The CLOUD project; climate research with accelerators

International Particle Accelerator Conference 2010

Kyoto, 28May10

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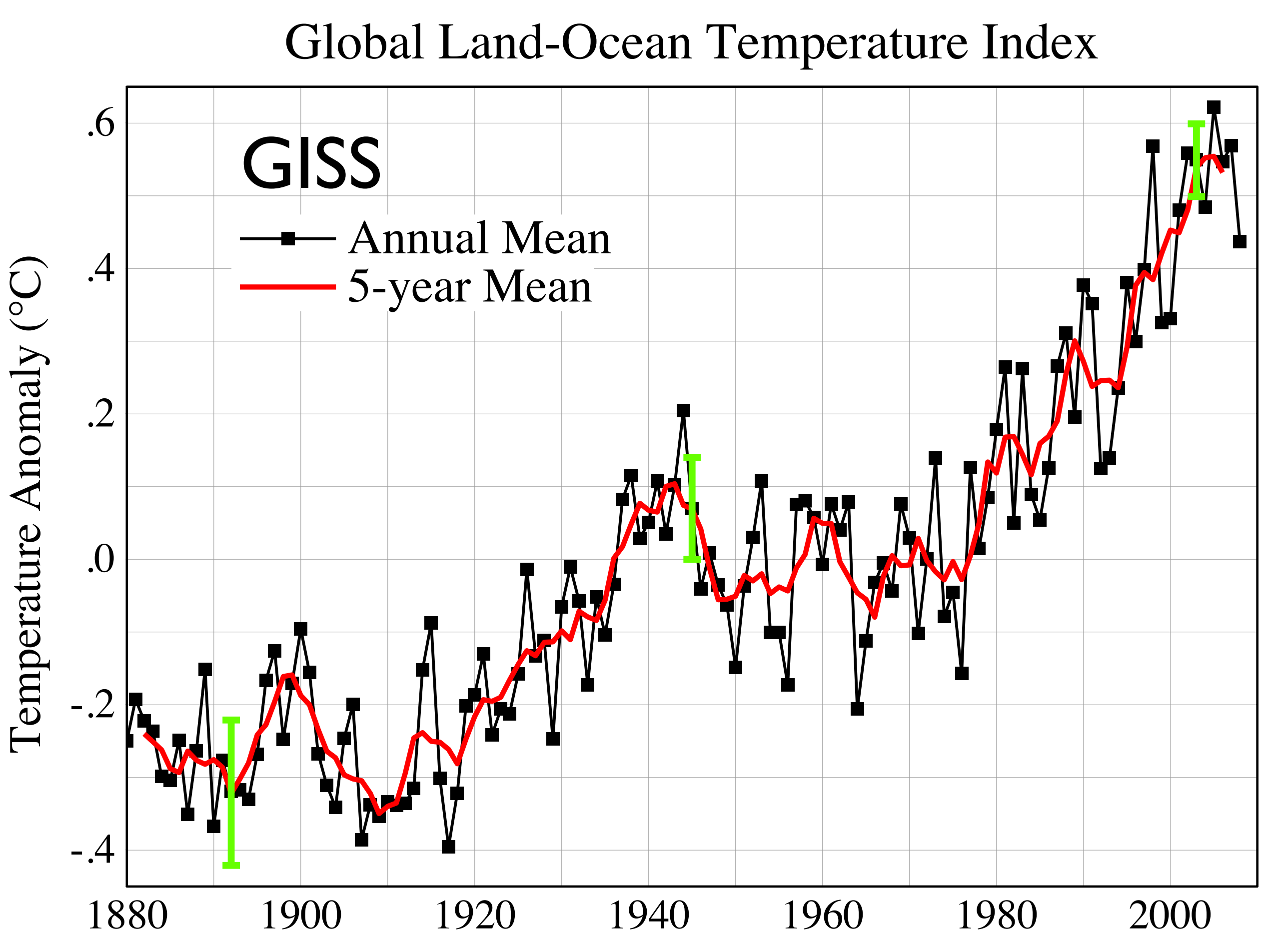
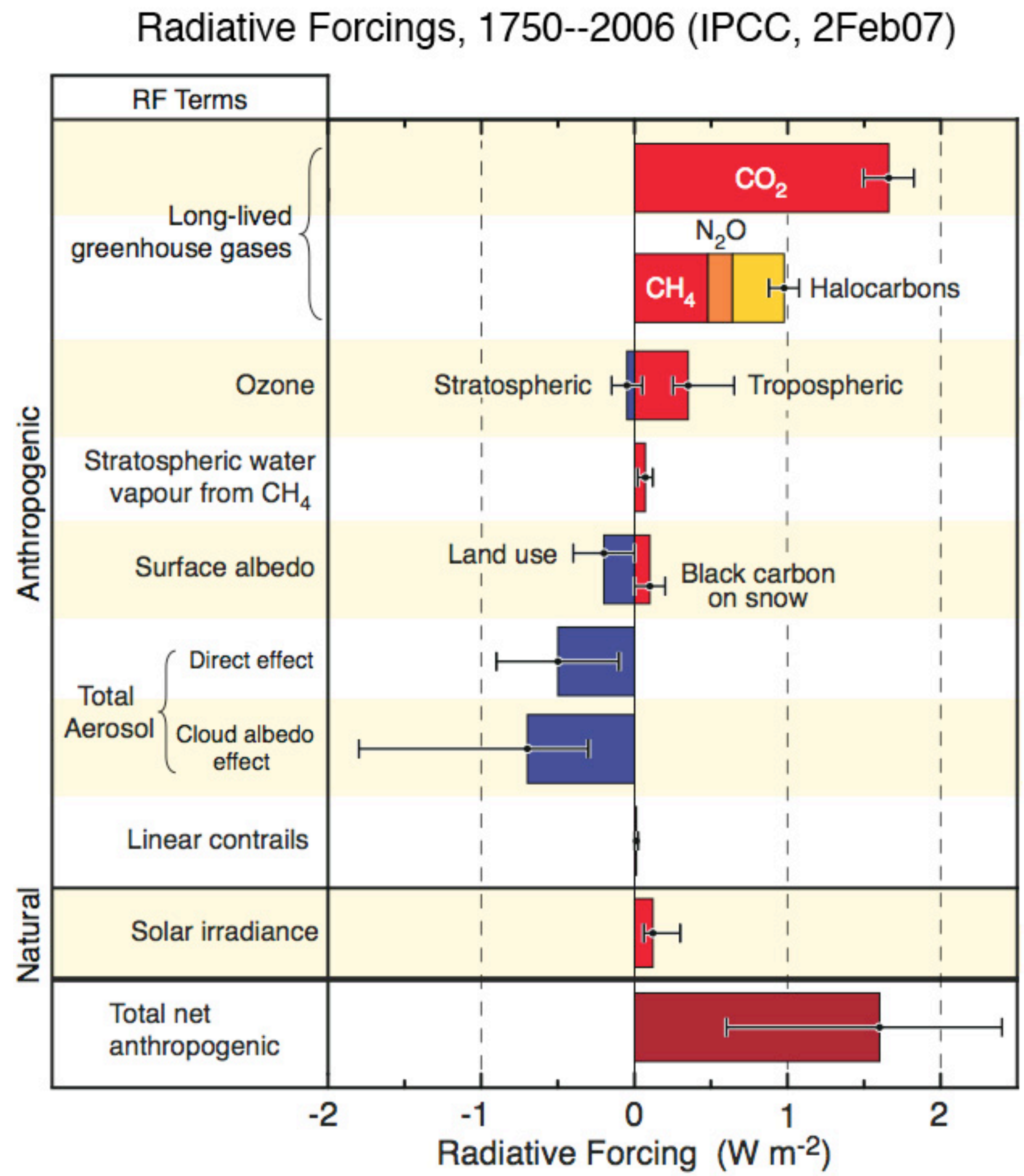
On behalf of the CLOUD Collaboration:
Caltech, CERN, U Frankfurt, FMI Helsinki, U Helsinki, U Innsbruck, UEF Kuopio, U Leeds, IfT Leipzig, U Lisbon, LPI Moscow, PSI, RAL, U Reading, INRNE Sofia, U Tampere, U Vienna

1. Present climate change

Climate forcings (IPCC 2007)





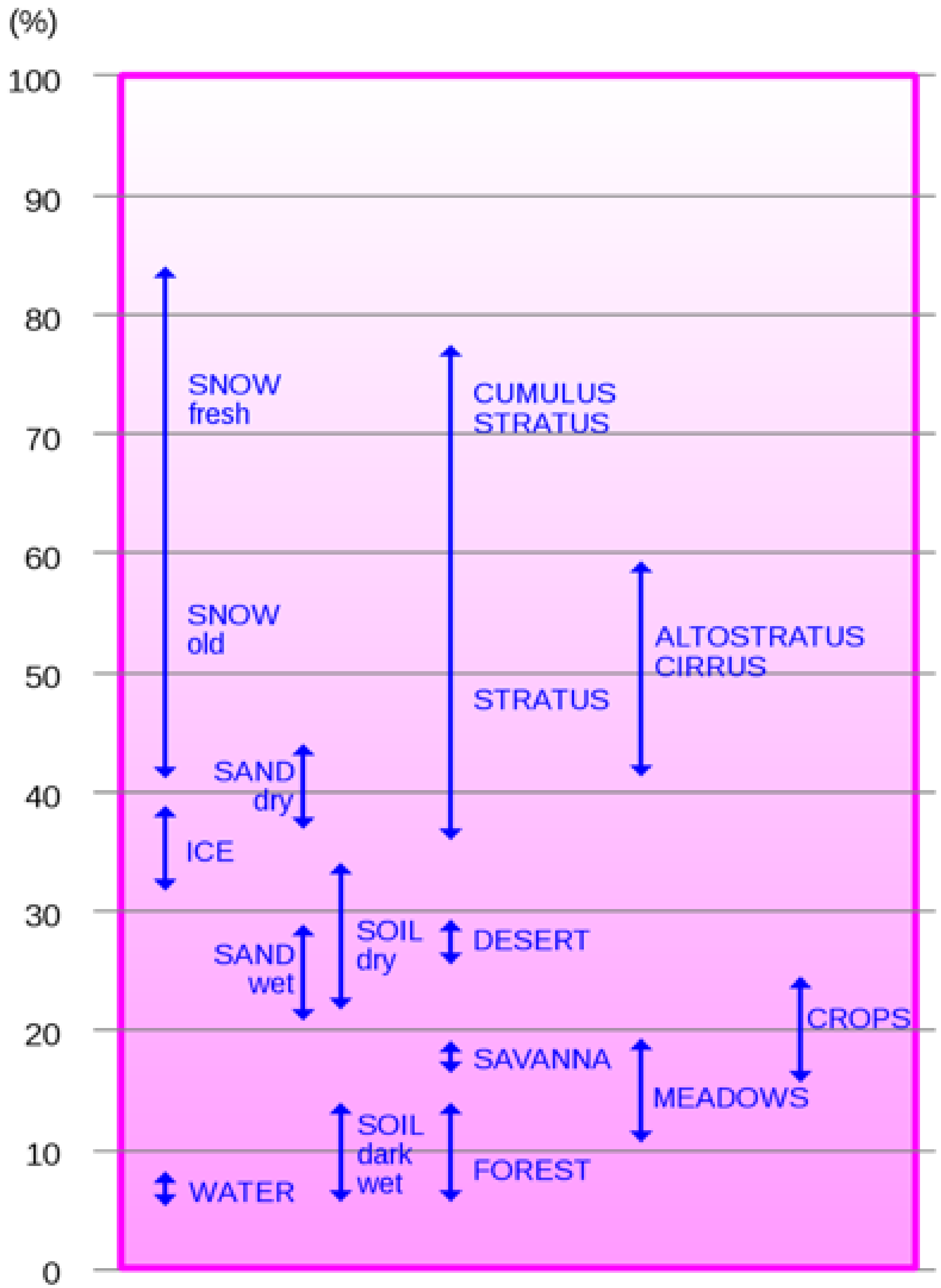
- 0.7°C rise since 1900 (not uniform)
- IPCC findings:
  - Total anthropogenic 1.6 W/m^2 (≅ 1 candle per 25 m^2)
  - Negligible natural (solar) contribution: 0.12 W/m^2
  - Aerosols and clouds poorly understood

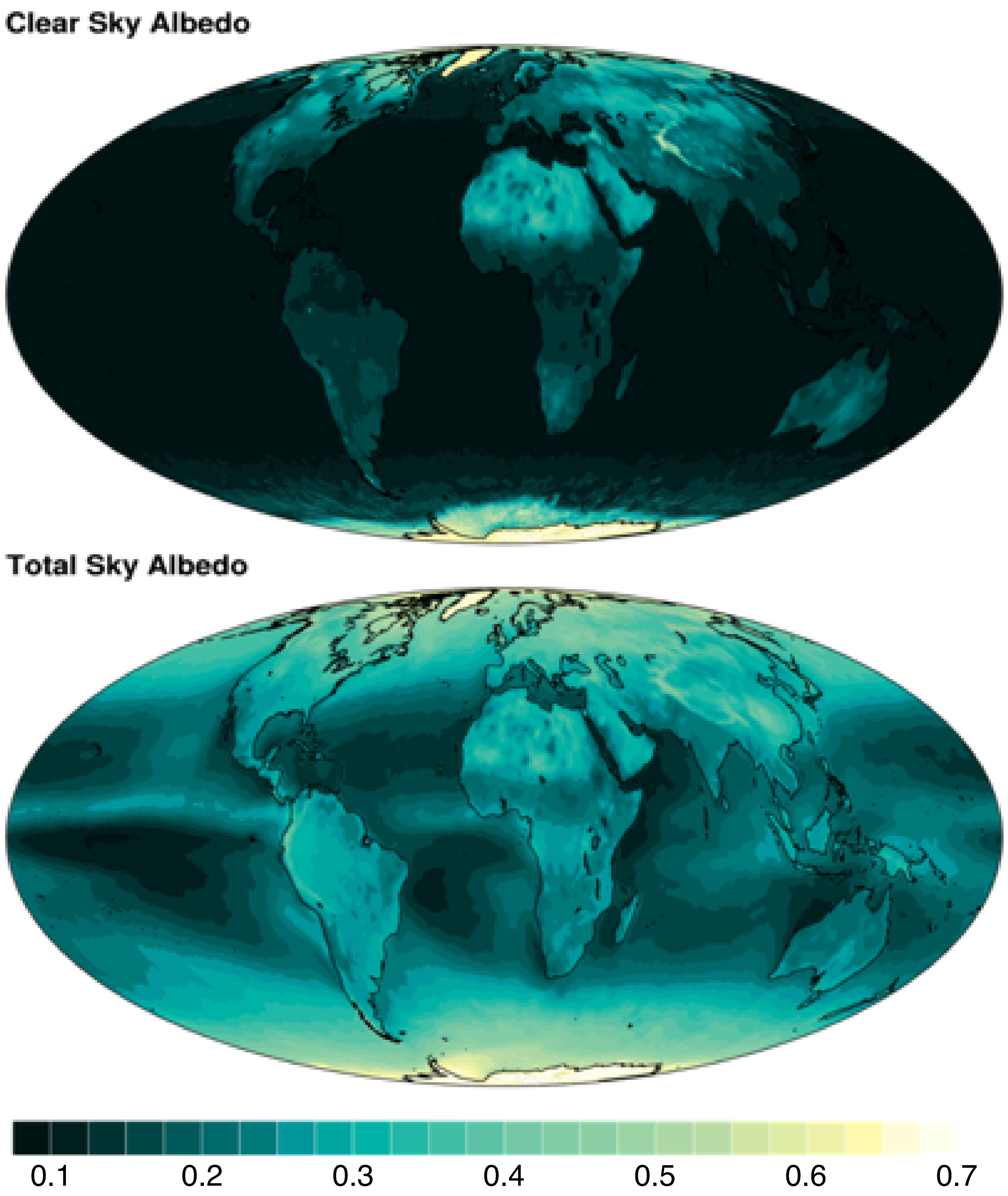
Why clouds are important for climate change

