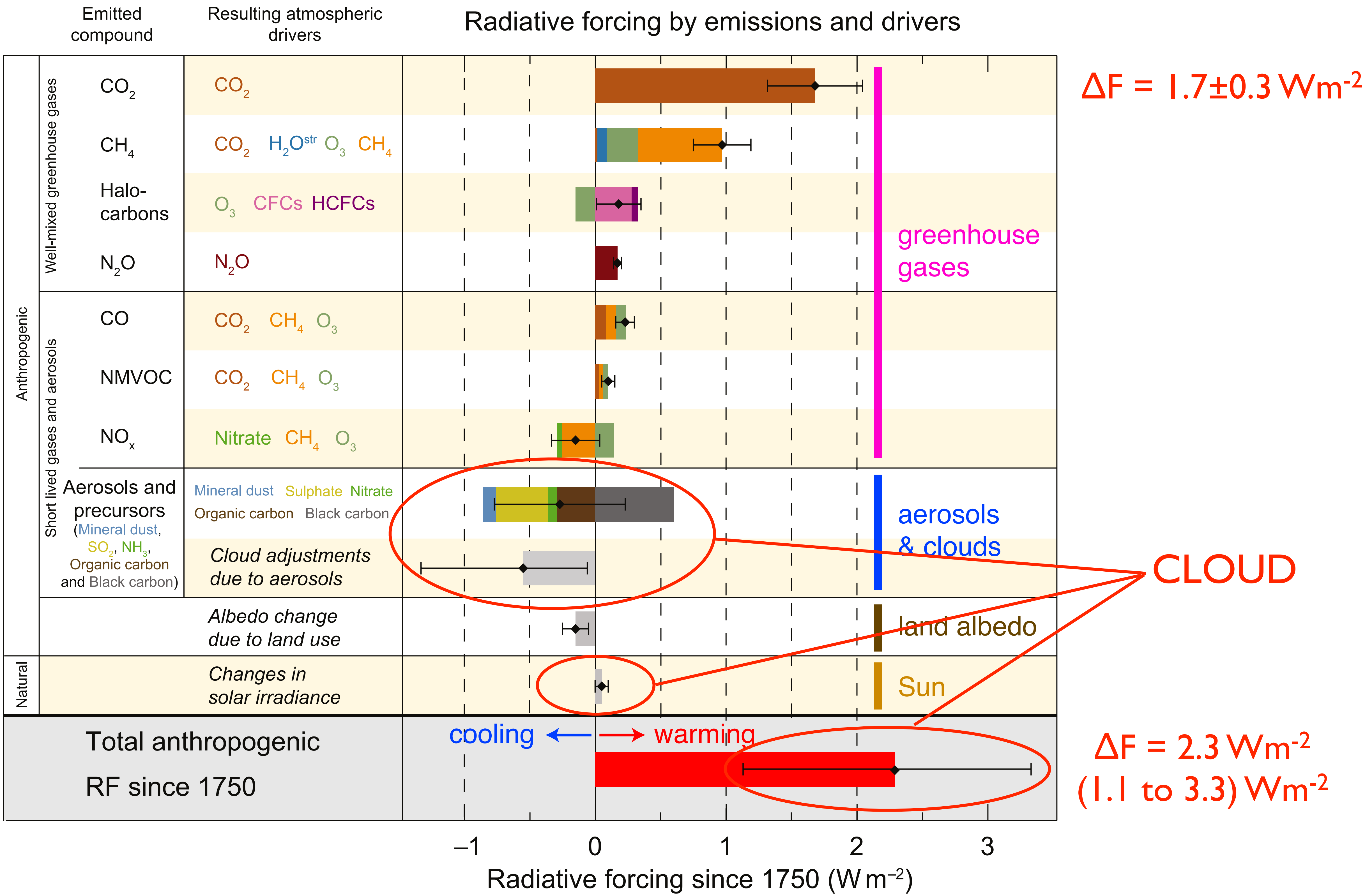


ΔF = 1.7±0.3 Wm^{-2}

ΔF = 2.3 Wm^{-2} (1.1 to 3.3) Wm^{-2}

Climate radiative forcings

IPCC AR5 Summary for Policymakers, 27 September 2013



Climate sensitivity

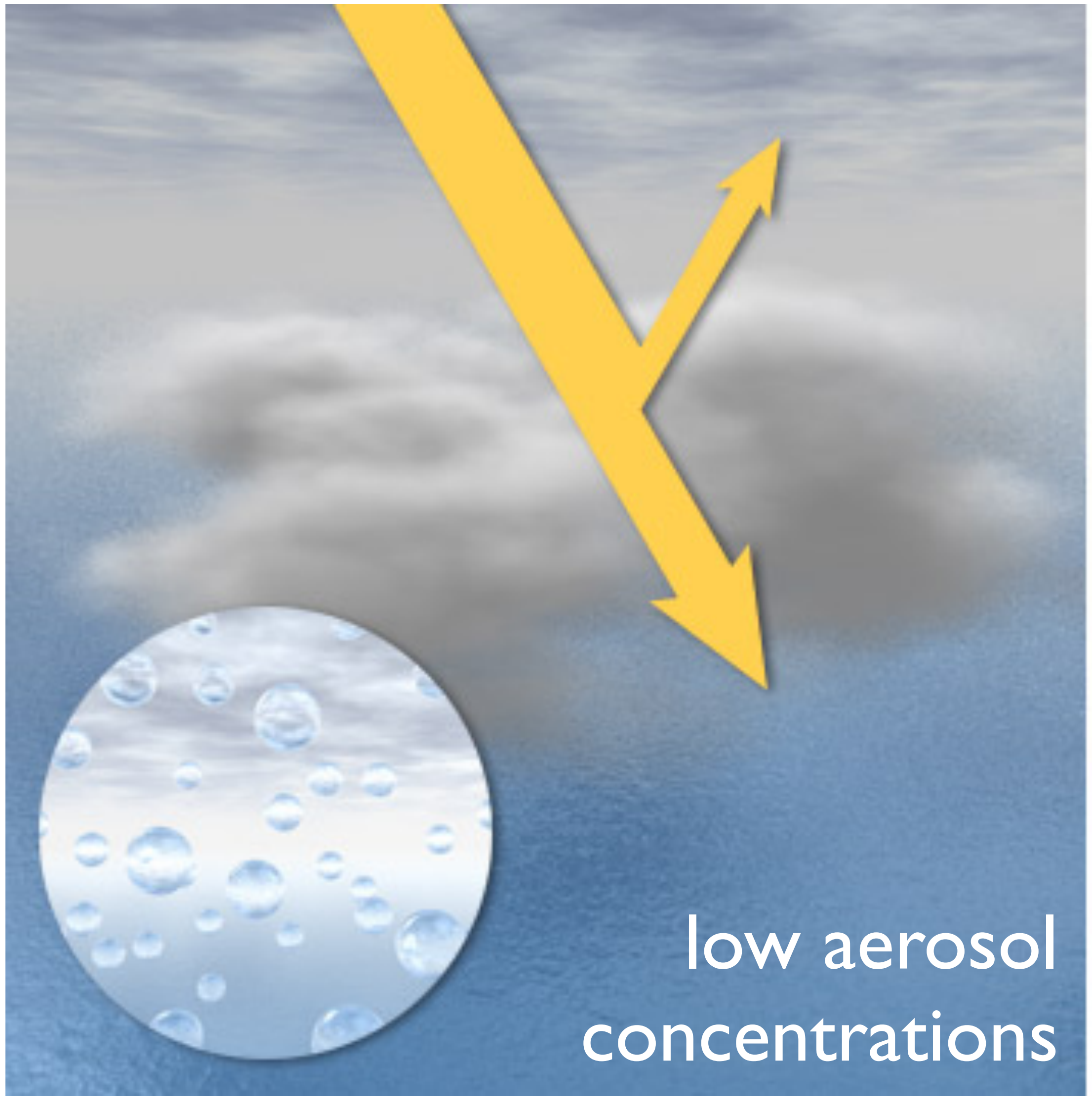
$$\text{climate sensitivity}, \lambda = \frac{\Delta T}{\Delta F}\left(K / Wm^{-2}\right)$$