John Constable, Cloud study, 1821

- Clouds cover ~65% of globe, annual average
- Net cooling of 30 W/m^2
- c.f. 1.6 W/m^2 total anthropogenic

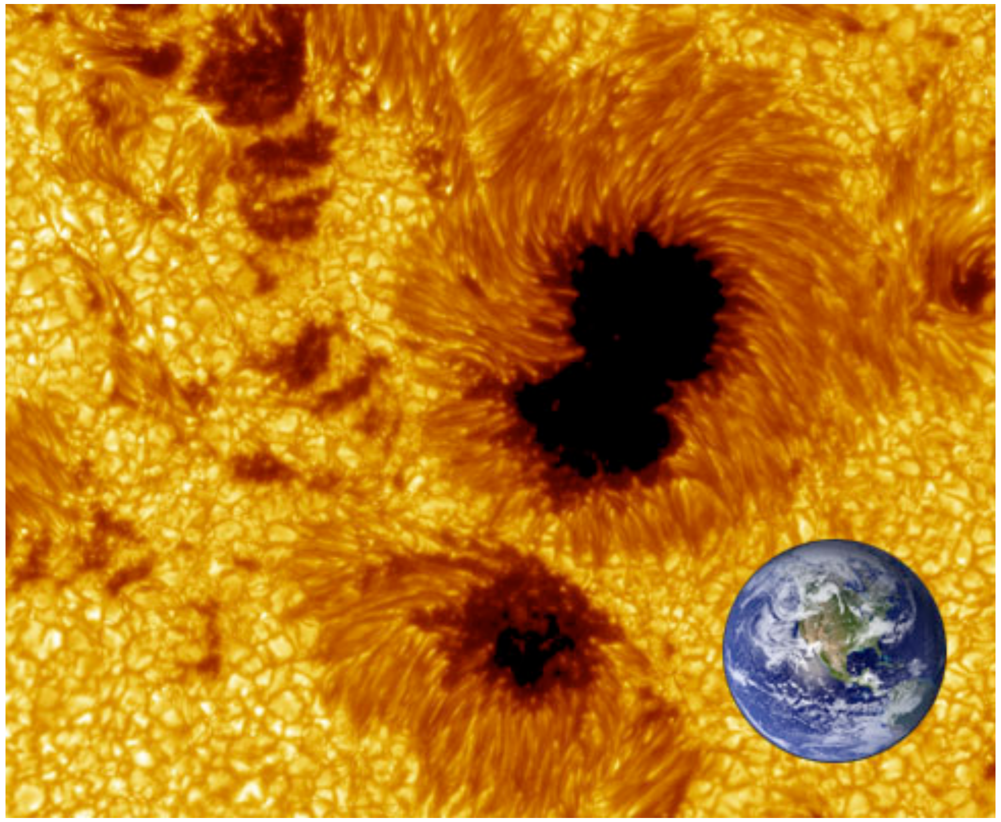
Solar albedo

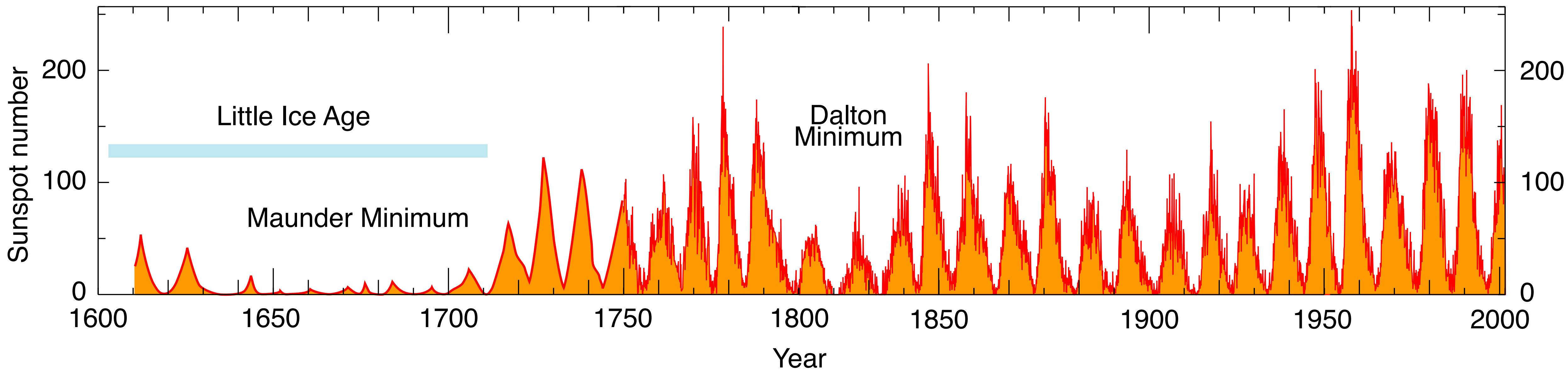




II. Evidence for pre-industrial solar-climate variability

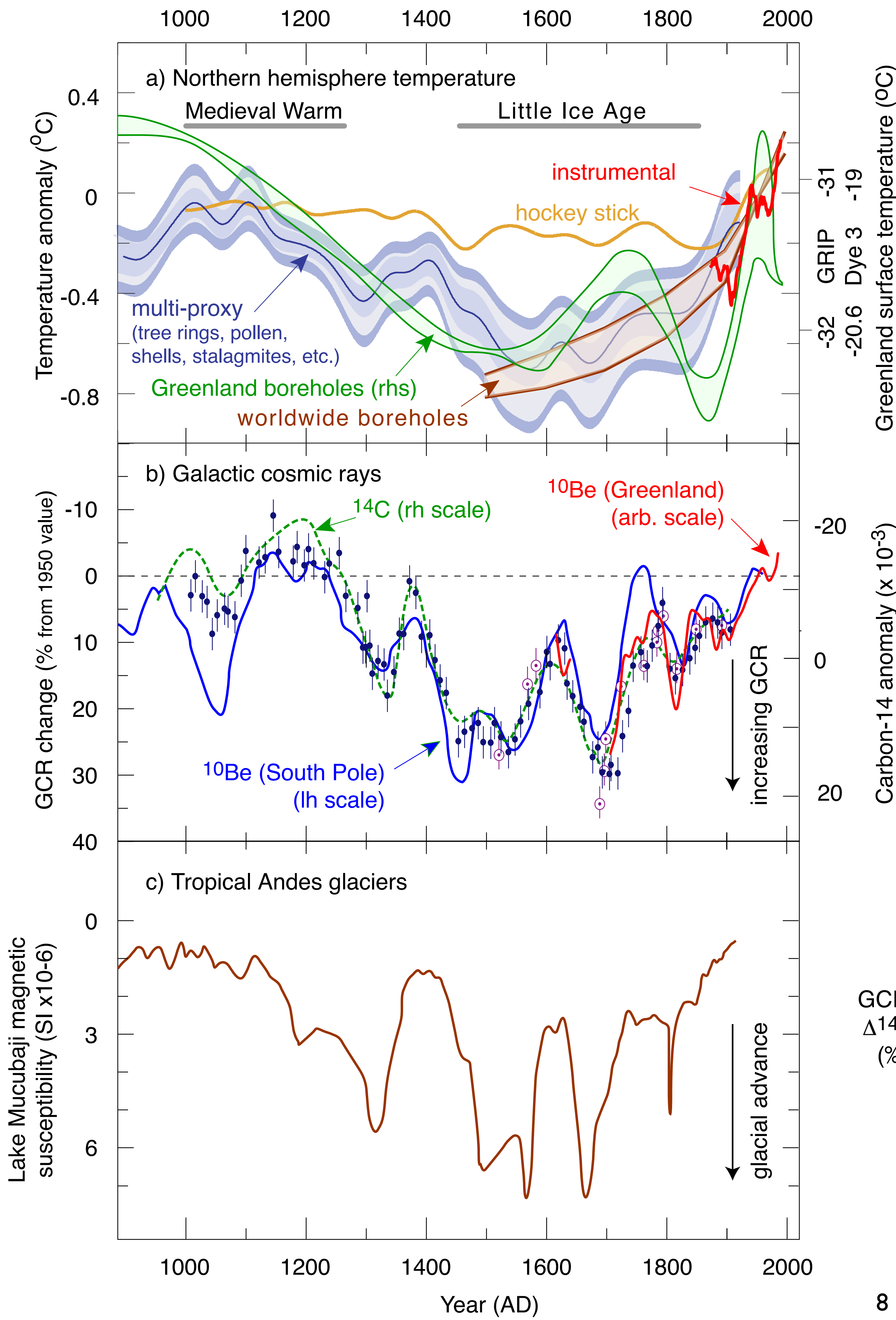
Little Ice Age and the sunspot record





- Inactive sun (low sunspot peak, long cycle length) ⇒ cold climate
- Active sun (high sunspot peak, short cycle length) ⇒ warm climate

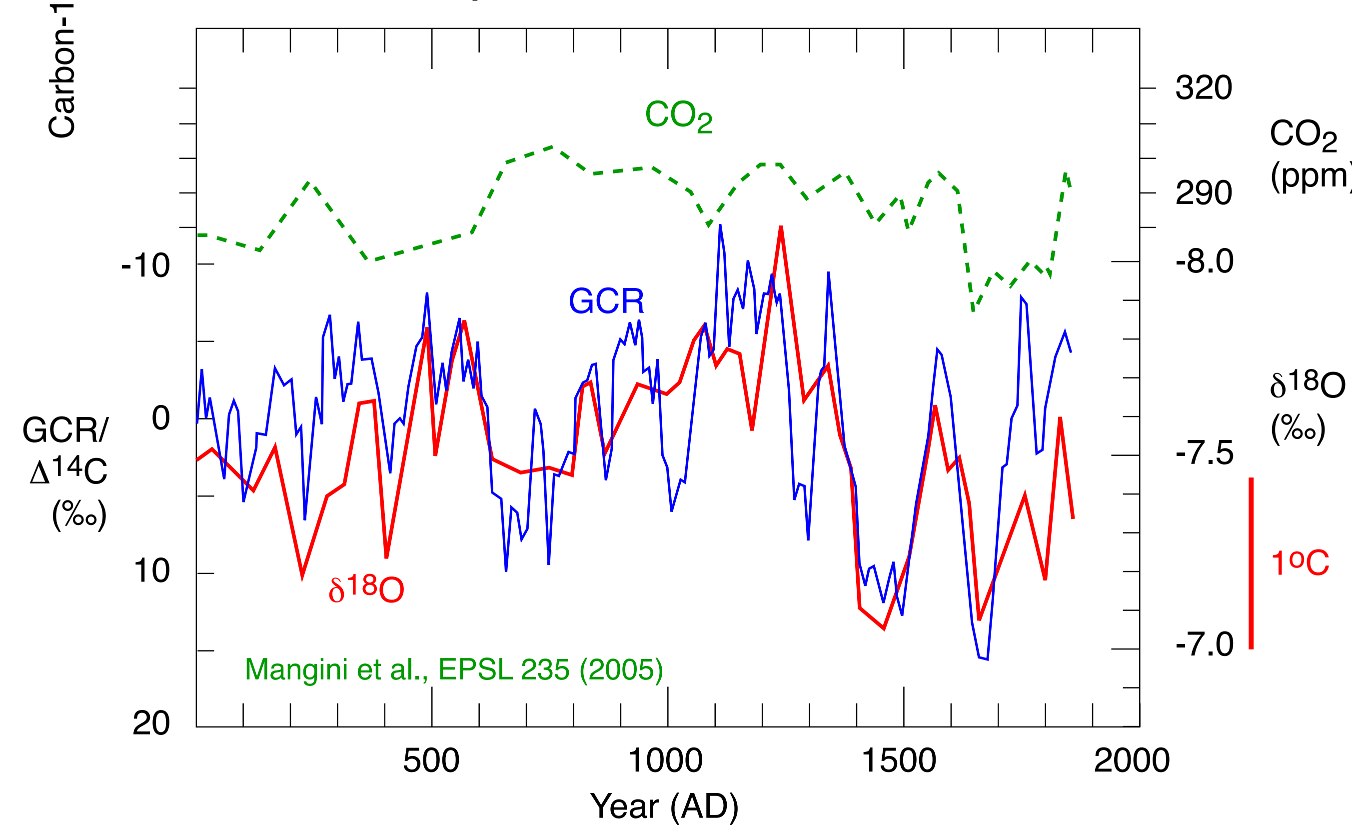
Global climate - last 2000yr



- Little Ice Age and Medieval Warm Period
- Global observations

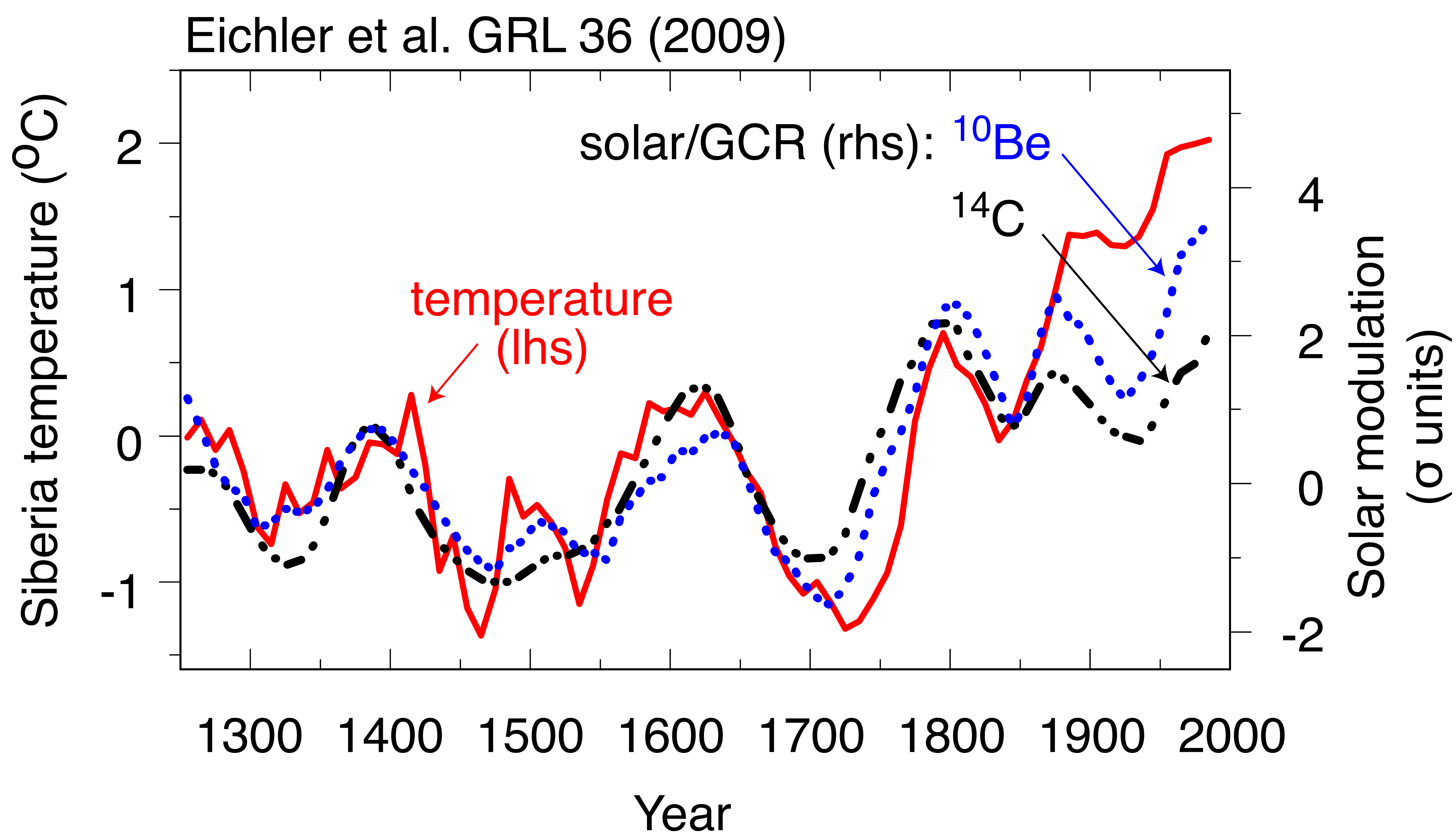
high GCR flux	cool climate
low GCR flux	warm climate