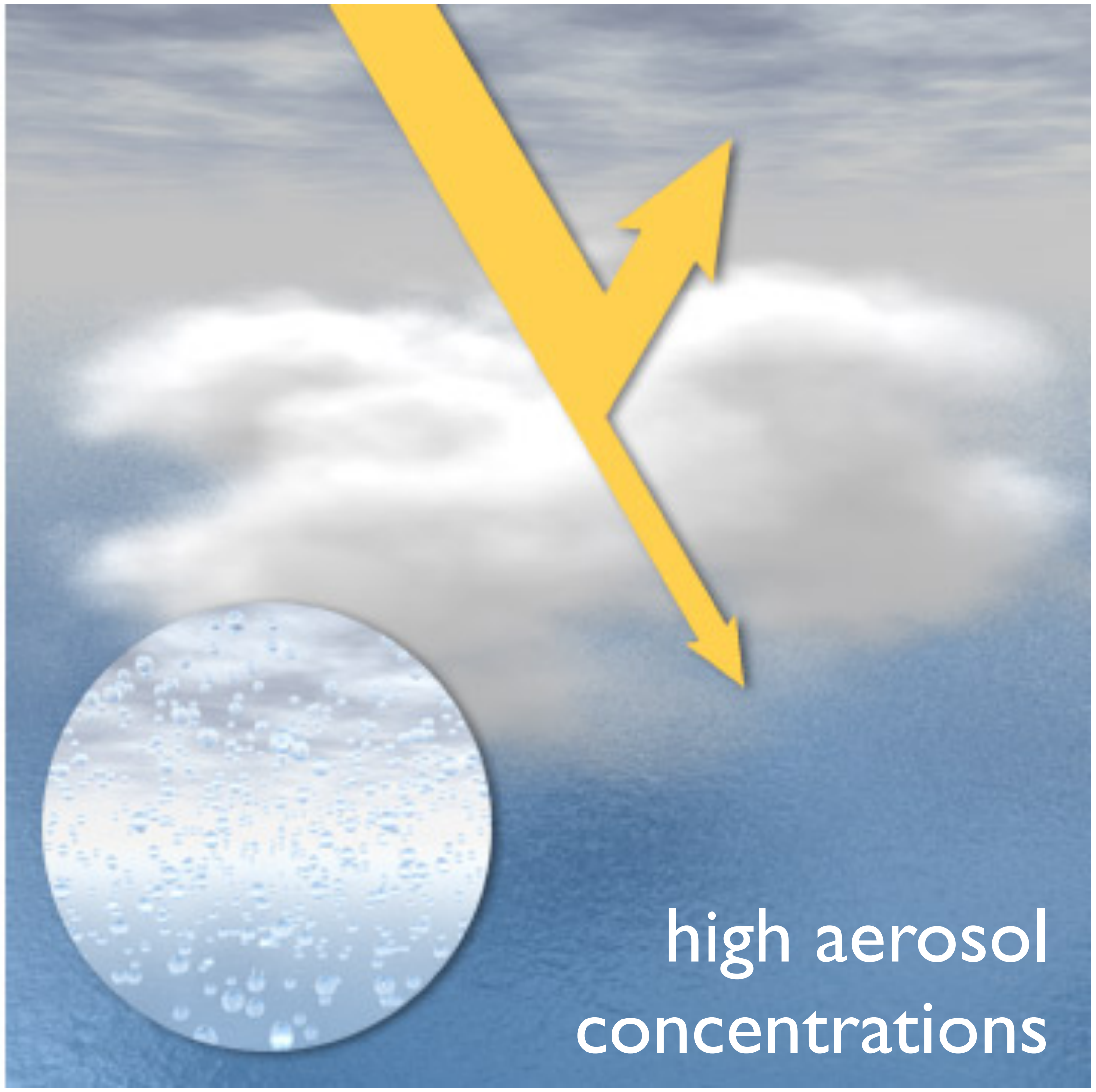
$\Delta T \Rightarrow$ well measured

$\Delta F \Rightarrow$ factor 3 uncertainty (aerosols & clouds)

- Earth's climate sensitivity, λ, implicitly includes all climate feedbacks
- The reason for the wide range of climate projections for 21st century (doubling of CO_2) is the large uncertainty for λ:
  - High $\lambda \Rightarrow$ up to +4.5°C relative to 1850 (IPCC AR5)
  - Low $\lambda \Rightarrow$ about +1.5°C relative to 1850 (IPCC AR5)
- The estimate and uncertainty on λ has not improved in the last 35 years since the 1979 Charney Report to the US National Research Council: *"We estimate the most probable global warming for a doubling of CO_2 to be near 3°C with a probable error of ±1.5°C."*

Aerosol effect on clouds





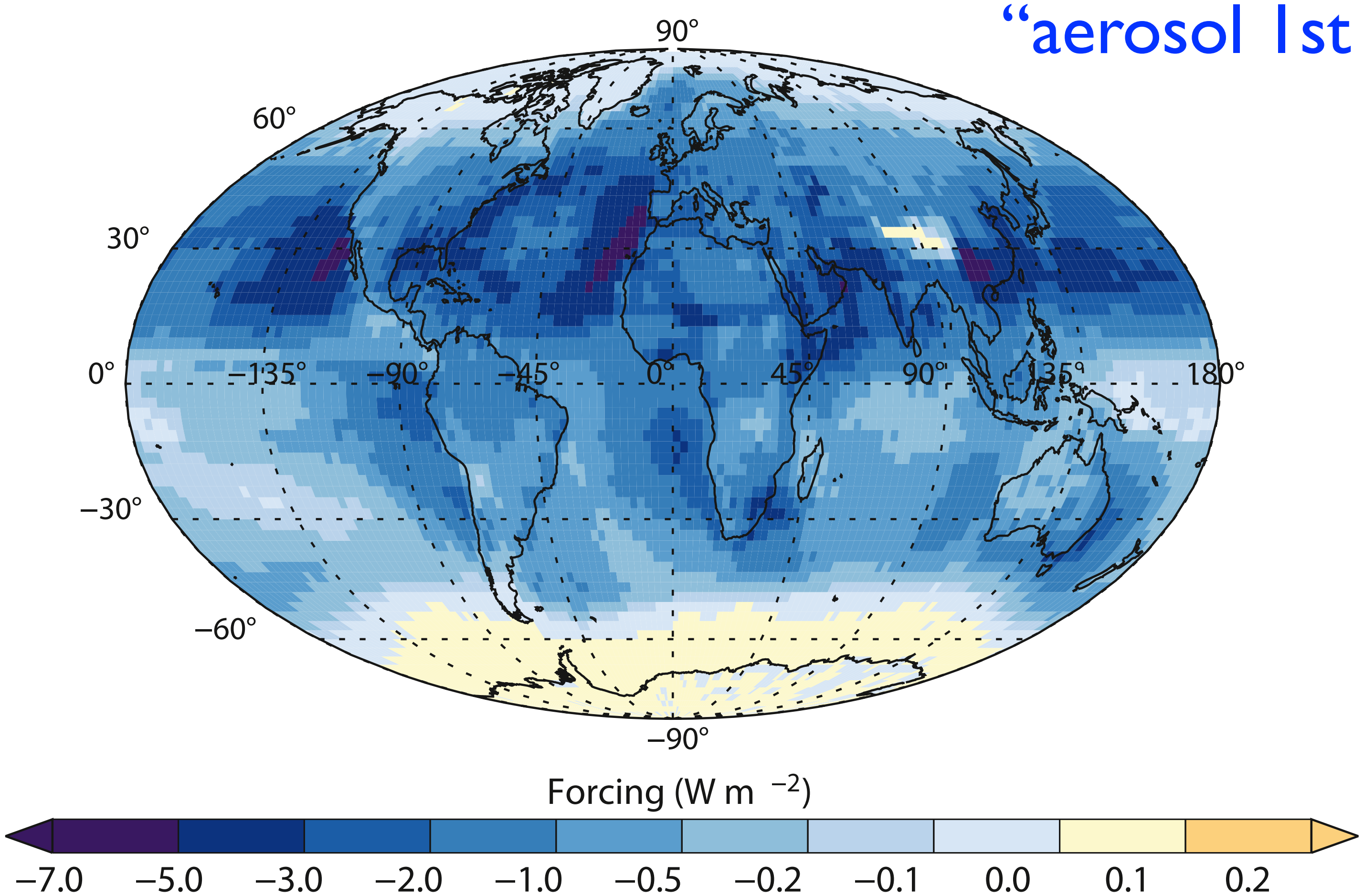
- Cloud droplets form on aerosol particles (cloud condensation nuclei, CCN)
- Increased aerosol particles produce:

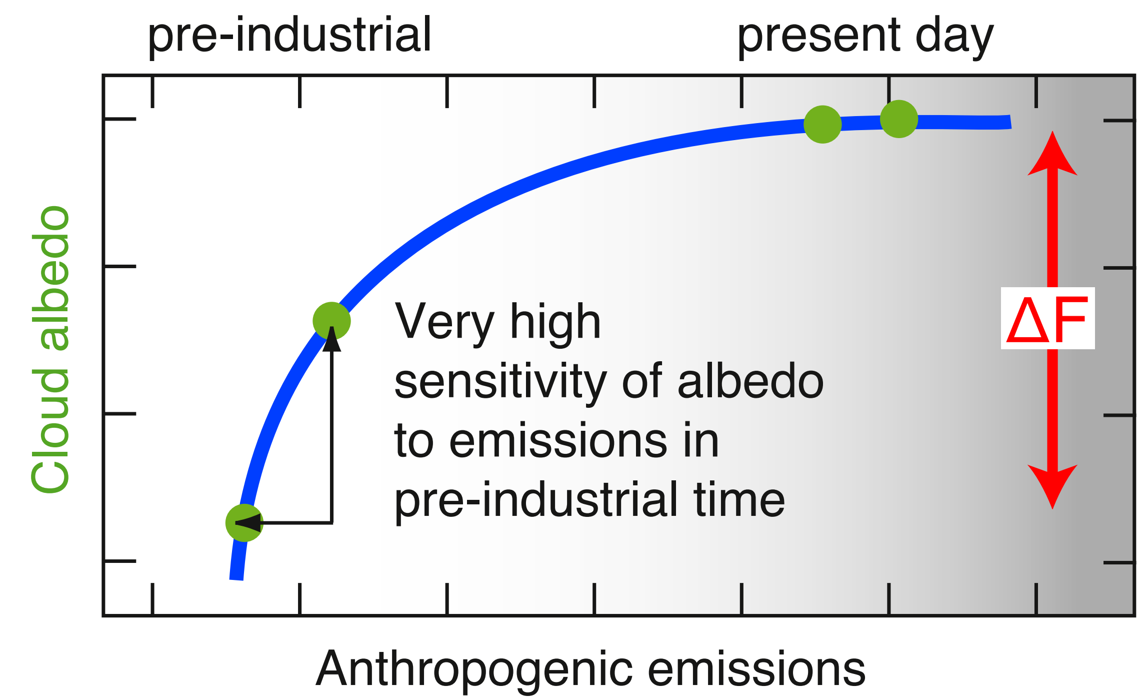
  1) brighter clouds ("aerosol 1st indirect effect") and

  2) more clouds/longer lifetime ("aerosol 2nd indirect effect")

Uncertainty of anthropogenic aerosol/cloud forcing

"aerosol 1st indirect effect": cloud albedo forcing





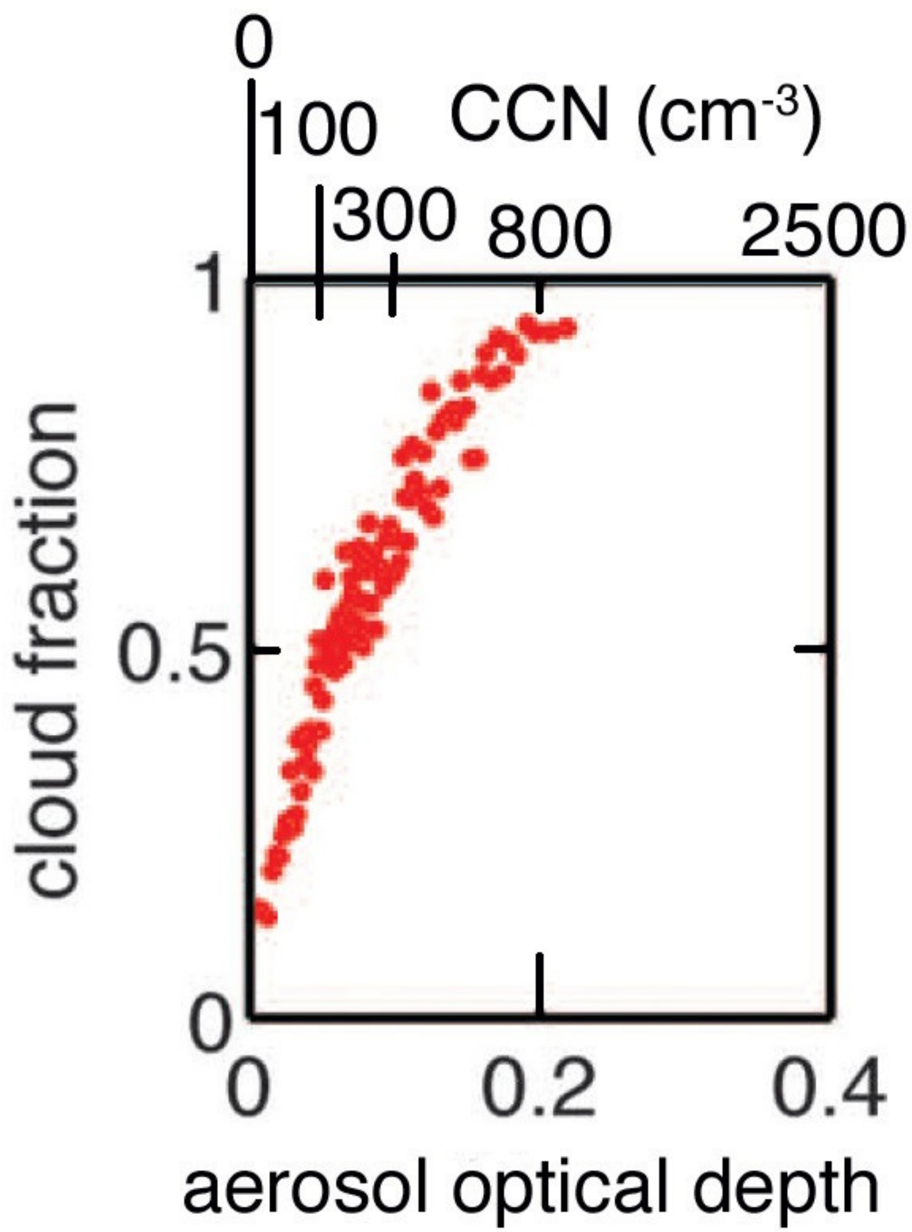
Carslaw et al, Nature, 2014

$\Delta F = -1.15 \pm 0.45\ \mathrm{Wm^{-2}}$ (cf. $\Delta F_{CO_2} = +1.7\ \mathrm{Wm^{-2}}$)

- Pre-industrial atmosphere thought to have very low CCN (no industrial pollution/SO_2), so very sensitive to aerosol nucleation
  - Uncertainty of anthropogenic forcing depends on pre-industrial atmosphere
- Cannot be directly measured so relies on models + CLOUD measurements of fundamental nucleation and growth processes