Austrian speleothem:

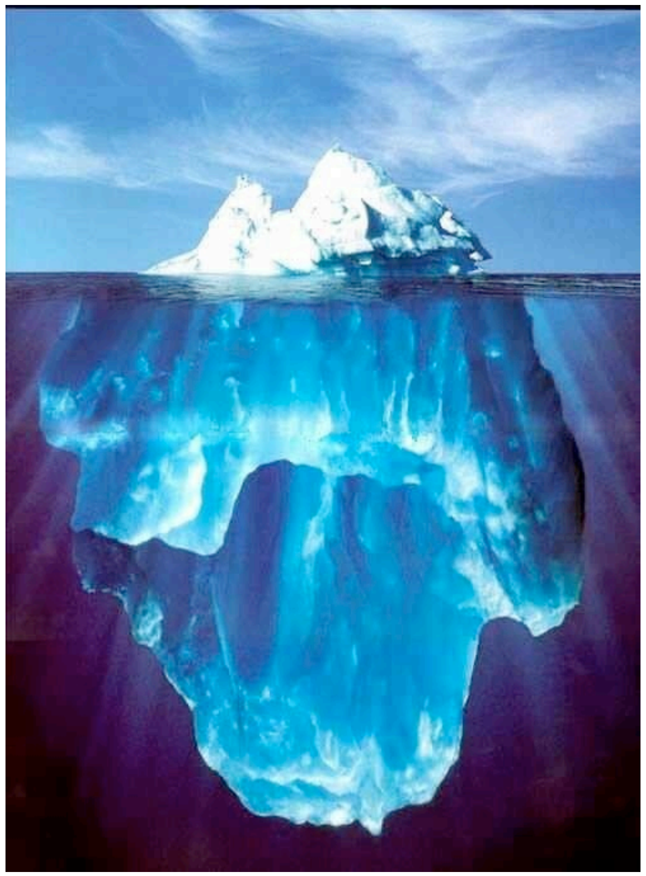


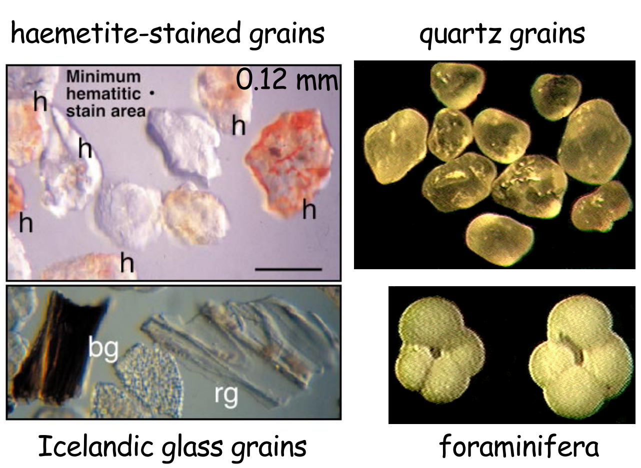
Siberian climate - last 700 yr

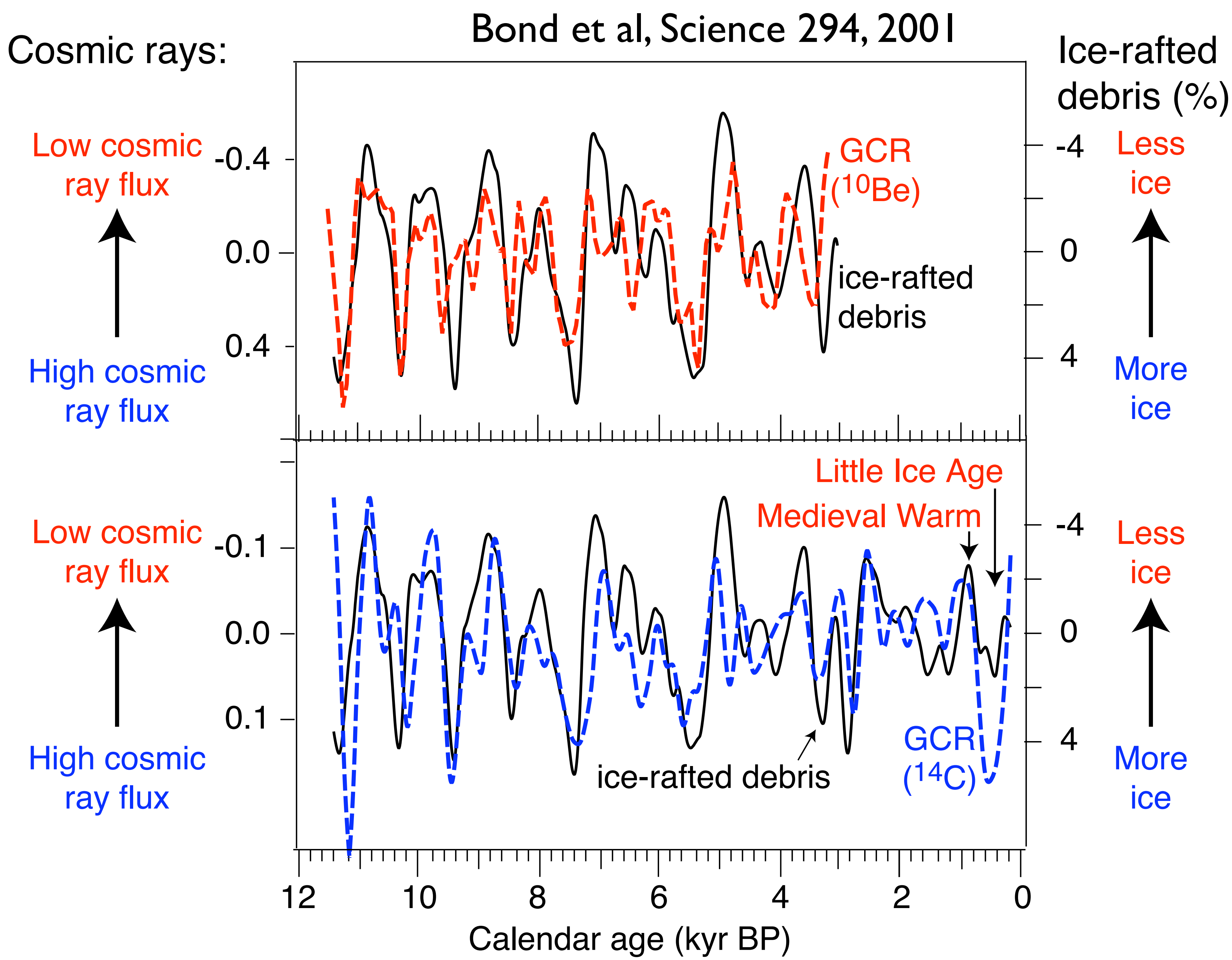
- Solar/GCR forcing of Siberian temperature (glacial ice core)
- 30 yr temperature lag (ie. ocean currents may be part of response)



N. Atlantic ice rafted debris - last 10 kyr (Holocene)



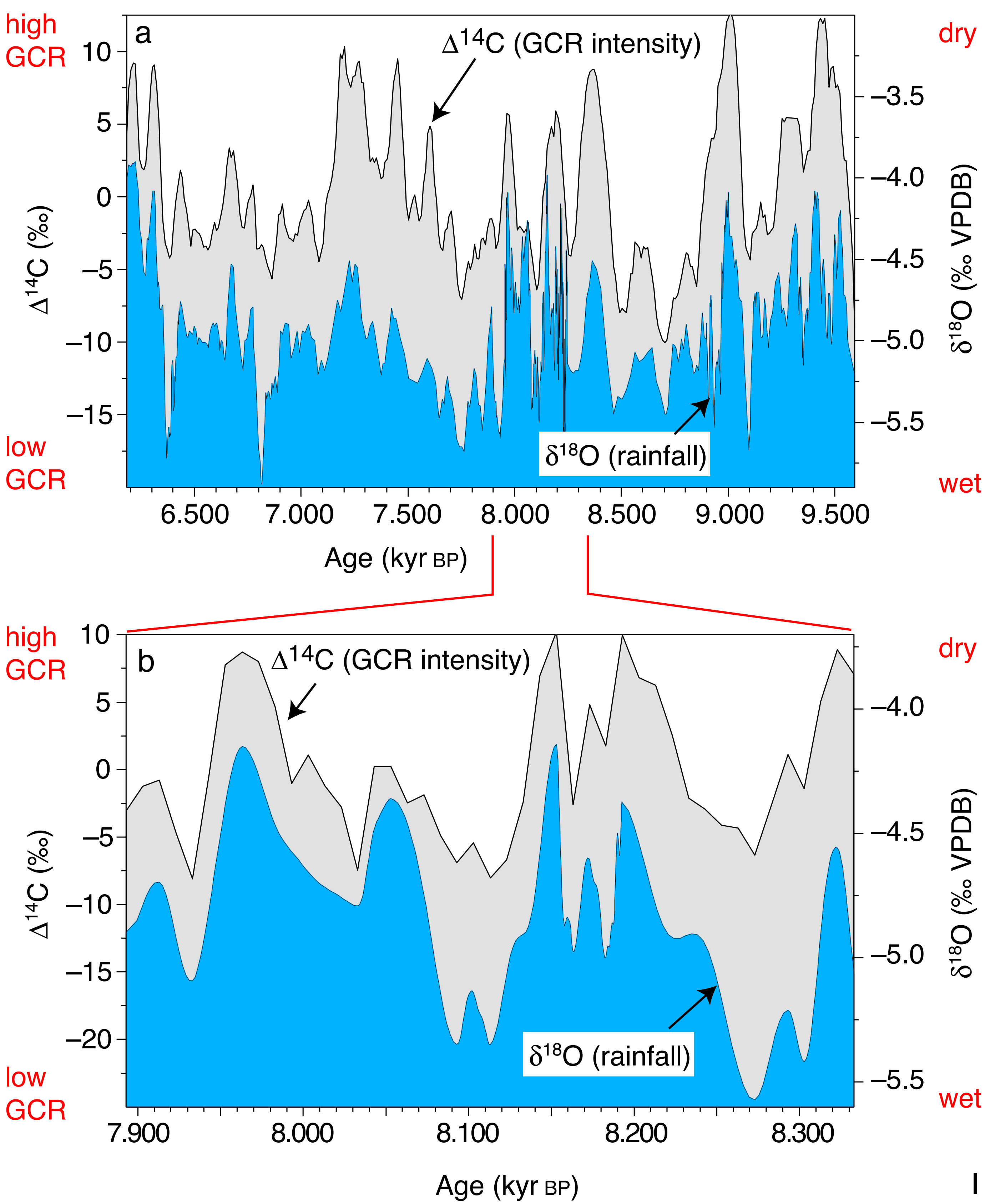


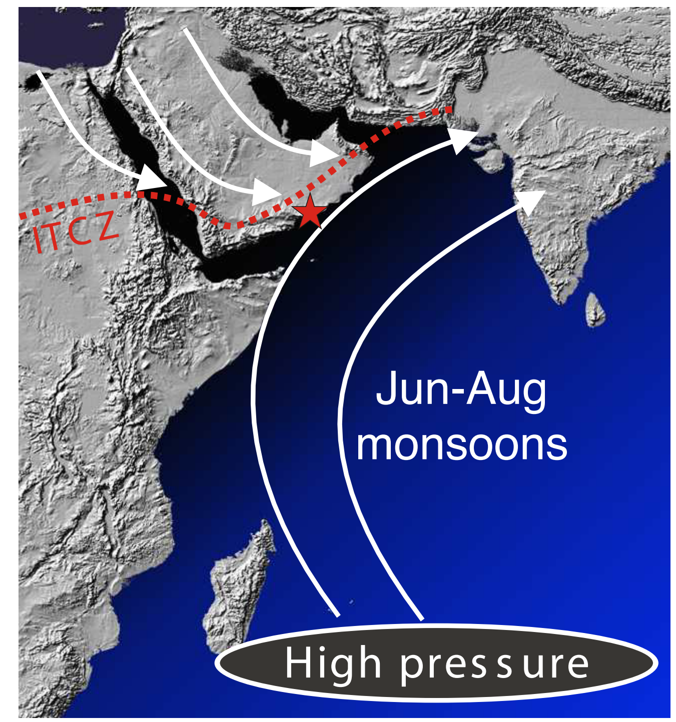


- LIA is merely the most recent of around 10 such events in Holocene
- Climate shifts synchronous with “Bond cycles” observed elsewhere