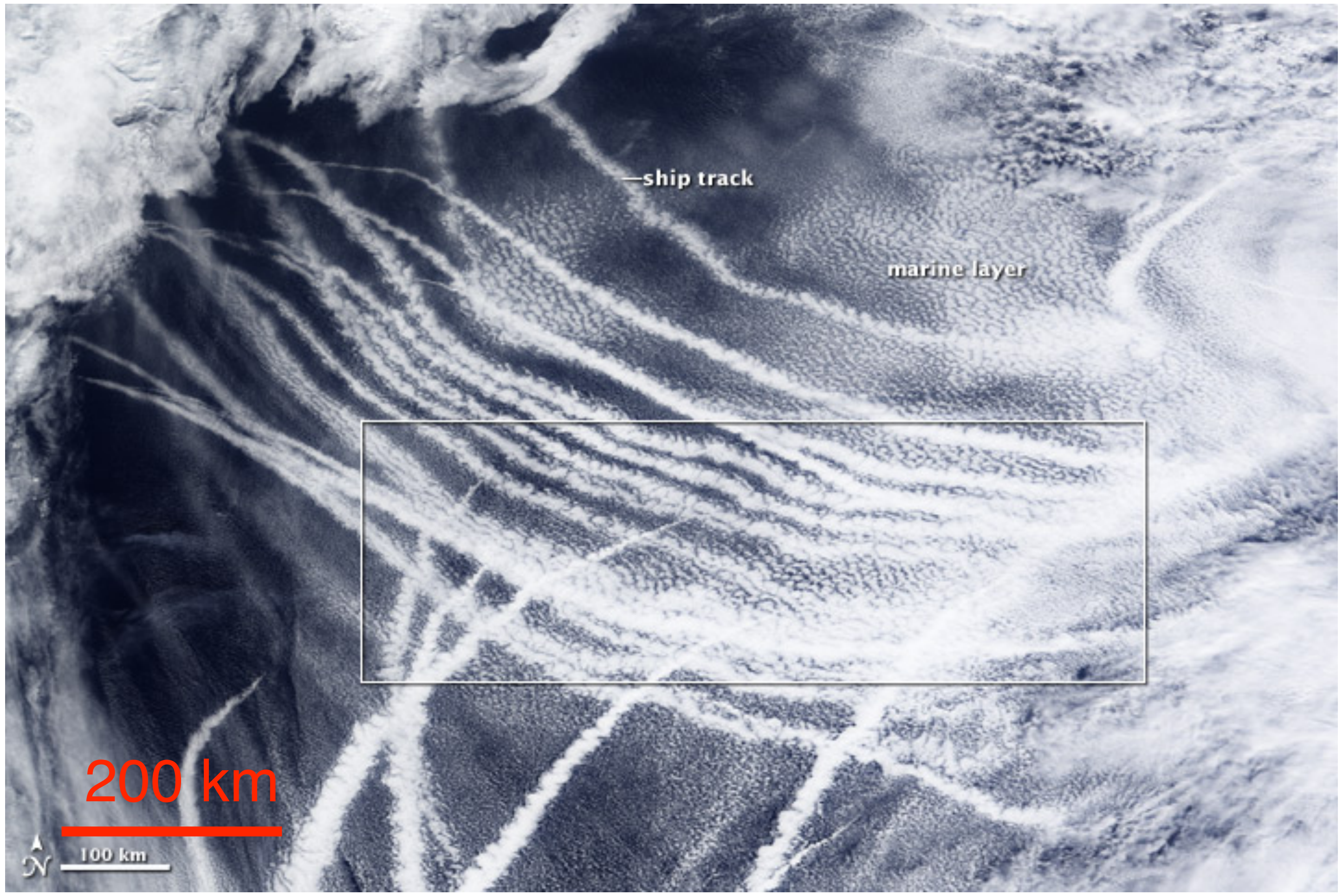
Effect on pristine atmosphere of more aerosol particles

"aerosol 2nd indirect effect":
cloud lifetime forcing

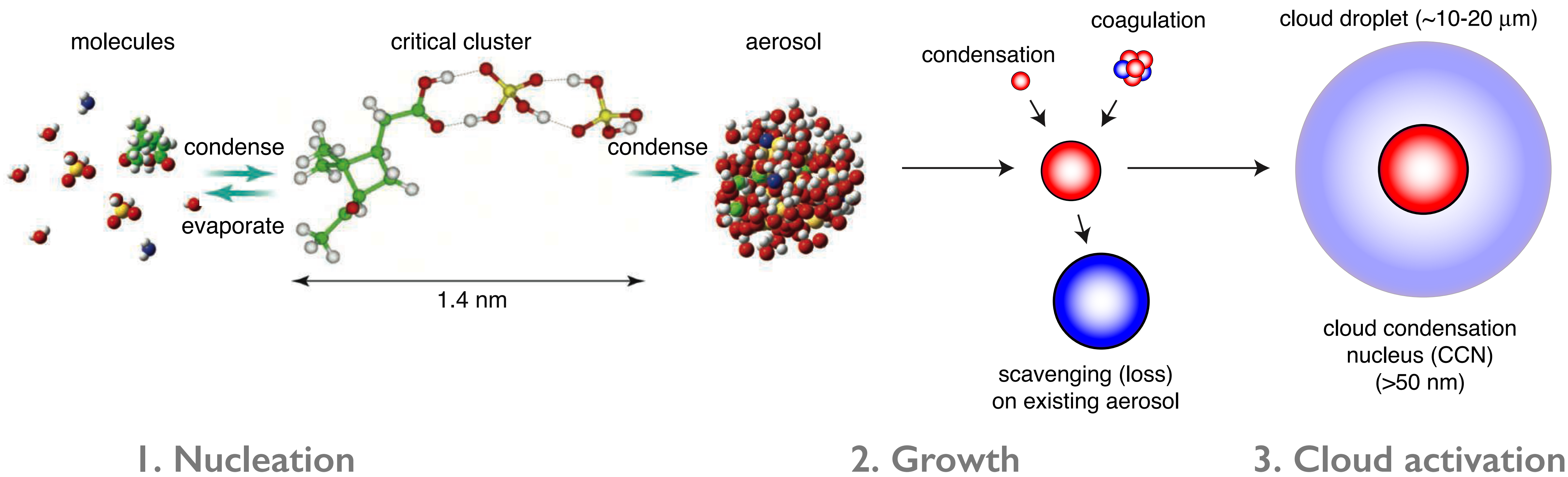


Koren et al, Nature 2014

both aerosol indirect effects seen in satellite images of ship tracks in N. Pacific:



Atmospheric aerosol nucleation (gas-to-particle conversion)



- Responsible for about half of global cloud seed particles but poorly understood

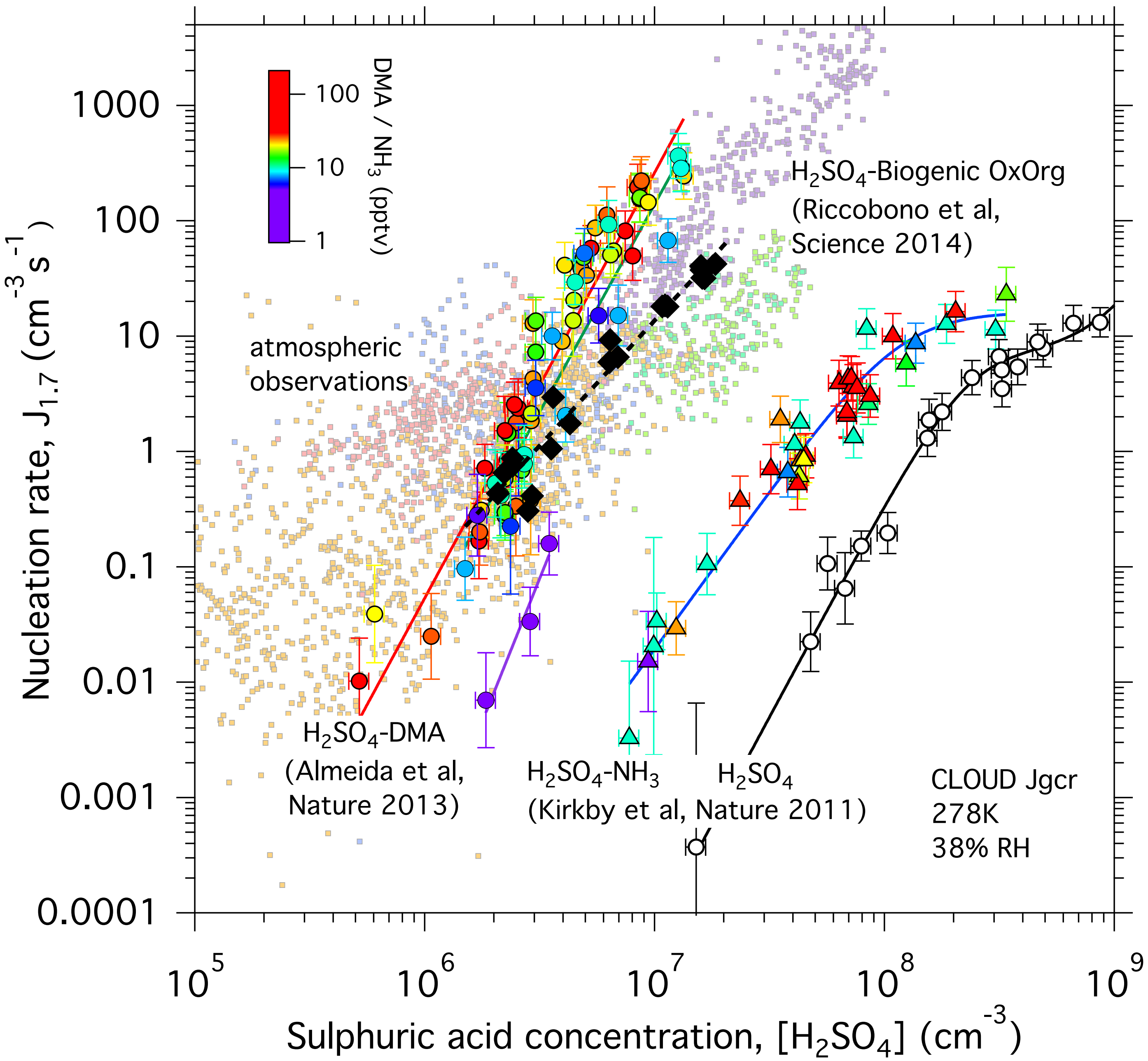
- Ionisation from galactic cosmic rays can stabilise initial molecular clusters and help them grow above critical size ⇒ possible solar-GCR-climate mechanism

CLOUD progress in first 5 years operation

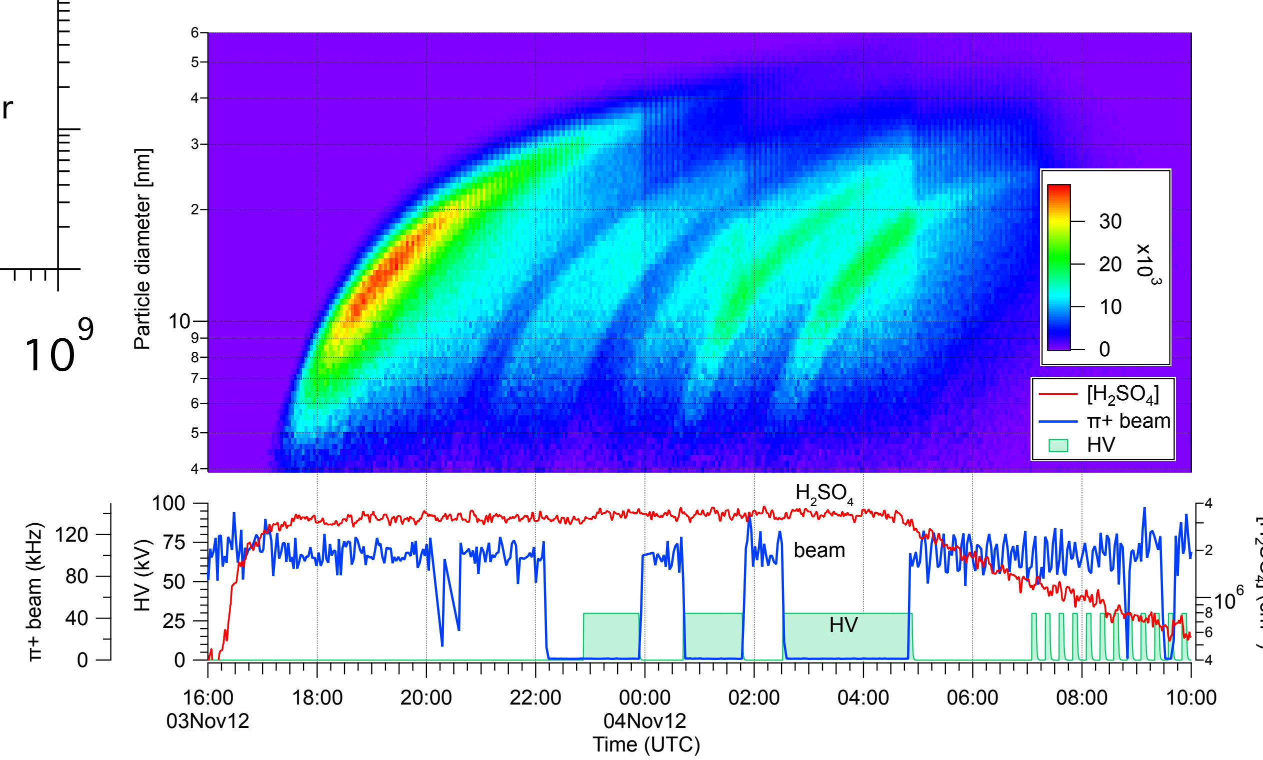
CLOUD1	2009	Commissioning
CLOUD2	2010	H_2SO_4-NH_3 nucleation
CLOUD3	2010	H_2SO_4-NH_3 nucleation
CLOUD4	2011	Dimethylamine (DMA) & pinanediol nucleation
CLOUD5	2011	Free tropospheric H_2SO_4-NH_3 nucleation
CLOUD6	2012	Initial cloudy exeriments
CLOUD7	2012	H_2SO_4-NH_3-DMA-α-pinene nucleation
CLOUD8	2013	Low H_2SO_4 nucl. + cloudy experiments (aqu. phase + ice) - GCR
CLOUD9	2014	Cloudy experiments (aqueous phase + ice)+ small ion studies

- 4 high-impact publications (2 Nature, 1 Science, 1 PNAS)
- 8 further publications (physics + technical & method developments)
- 3 manuscripts under review
- 5 draft manuscripts close to submission