Indian Ocean monsoon - 6.5-9.5 kyr ago

U. Neff et al. (Nature 411, 2001)

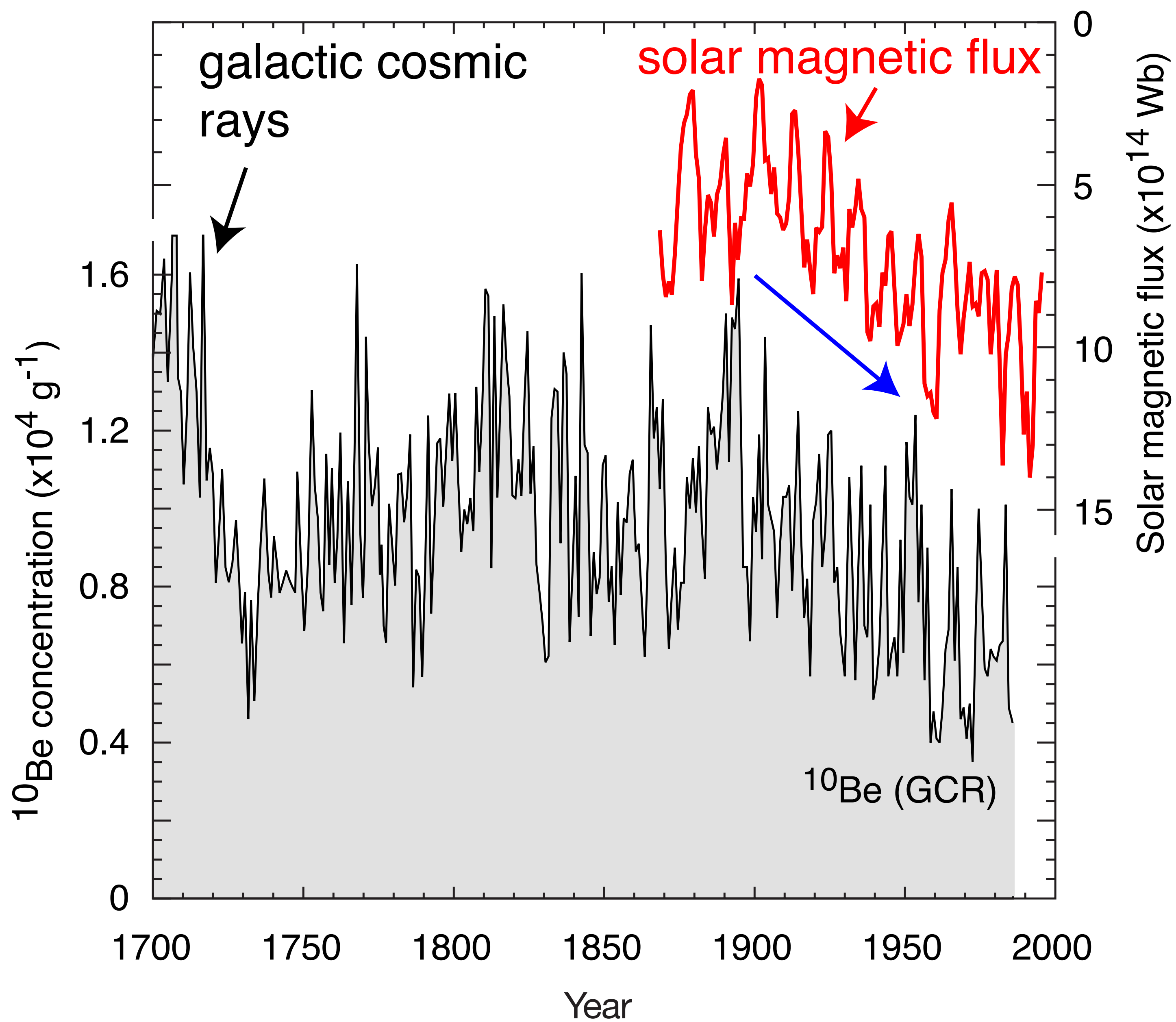




- Solar/GCR forcing of Indian Ocean monsoons (ITCZ migration) on centennial—even decadel—timescales

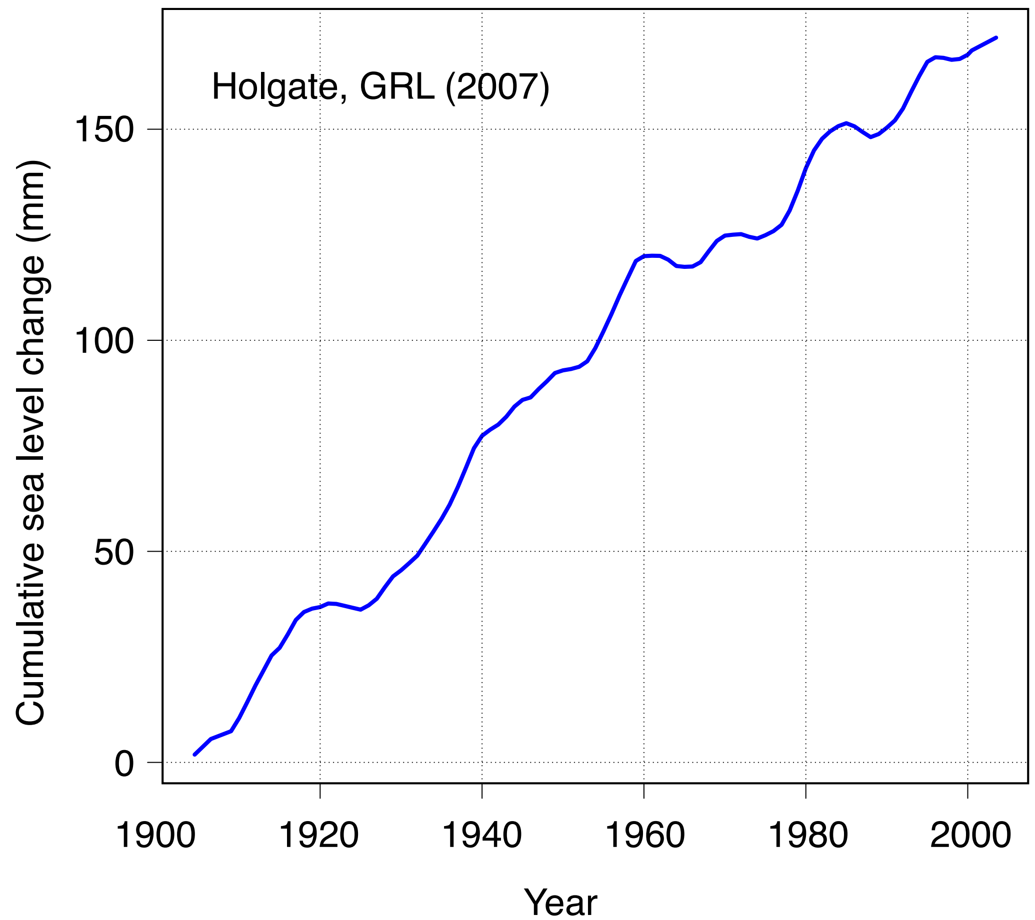
III. Solar variability in the 20th century

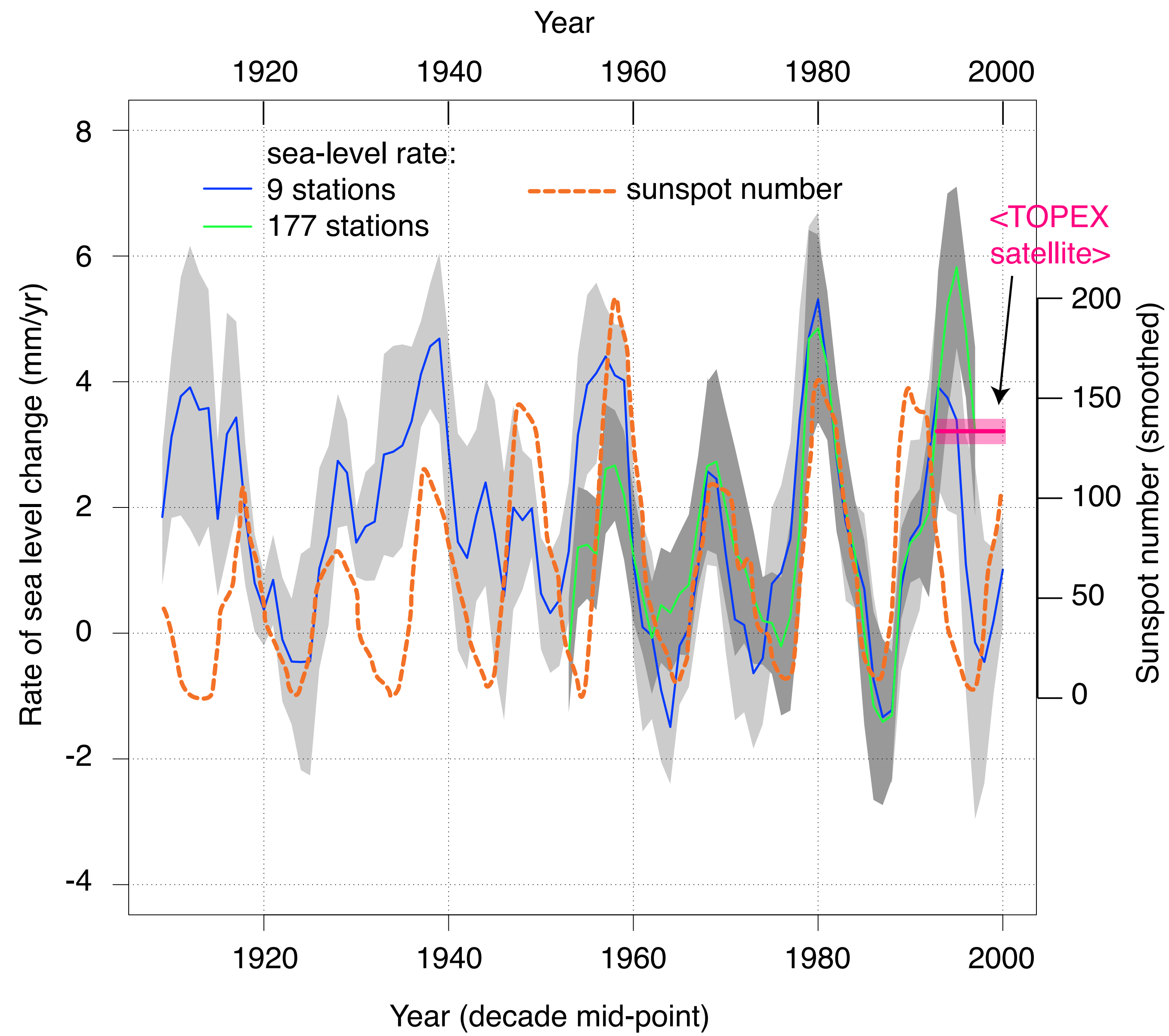
Cosmic ray changes during 20th century



- Solar open magnetic flux increased by x2.3 in 20th century
- GCR net decrease by ~20% in first half of century
- Largely only solar cycle variations of GCR flux in second half

Sea-level change in 20th century

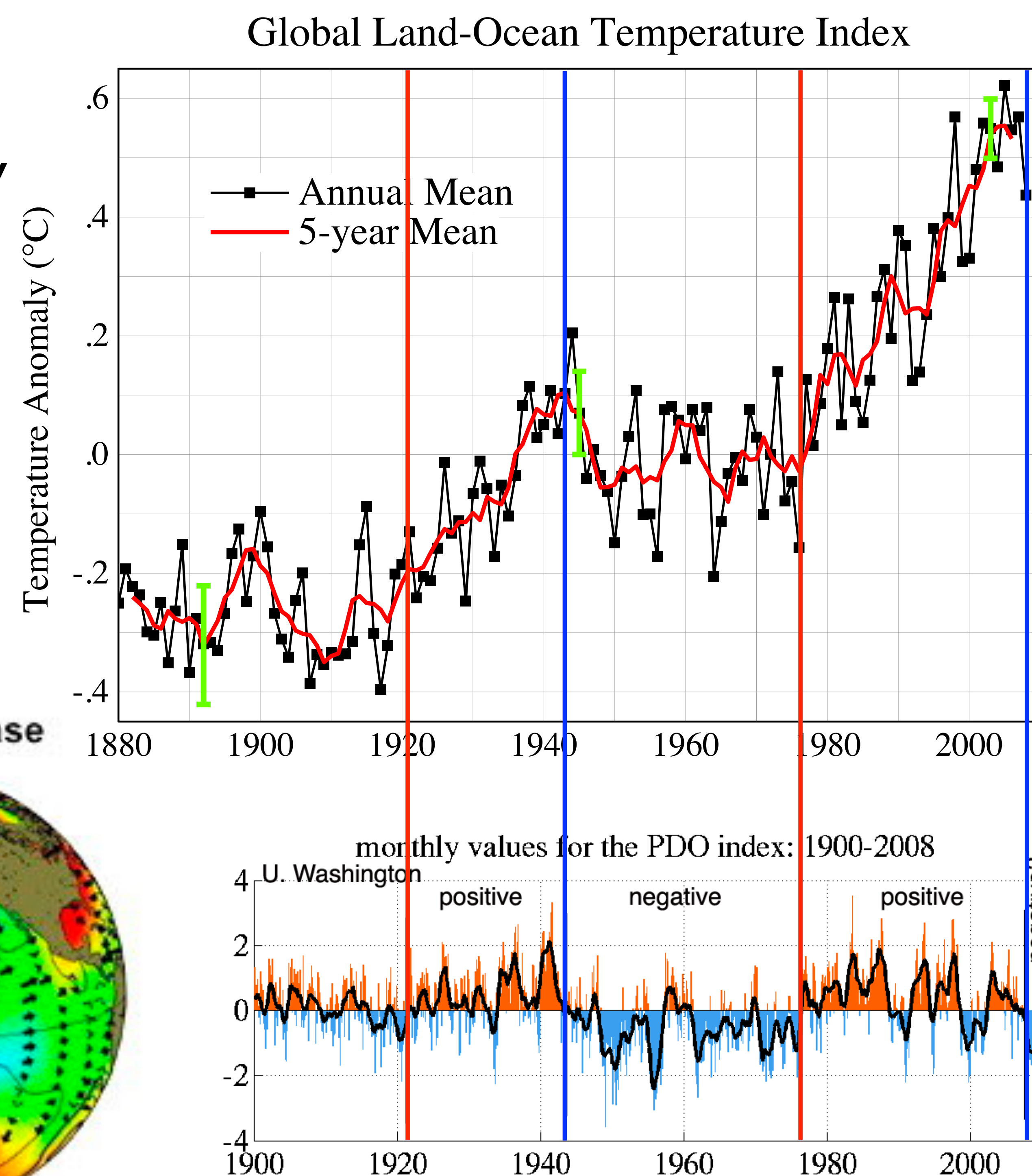


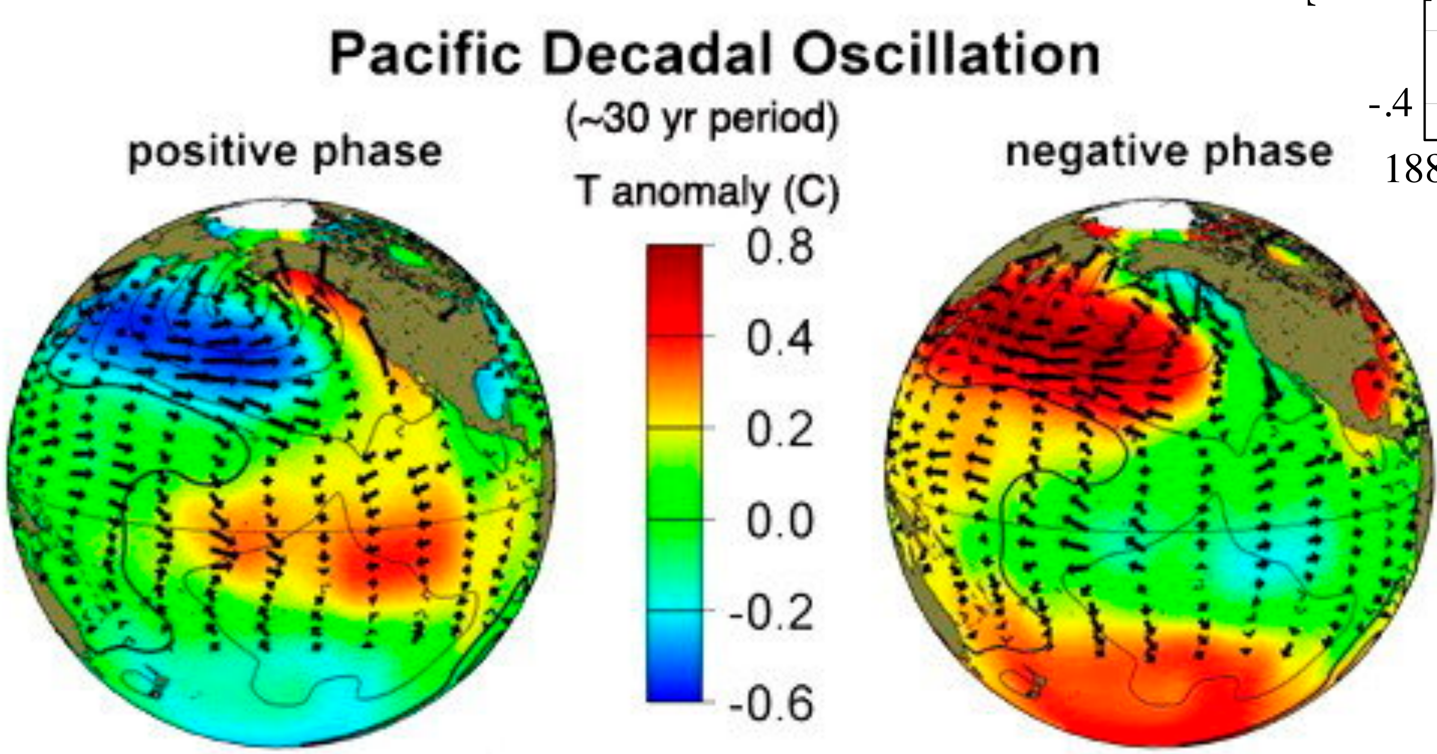


- Steady rise of sea-level; mean rate = 1.7 mm/yr
- No increase in rate during recent decades
- Thermal expansion of oceans (mainly) + land ice melting
- Rate of sea-level rise appears to be solar-modulated (but solar irradiance is too small)

Pacific Decadel Oscillation

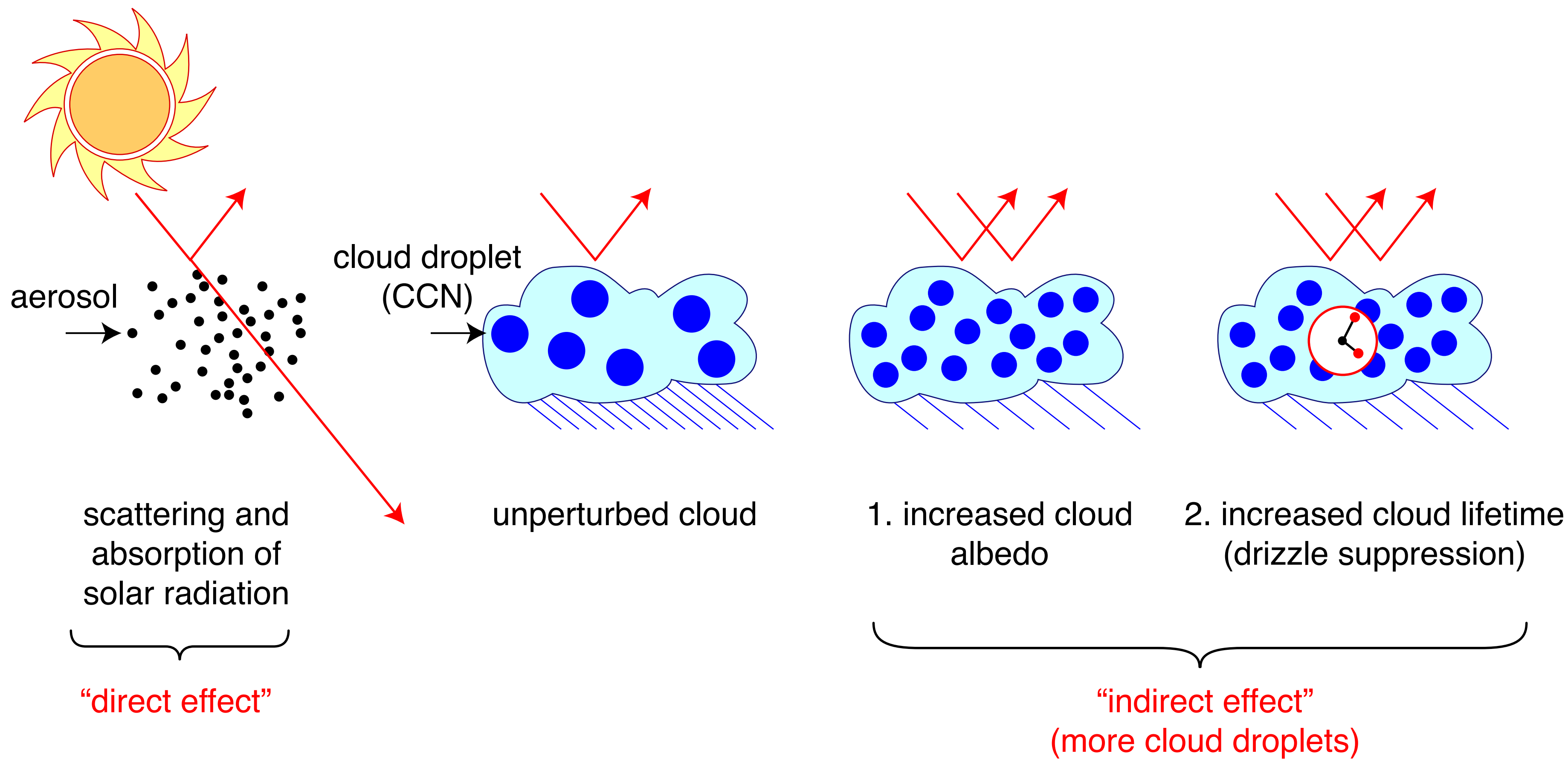
- PDO is similar to ENSO (temperature anomalies and surface winds), except long (30 yr) periodicity and strong effect on N Pacific
- Transitions coincide with gradient changes of global temperatures
- May be shifting to negative phase

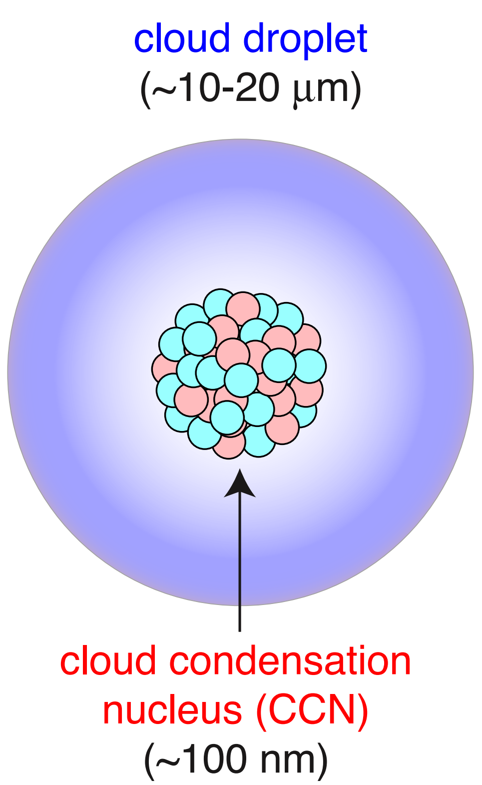




IV. Possible mechanism for solar-climate variability

Importance of aerosols for the climate

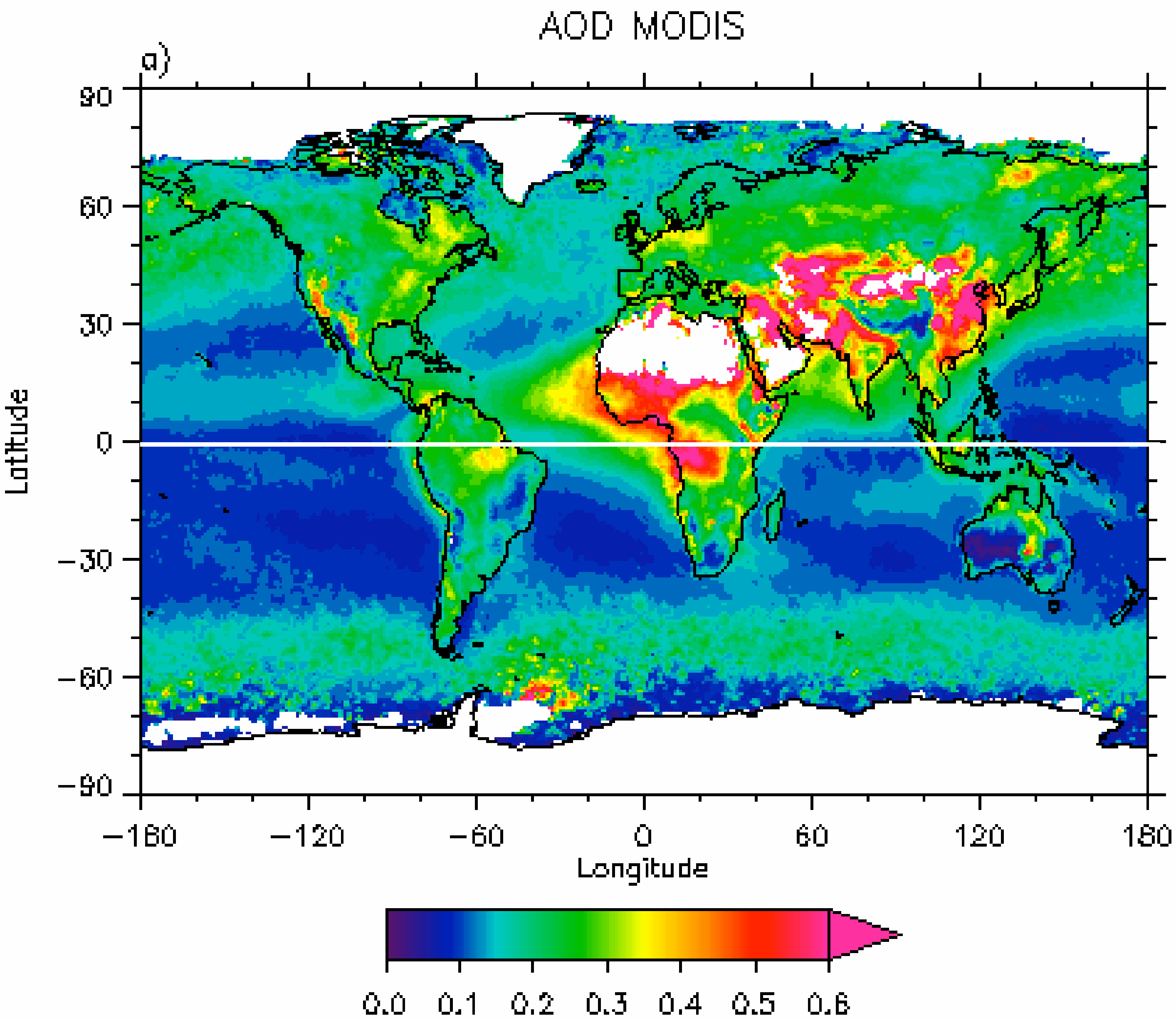


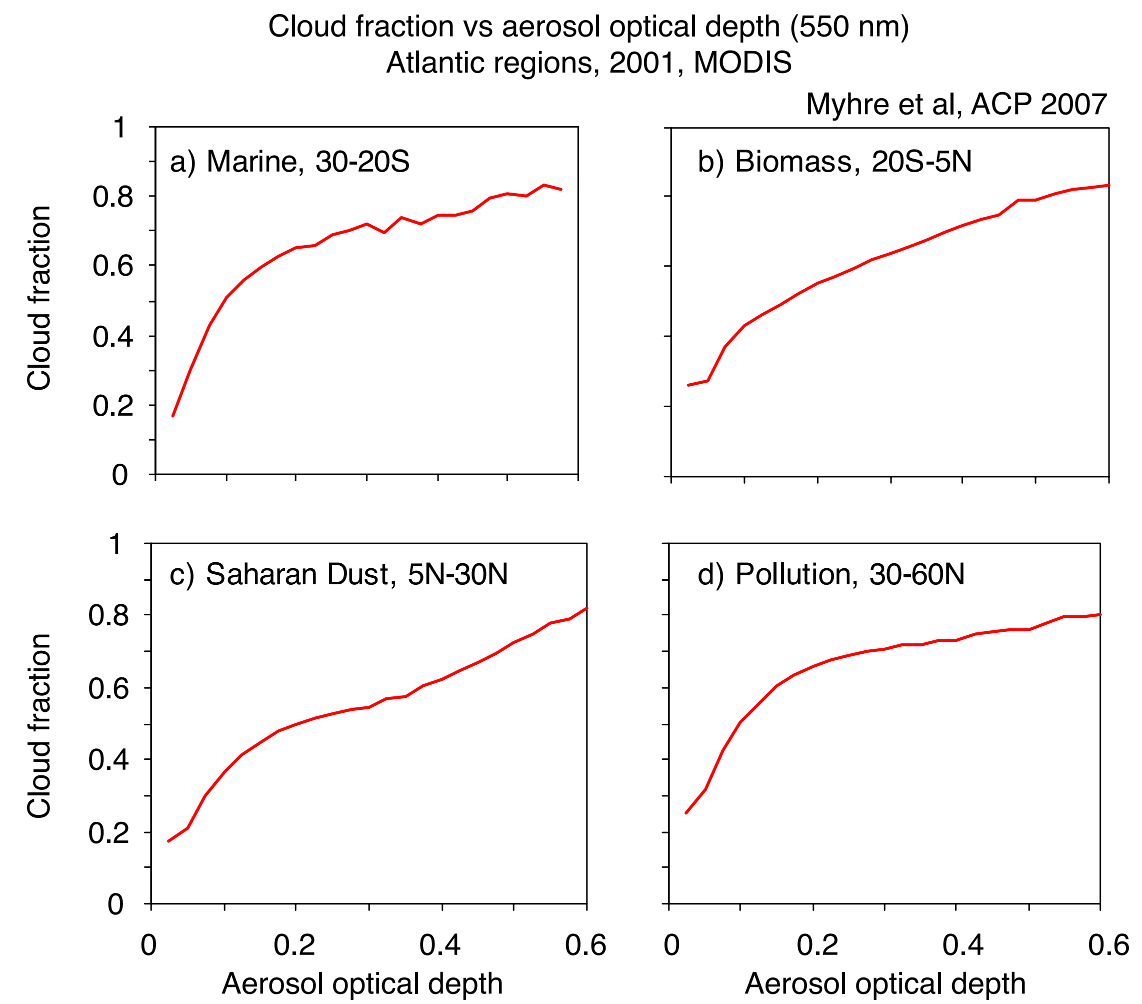


- All cloud droplets form on aerosol "seeds" known as cloud condensation nuclei - CCN
- Cloud properties are sensitive to number of droplets
- More aerosols/CCN:
  - brighter clouds, with longer lifetimes
- Sources of atmospheric aerosols:
  - direct (dust, sea salt, fires)
  - indirect (gas-to-particle conversion)