CLOUD progress: aerosol nucleation & growth to CCN

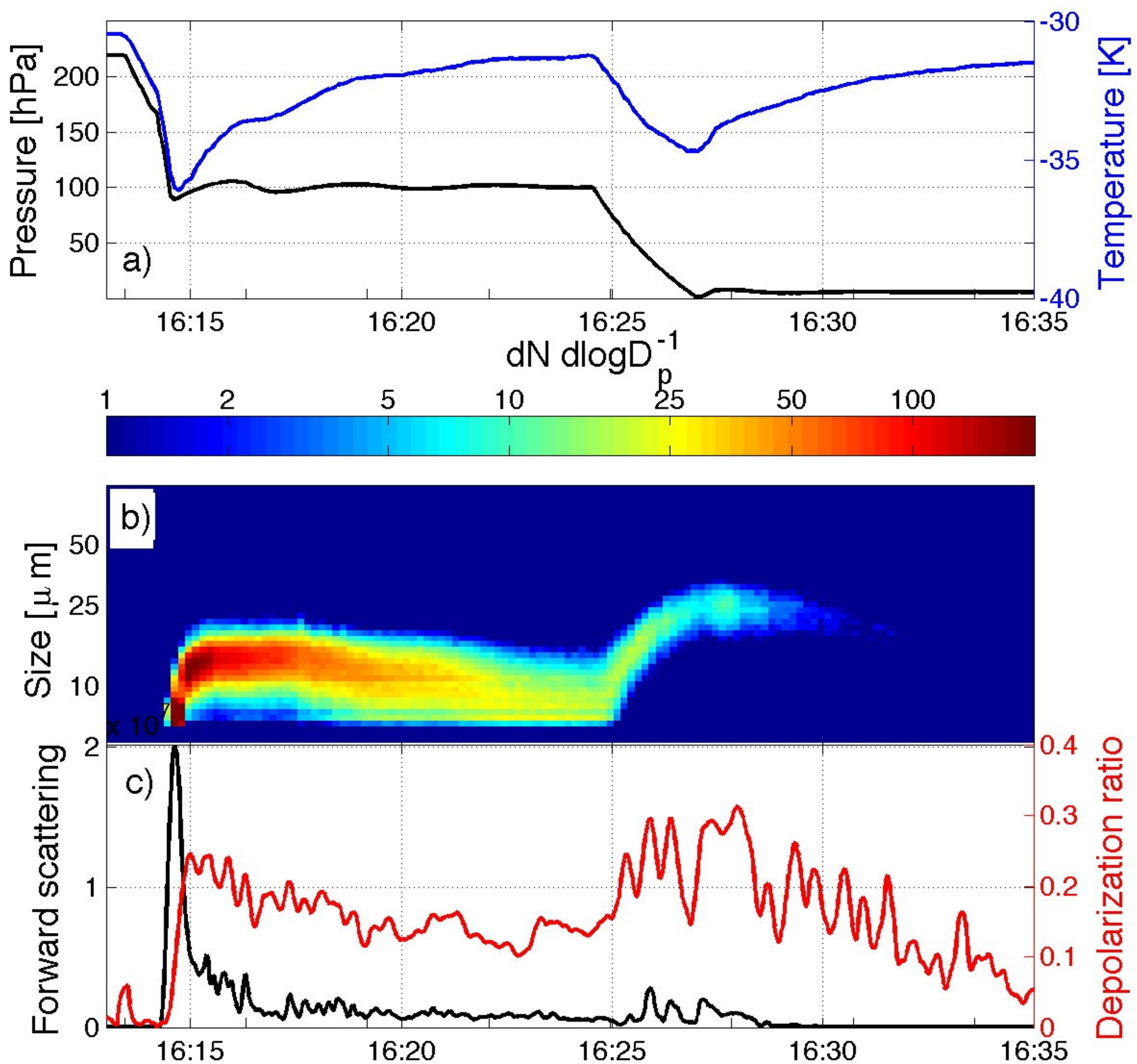


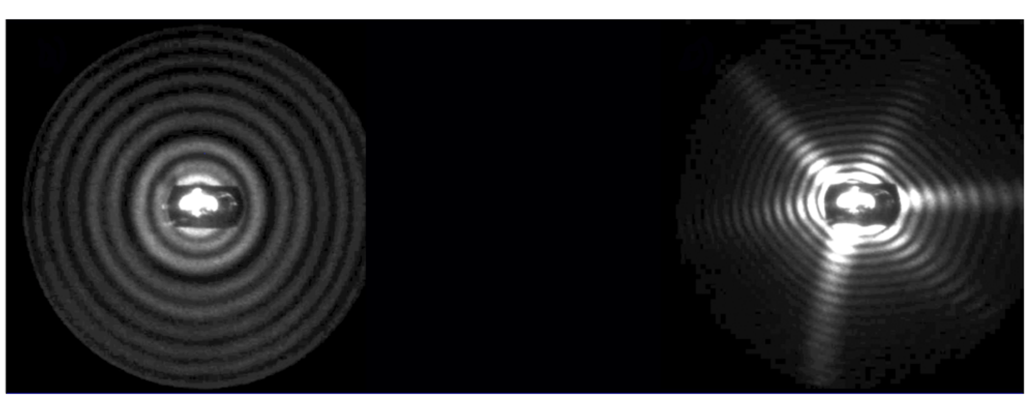
- Main nucleation vapours established (H_2SO_4, NH_3, amines, biogenic vapours)
- Significant enhancement of ions depending on vapours and conditions:



CLOUD progress: ice formation

CLOUD8 results:

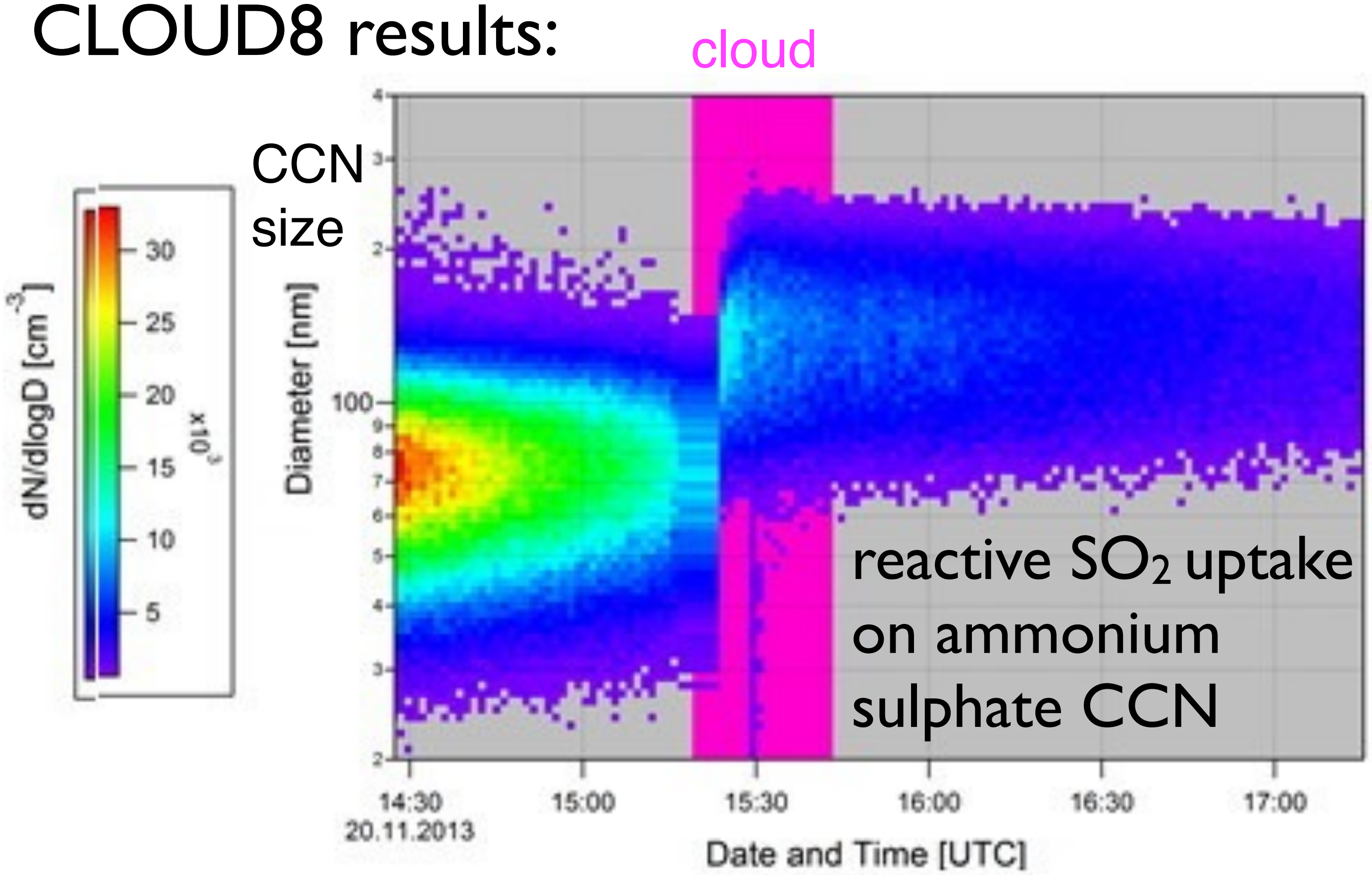


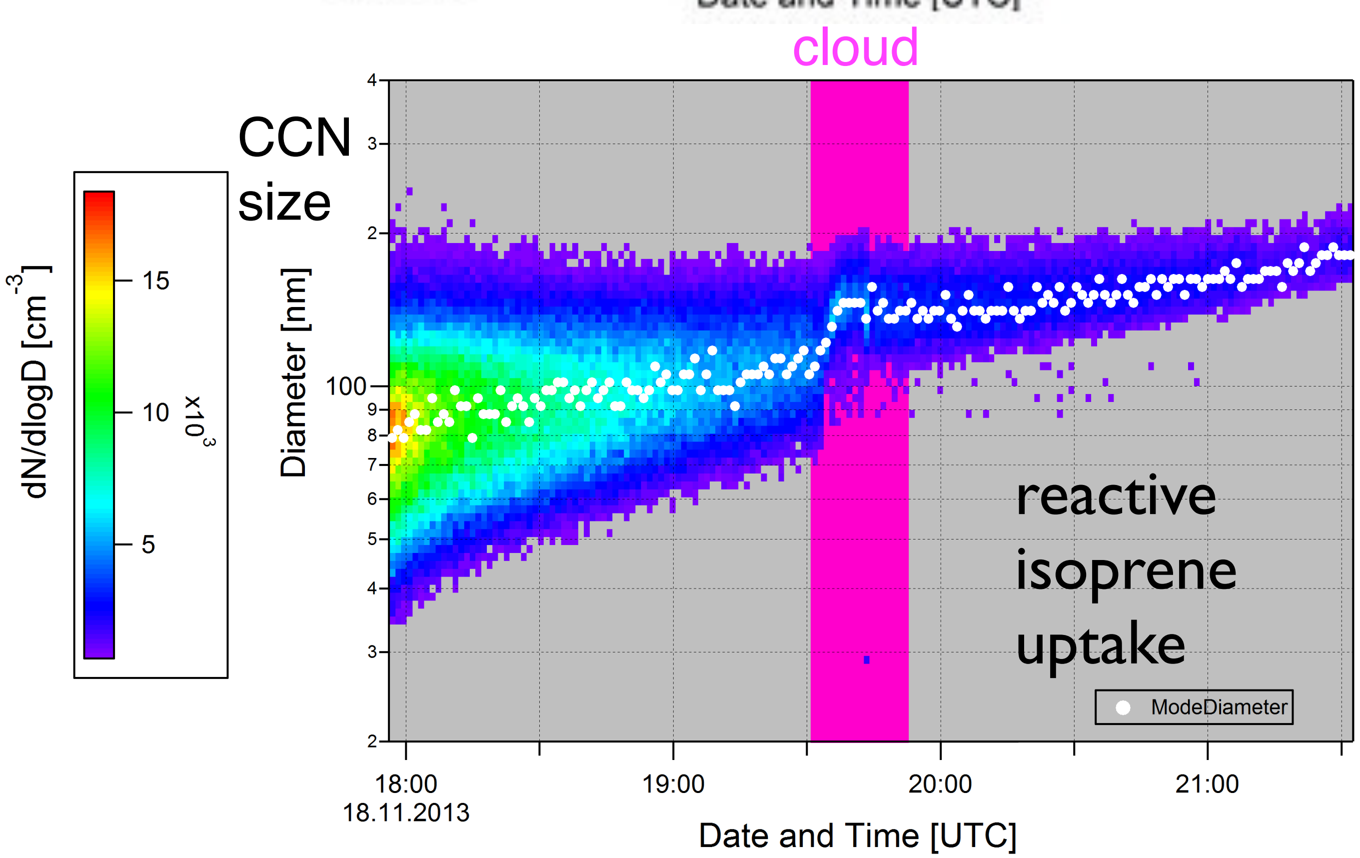


- Many clouds contain super-cooled water between 0°C and -37°C, the homogeneous freezing point of water, since ice nuclei are rare (~10^{-6} of all CCN)
- Freezing of supercooled water is important since almost all rain is initiated by freezing and then rapid ice particle growth and sedimentation
- However almost nothing is known of the effects of charge on ice formation in clouds

CLOUD progress: aqueous phase chemistry

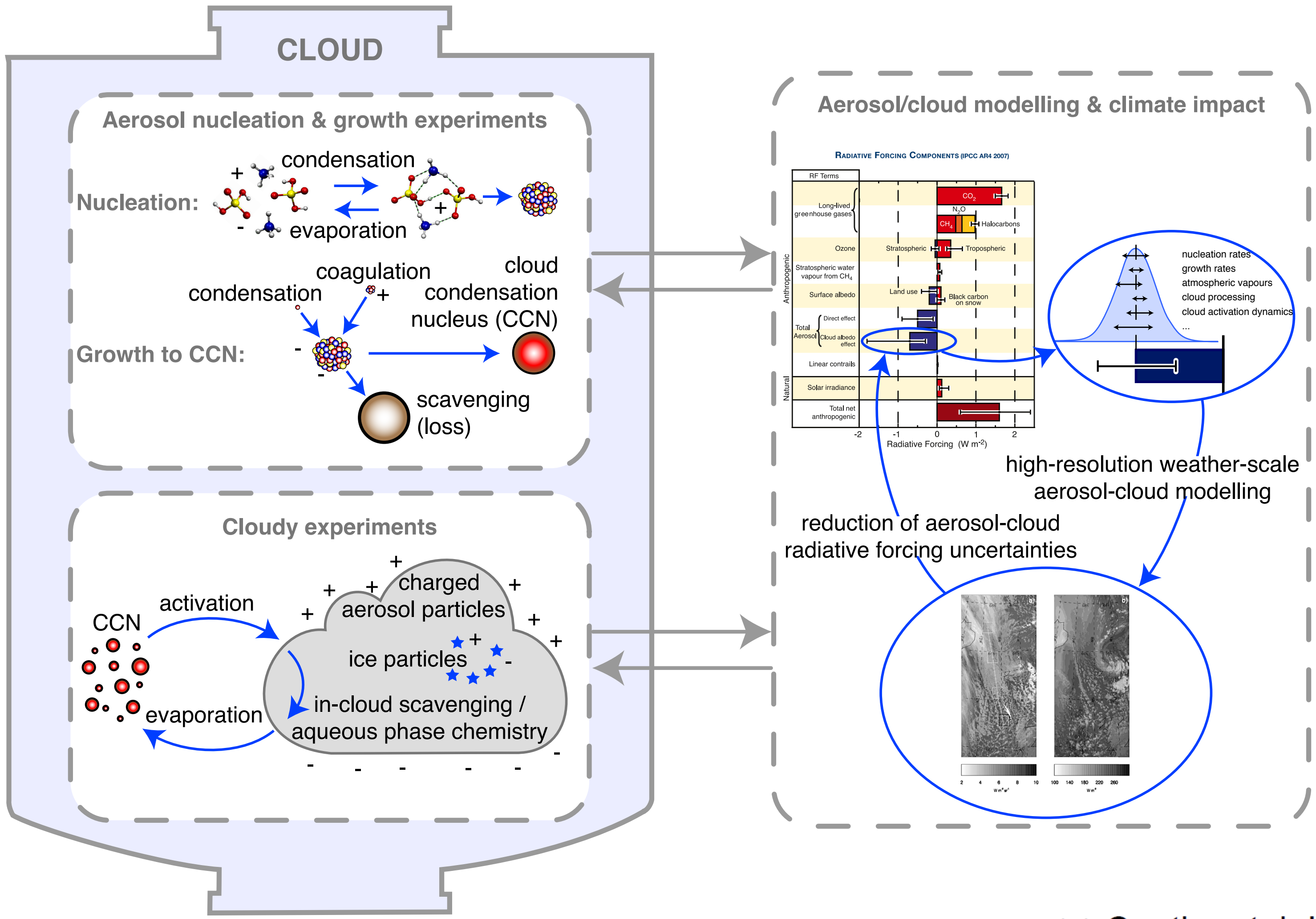
CLOUD8 results:





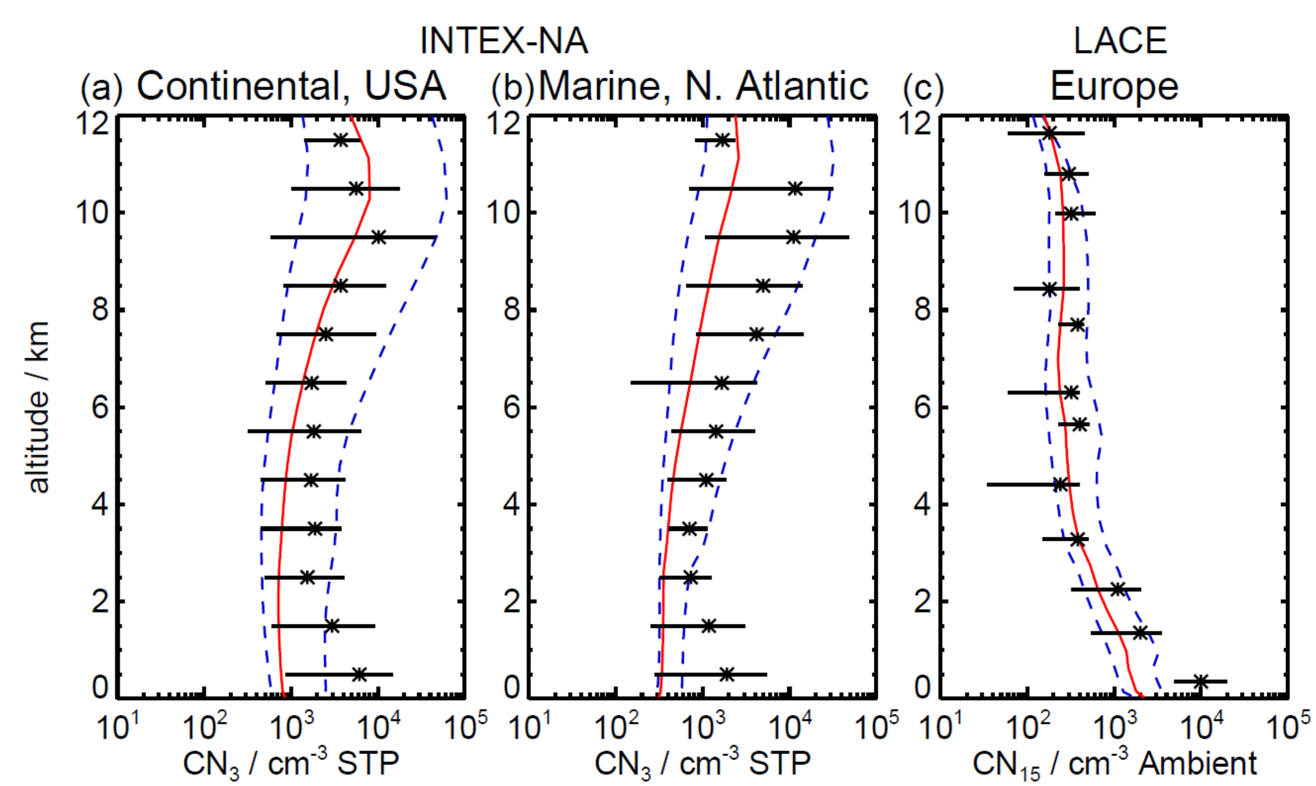
- Aqueous phase reactions with atmospheric vapours are key processes responsible for modifying aerosol before droplet evaporation and release of the processed aerosol
- However almost no laboratory measurements exist on reactive uptake of vapours in cloud droplets under atmospheric conditions
- Effect of ions is unknown

Future CLOUD experimental + modelling strategy



Modelled >3nm particle vertical profile from CLOUD $H_2SO_4+NH_3$ nucleation measurements (red line) vs atmospheric observations (data points with 25-75% percentile):

- First time that aerosol/climate modelling has been closely integrated with a laboratory experiment to focus measurements on the most critical variables and conditions required for climate models



Prospective CLOUD campaigns (2015-2017)

Global models will define the parameter range

Campaign	Year	Variables	Goals
CLOUD10	2015	C_5H_8, $C_{10}H_{16}$ H_2SO_4, NH_3 IONS OH, O_3, NO_3, T, RH	Biogenic nucleation & growth: - monoterpenes and isoprene - IONS dependence - day vs night-time chemistry; role of NO_3 - pre-industrial vs. present day - O_3 vs. OH oxidation - size-dependent growth to CCN size - T, RH dependence
CLOUD12	2016	$C_{15}H_{24}$, C_9H_{12} C_2H_7N, CH_5N, C_3H_9N H_2SO_4, NH_3 IONS OH, O_3, NO_3	Biogenic & anthropogenic nucleation & growth: - sesquiterpenes - anthropogenic organics (trimethylbenzene, TMB) - amines (MEA, MMA, and TMA) - goals as above
CLOUD14	2017	C_2H_6S, OIO, amines IONS OH, O_3, NO_3 T, RH	Marine and coastal nucleation & growth: - DMS oxidation - iodine oxides, amines - goals as above

- Aim for a single 12-week run each year split into 2 CLOUD campaigns:
  - a) aerosol nucleation & growth (6 wk) and
  - b) cloudy experiments (6 wk) [aqueous phase chemistry & ice formation; not shown]

T11 beamline & infrastructure

T11 beamline & infrastructure

T11 beamline & infrastructure

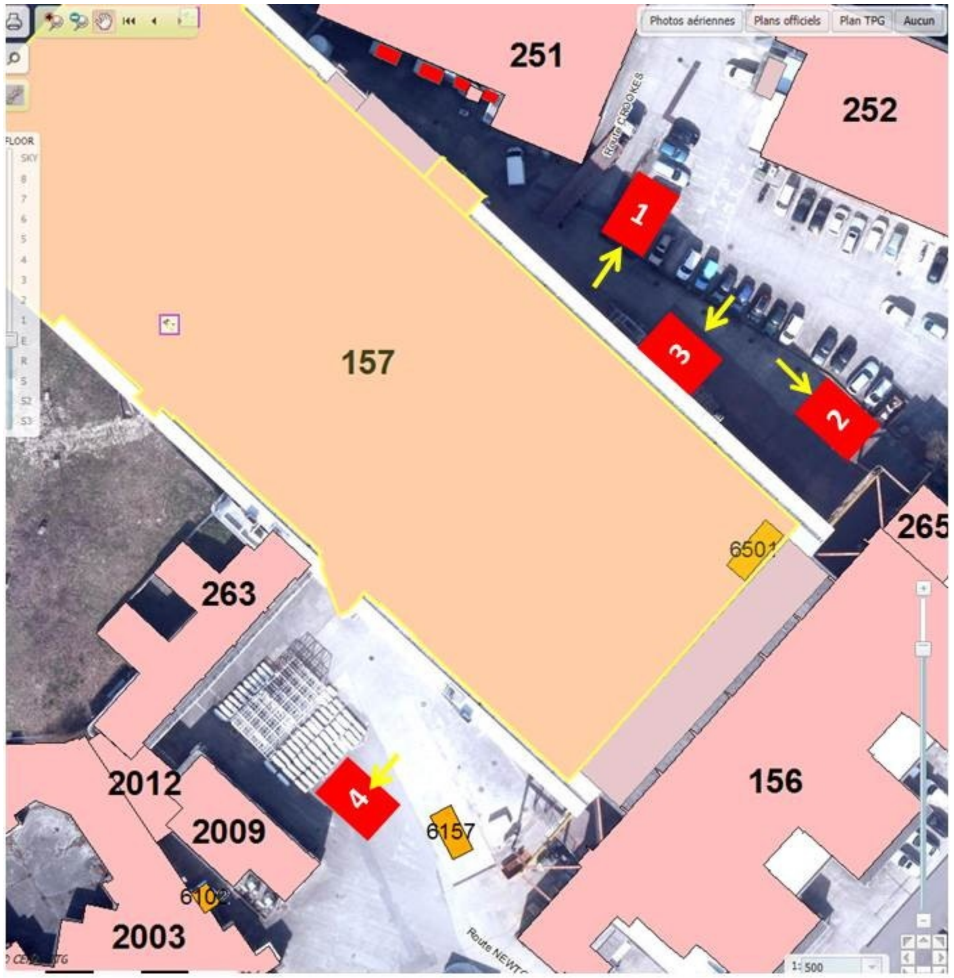
- CLOUD aims for typically a single campaign per year of up to about 12 weeks. This maximises the physics output (data taking/analysis balance)

- At other times we need free access to CLOUD in the T11 zone for maintenance and upgrades:
  - CLOUD facility is continually in a state of development to extend physics reach in response to new findings
  - Each CLOUD campaign involves a new configuration of instruments with new interface requirements to the CLOUD chamber
  - Strong support of CERN technical experts will continue to be crucial for CLOUD's future success

- T11 beamline has proved very well-suited to CLOUD and we would like to retain it in future East Hall upgrades

- A small increase in T11 zone space towards the T10 side would be very valuable for CLOUD

T11 beamline & infrastructure



- CLOUD Office Room Extension (CORE) with networked audio-visual equipment under study by CERN GS for location near East Hall/CLOUD

- Multi-purpose CLOUD room (54 m^2):
  - Daily data analysis and run planning meetings during campaigns
  - Weekly technical planning and virtual physics analysis working group meetings throughout the year
  - Open office for CERN CLOUD team (6 fellows and students - presently using temporary borrowed offices)
  - Open office space for CLOUD experimenters during campaigns at PS (20-30 additional people)

Summary

- CLOUD goals:
  - Settle the GCR-cloud-climate question
  - Reduce the uncertainties of aerosol/cloud radiative forcing and so sharpen climate change projections for the 21st century

- Ambitious but realistic goals. At present CLOUD is the unique experiment in the world for these measurements

- Based on the first 5 year's experience, we estimate it will require 10 more years operation of CLOUD