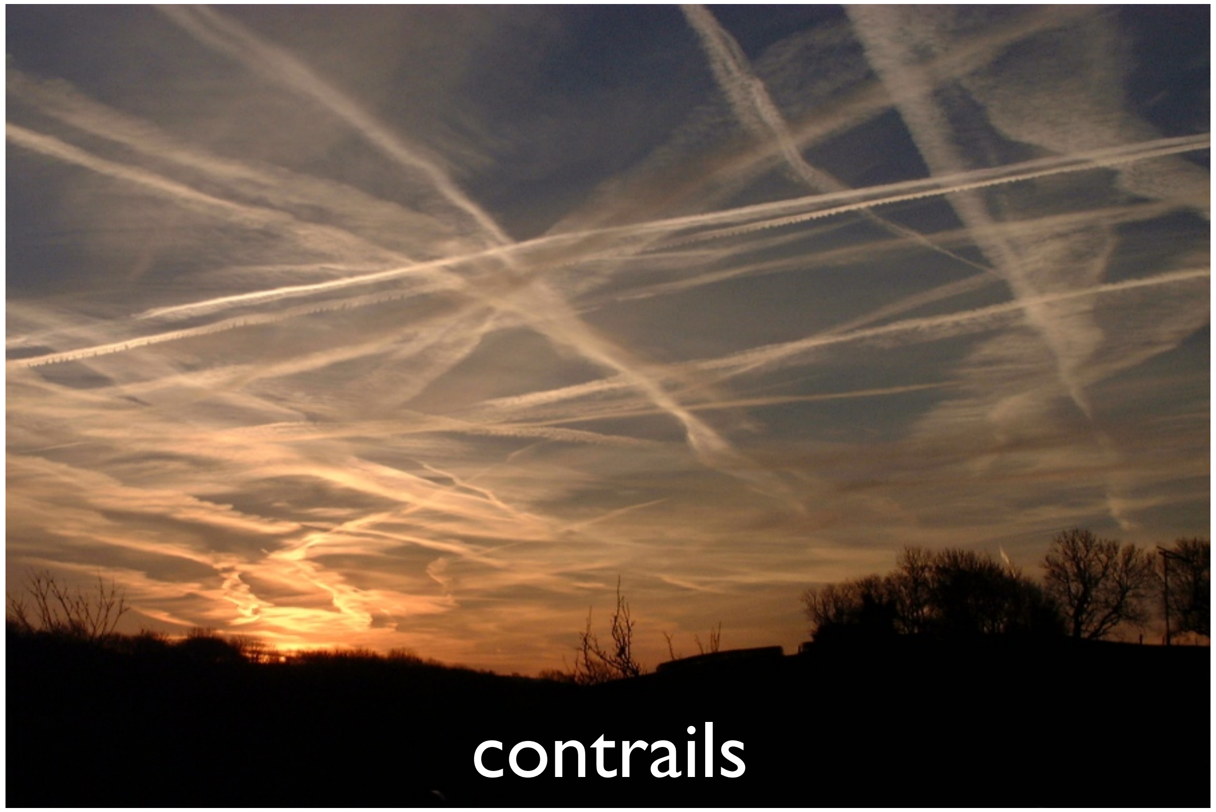
Effect of aerosols on clouds

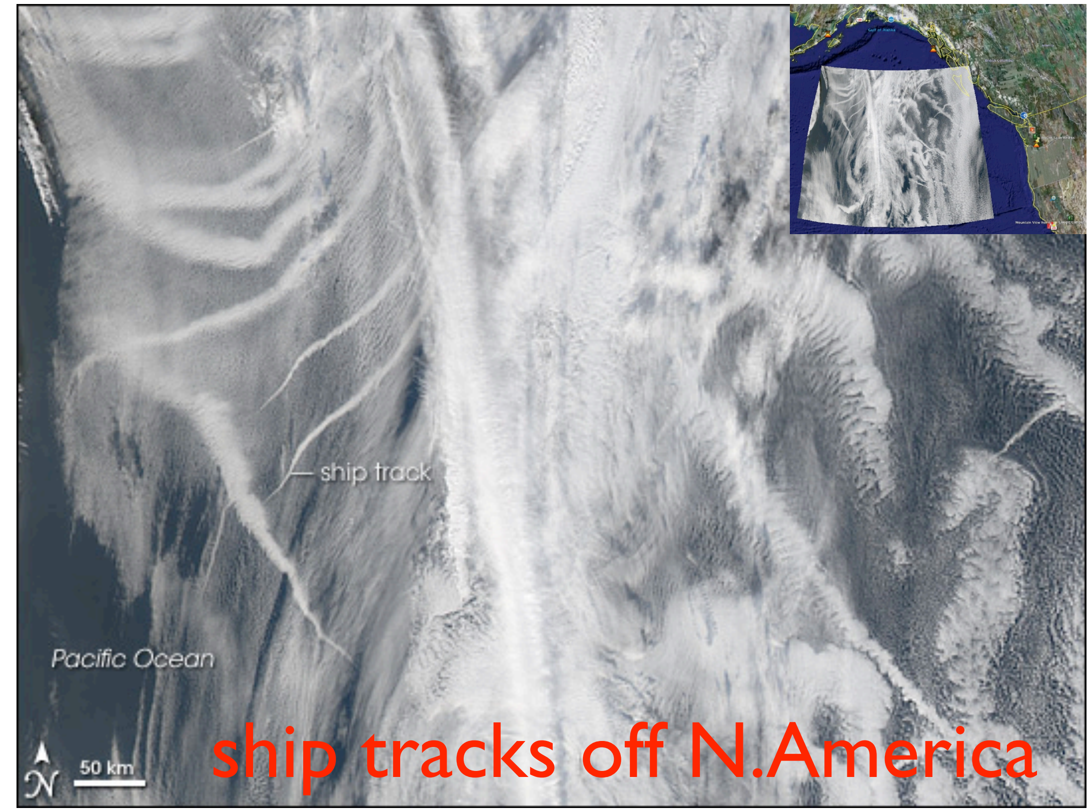
- Aerosol optical depth measured by MODIS satellite



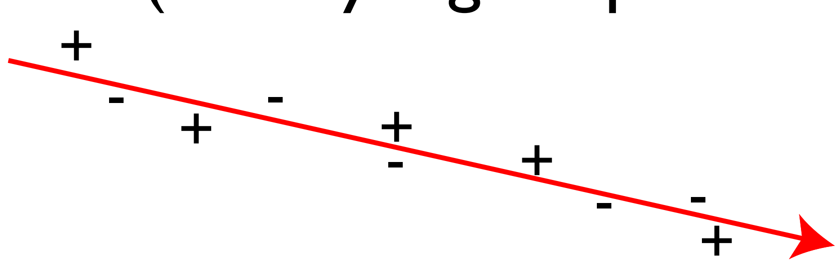


Seeds for cloud formation



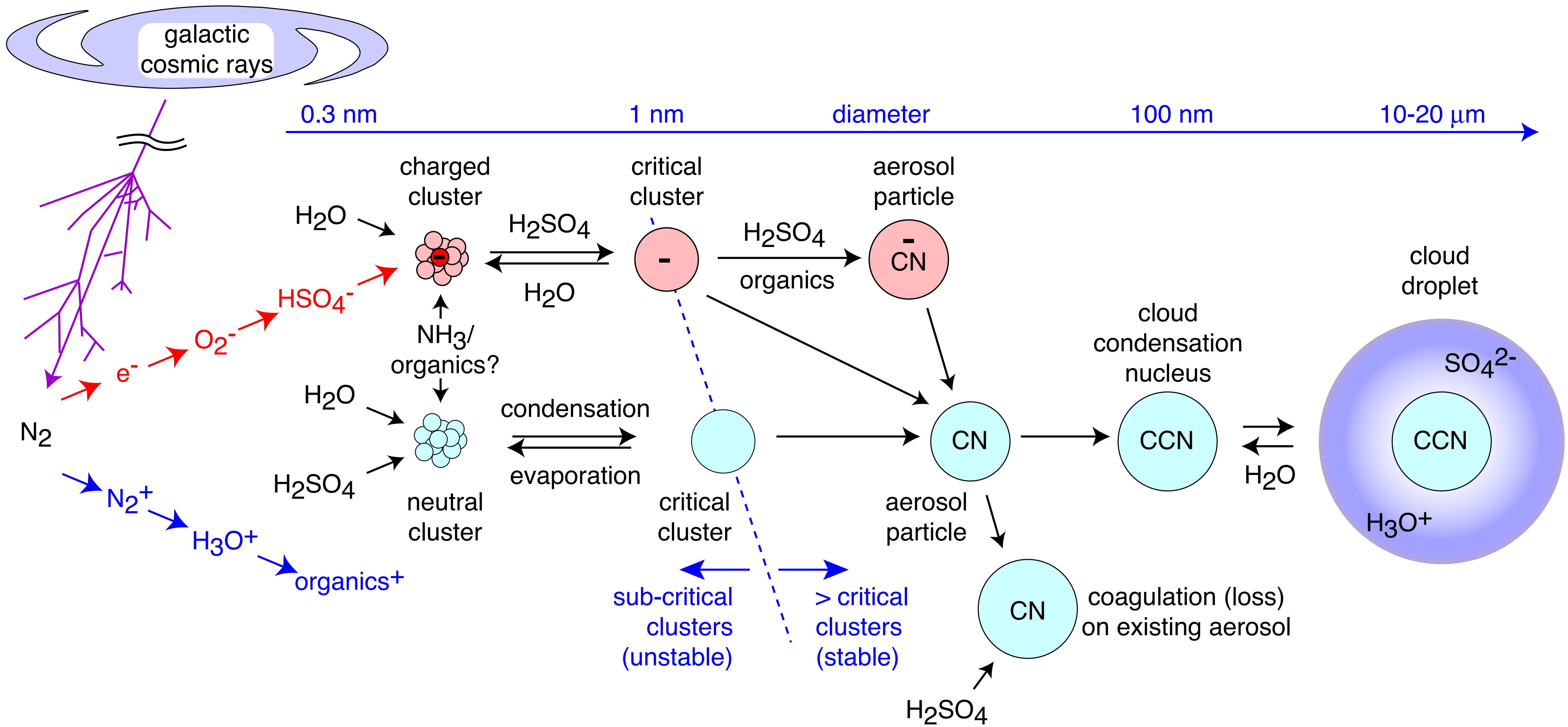


- Aerosol particles = condensation seeds
- Charged particles = condensation seeds
  (at very high supersaturations)



- Can cosmic rays, under natural conditions, influence aerosols, clouds and climate?

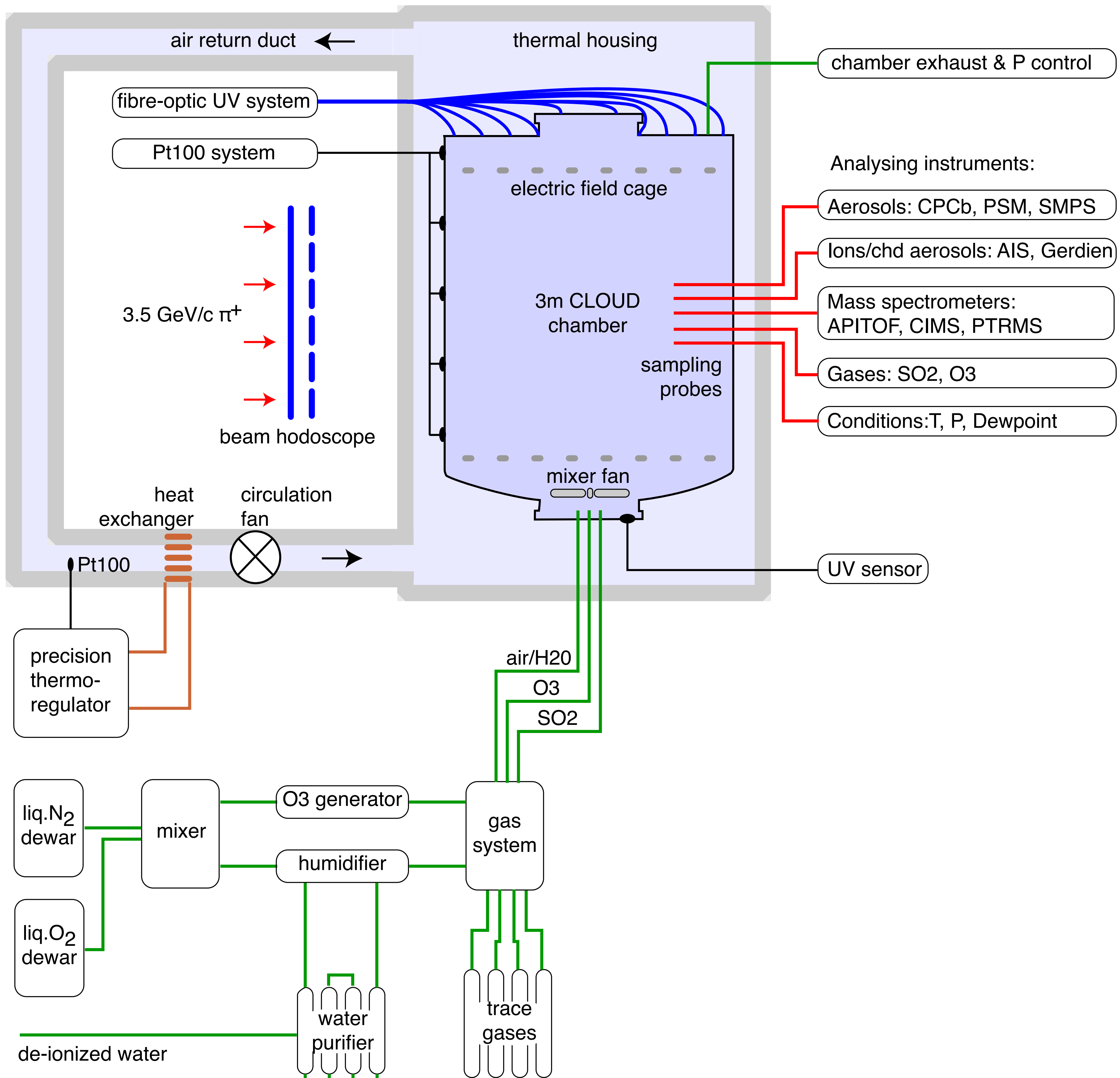
Ion-induced nucleation and growth to CCN



- Ion-induced nucleation pathway is energetically favoured but limited by the ion production rate and ion lifetime
- Nucleation rates (neutral and ion-induced) are poorly known
- Roles of important vapours (H_2SO_4, NH_3, organics...) also poorly known
- And gas-to-particle conversion may be responsible for up to 50% of global CCN!

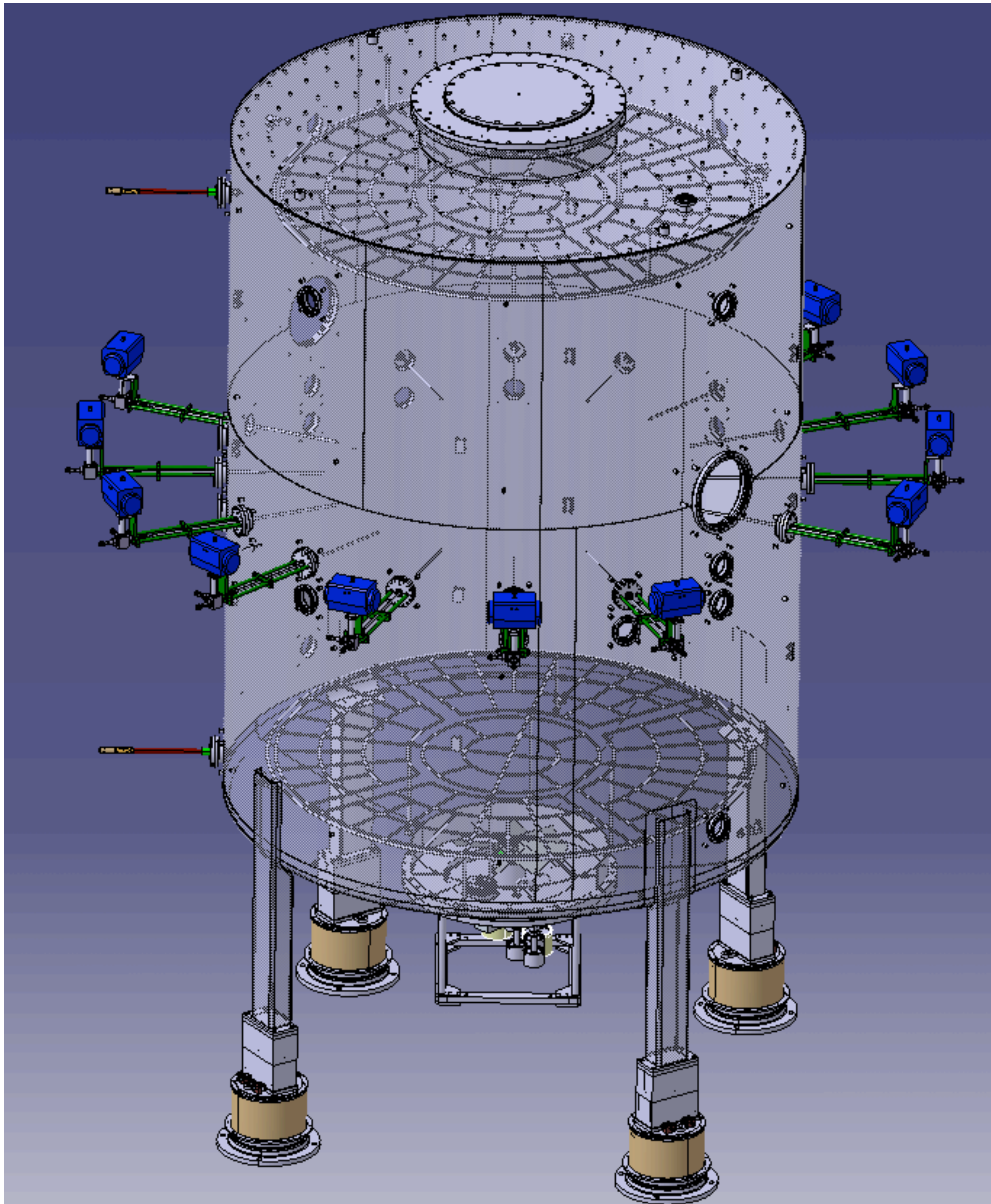
V. CLOUD experiment at CERN

CLOUD



air return duct
thermal housing
chamber exhaust & P control
fibre-optic UV system
Pt100 system
Analysing instruments:
electric field cage
Aerosols: CPCb, PSM, SMPS
Ions/chd aerosols: AIS, Gerdien
3m CLOUD chamber
Mass spectrometers: APITOF, CIMS, PTRMS
3.5 GeV/c π+
sampling probes
Gases: SO2, O3
Conditions:T, P, Dewpoint
beam hodoscope
mixer fan
heat exchanger
circulation fan
Pt100
UV sensor
precision thermo-regulator
air/H20
O3
SO2
liq.N2 dewar
mixer
O3 generator
gas system
humidifier
liq.O2 dewar
water purifier
trace gases
de-ionized water

CLOUD chamber



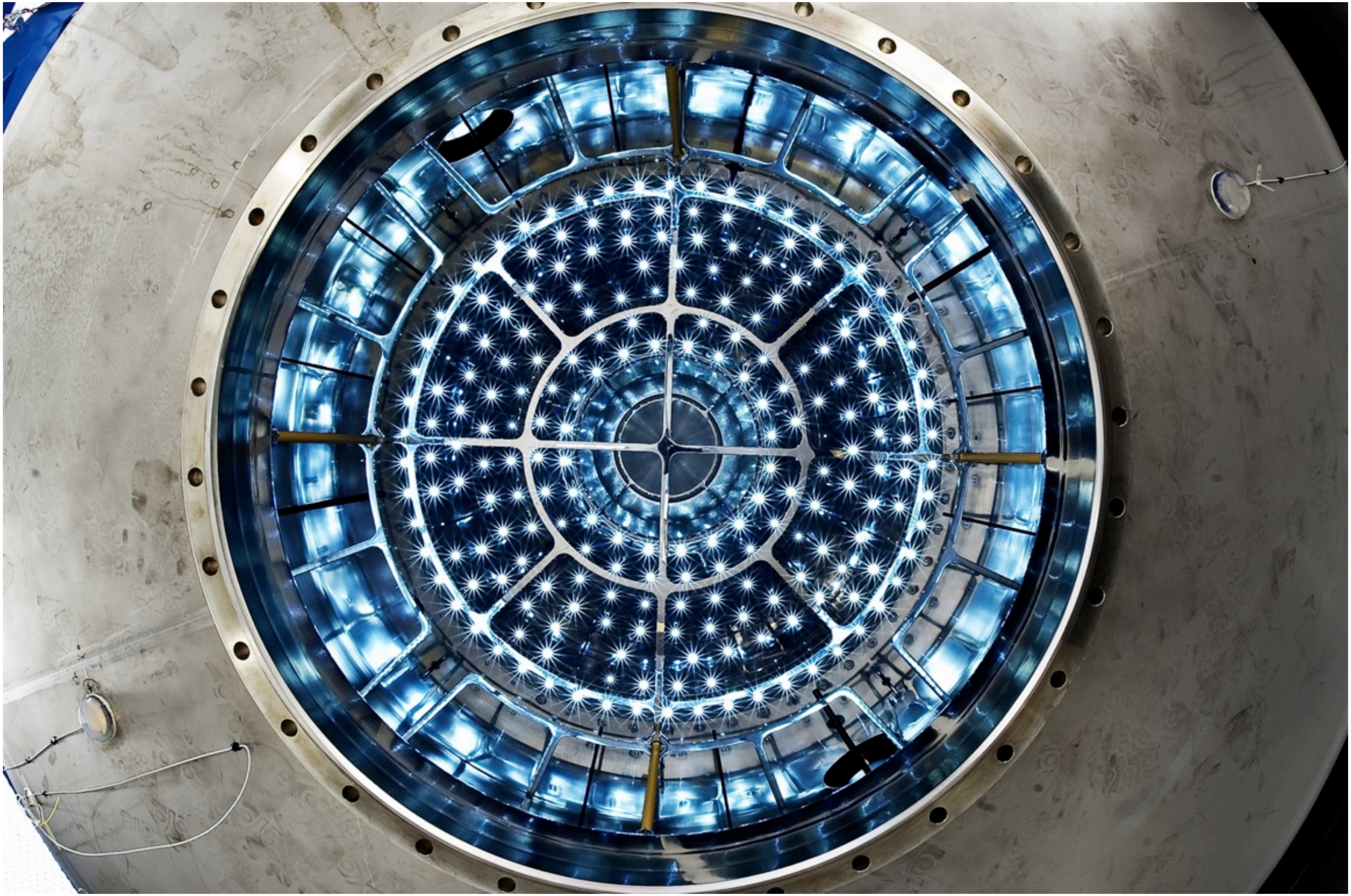
CLOUD in the T11 zone, Nov09

UV fibre optic system

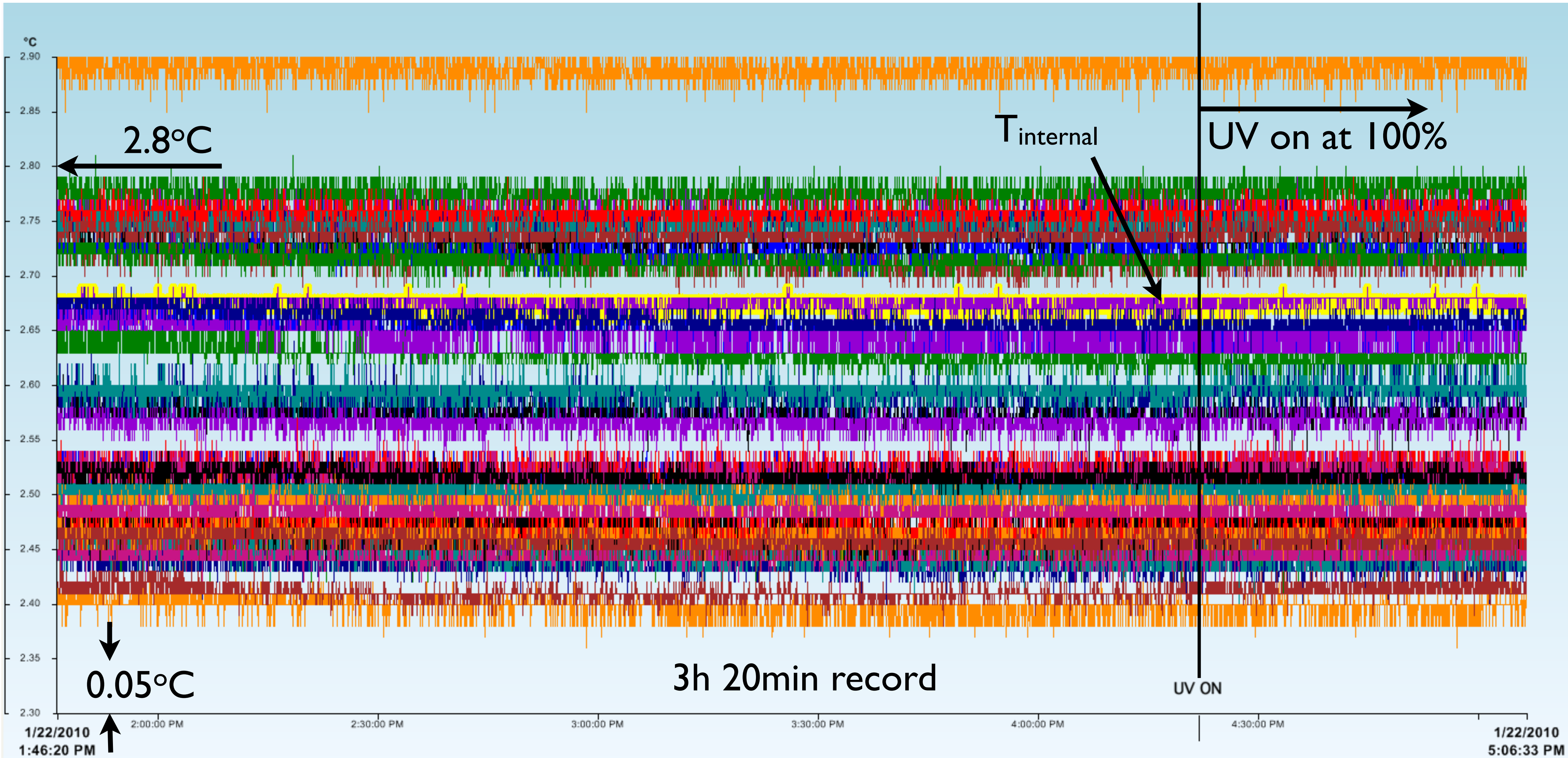
Field cage and UV fibre-optic vacuum feedthroughs

Manhole cover: mixer fan, gas inlets & valves, quartz window

UV system and field cage electrodes, before lower manhole installed



Thermal stability with UV lights; Pt100 record

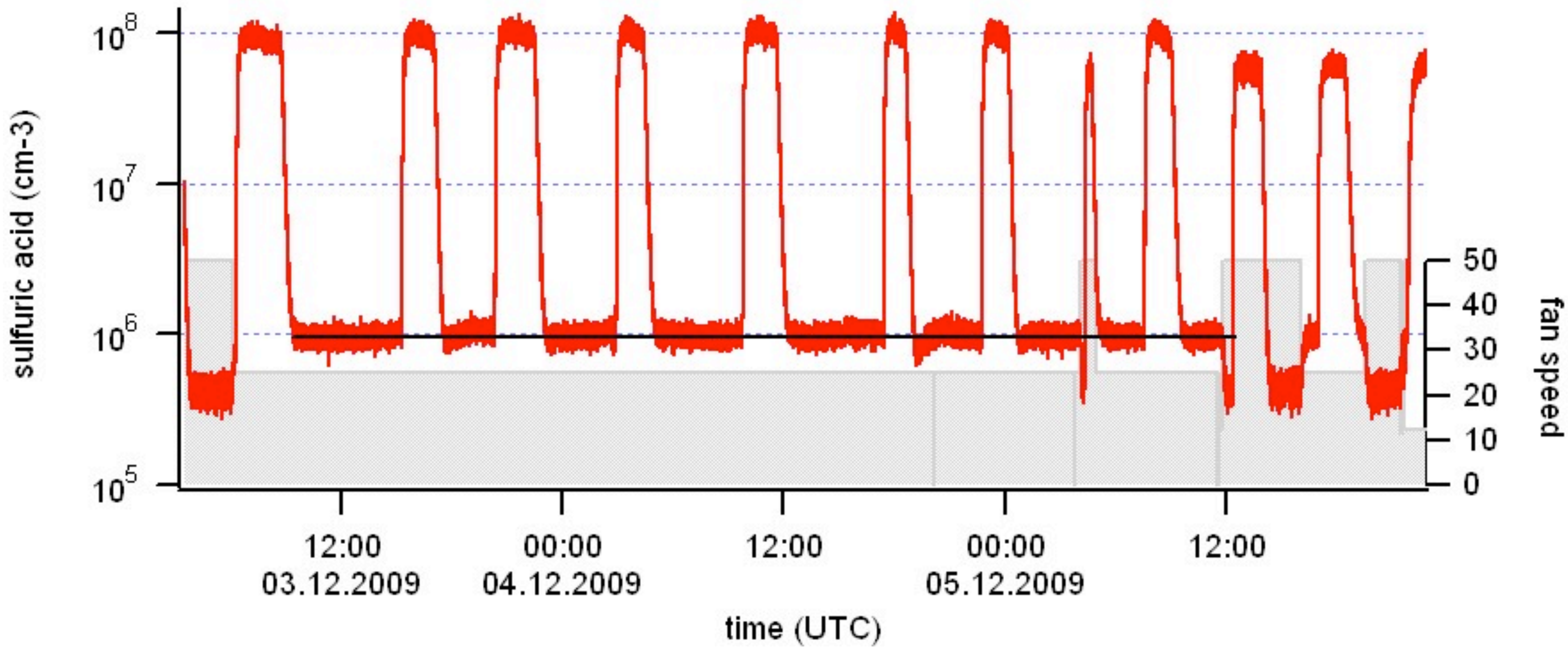


- Chamber walls & internal temperature stable to ~0.01°C over long periods
- No temperature change when UV lights turned on at 100%
- No spurious (T-induced) nucleations were observed during entire campaign
- All 2009 data recorded at T = 19°C

H_2SO_4 production and measurement

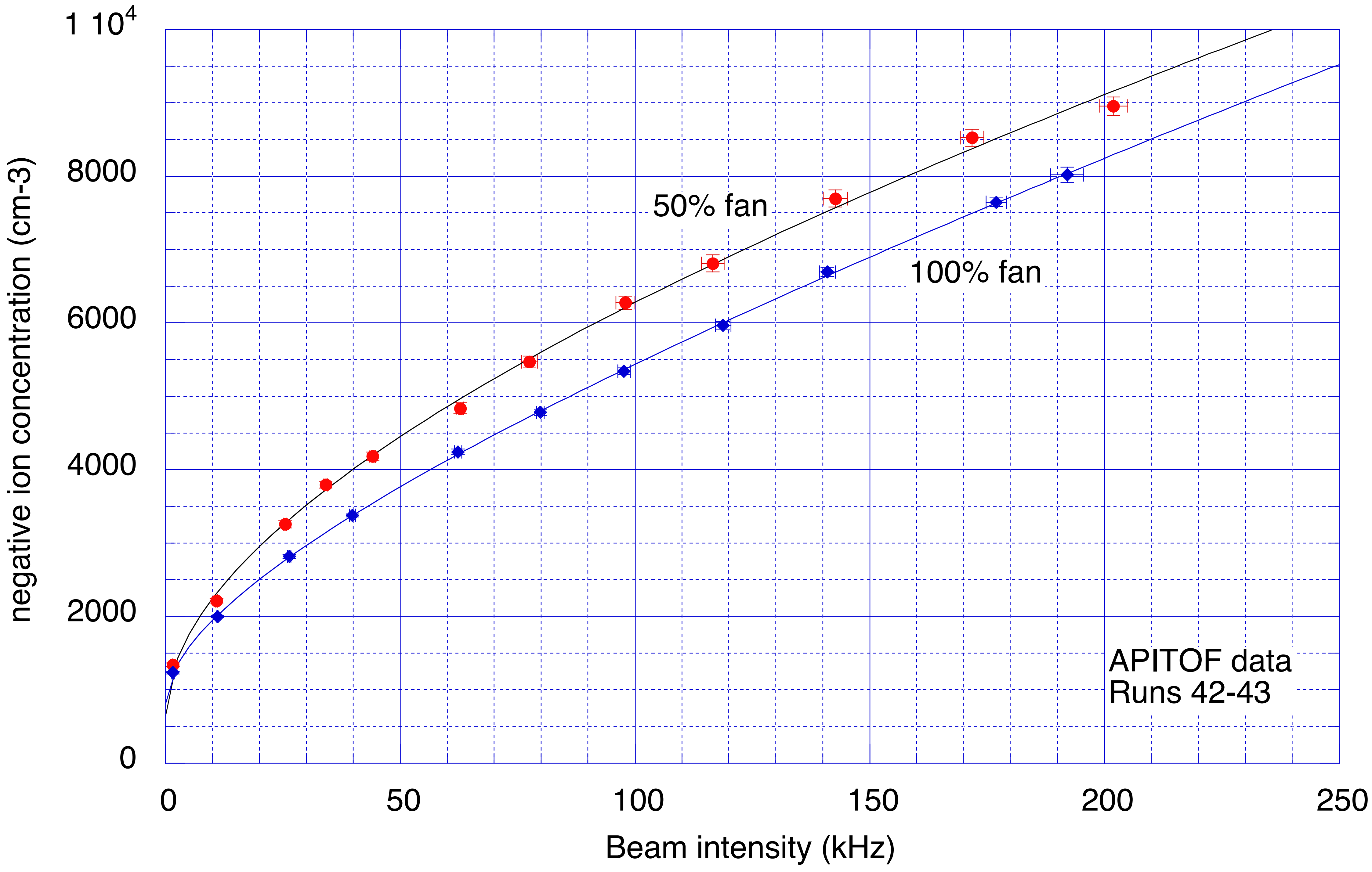
H_2SO_4 produced by oxidation of SO_2 by OH produced by photolysis of O_3:

$$\begin{aligned} O_3 + h\nu(< 320nm) &\rightarrow O(^1D) + O_2 \\ O(^1D) + H_2O &\rightarrow 2OH \\ OH + SO_2 &\rightarrow HSO_3 \\ HSO_3 + O_2 &\rightarrow SO_3 + HO_2 \\ SO_3 + 2H_2O &\rightarrow H_2SO_4 + H_2O \end{aligned}$$

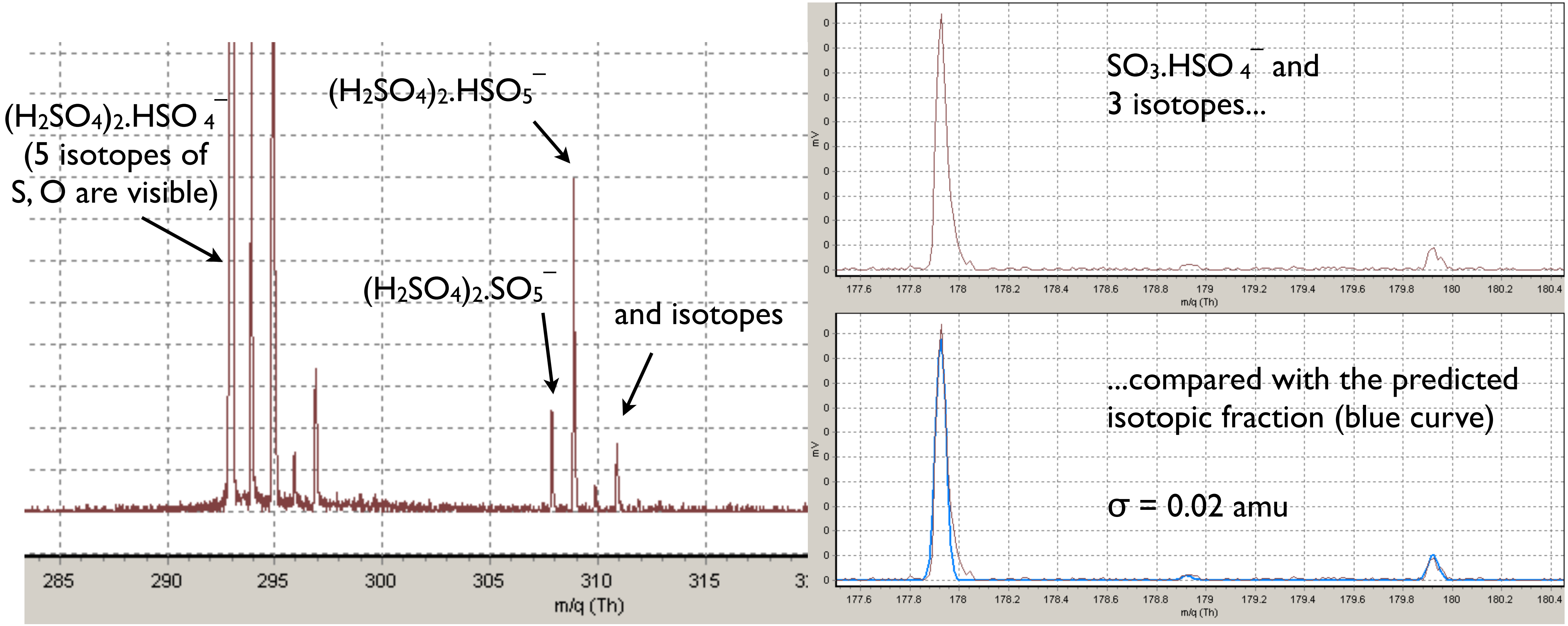


- H_2SO_4 production was stable and highly reproducible
- Fibre optic UV system allows for factor 100 fine control of [H_2SO_4]
- Absolute [H_2SO_4] known to ±50% calibration uncertainty

Ion concentration vs beam intensity



APITOF ion chemistry analysis

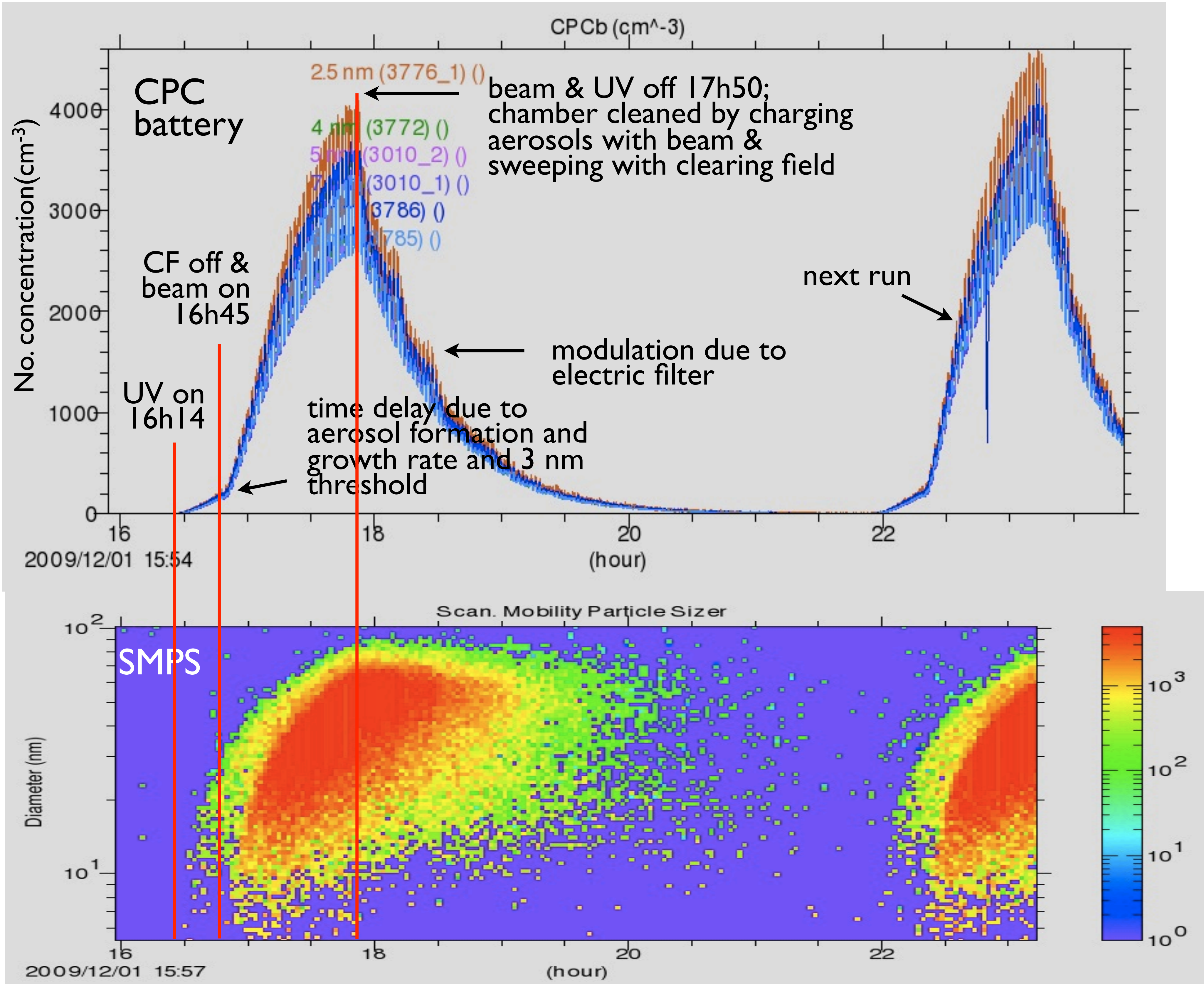


- The APITOF data provide a detailed chemical analysis of the time-evolution of the cluster ions (positive and negative, up to 2000 amu) during the nucleation bursts

Contaminants

- Nucleation is very sensitive to condensable vapour contaminants
- These backgrounds must be kept well below 1 ppt
- Great care has been taken in the CLOUD design to reduce backgrounds:
  - Inner surfaces electropolished and UHV procedures followed
  - Ultrapure air derived from cryogenic liquid O_2 + liquid N_2
  - No plastic materials; all seals for chamber and gas system are metal
  - Humidifier supplied by water recirculating through MilliQ filters
  - Magnetically-coupled mixer fan
- Condensable vapours detected at ~1 ppt level. Evidence that they are brought in by humidifier water.
- New synthetic water system under construction; uses electrolytic H_2 flame at 1400°C in pure O_2

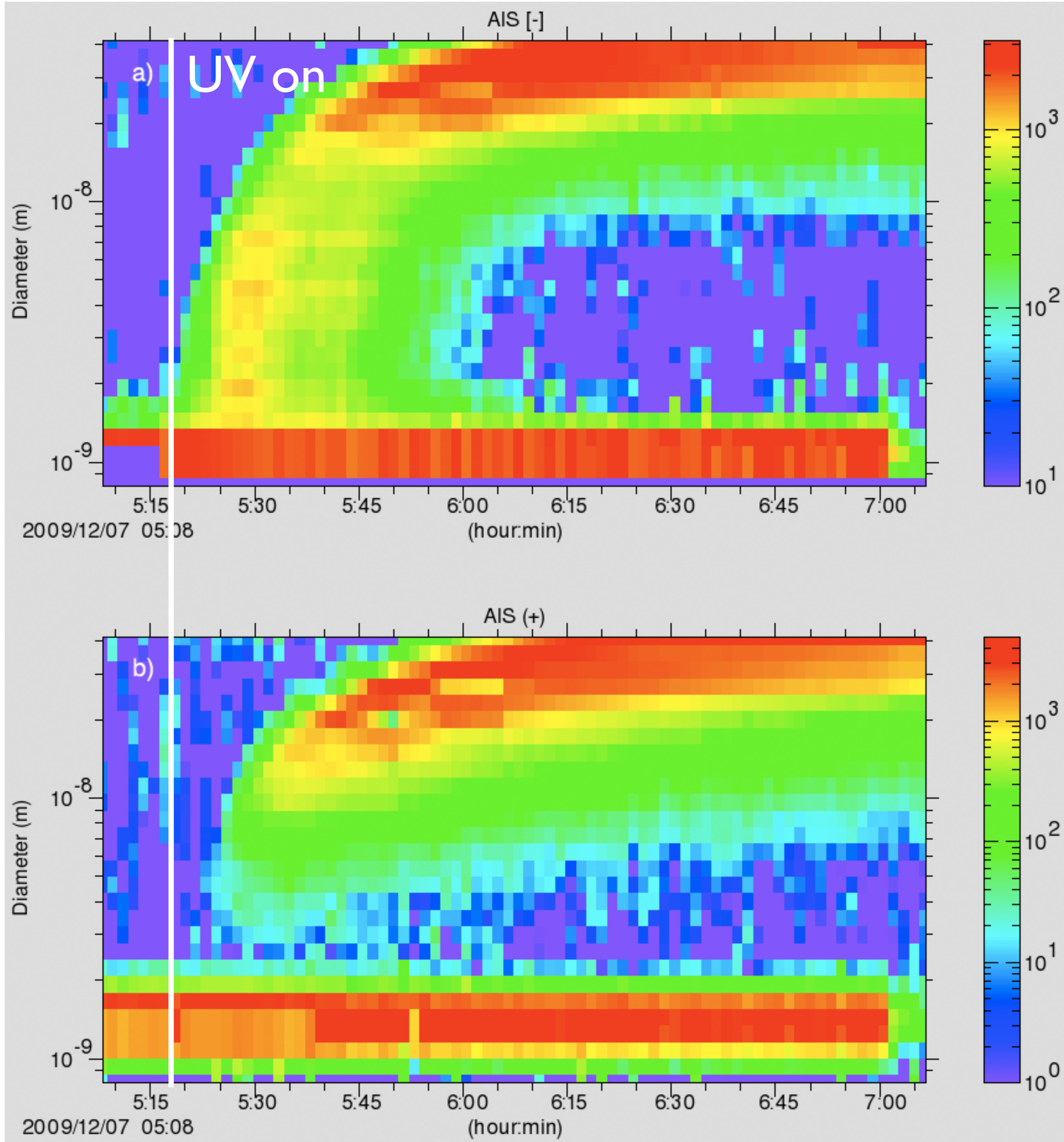
Observation of ion-induced nucleation



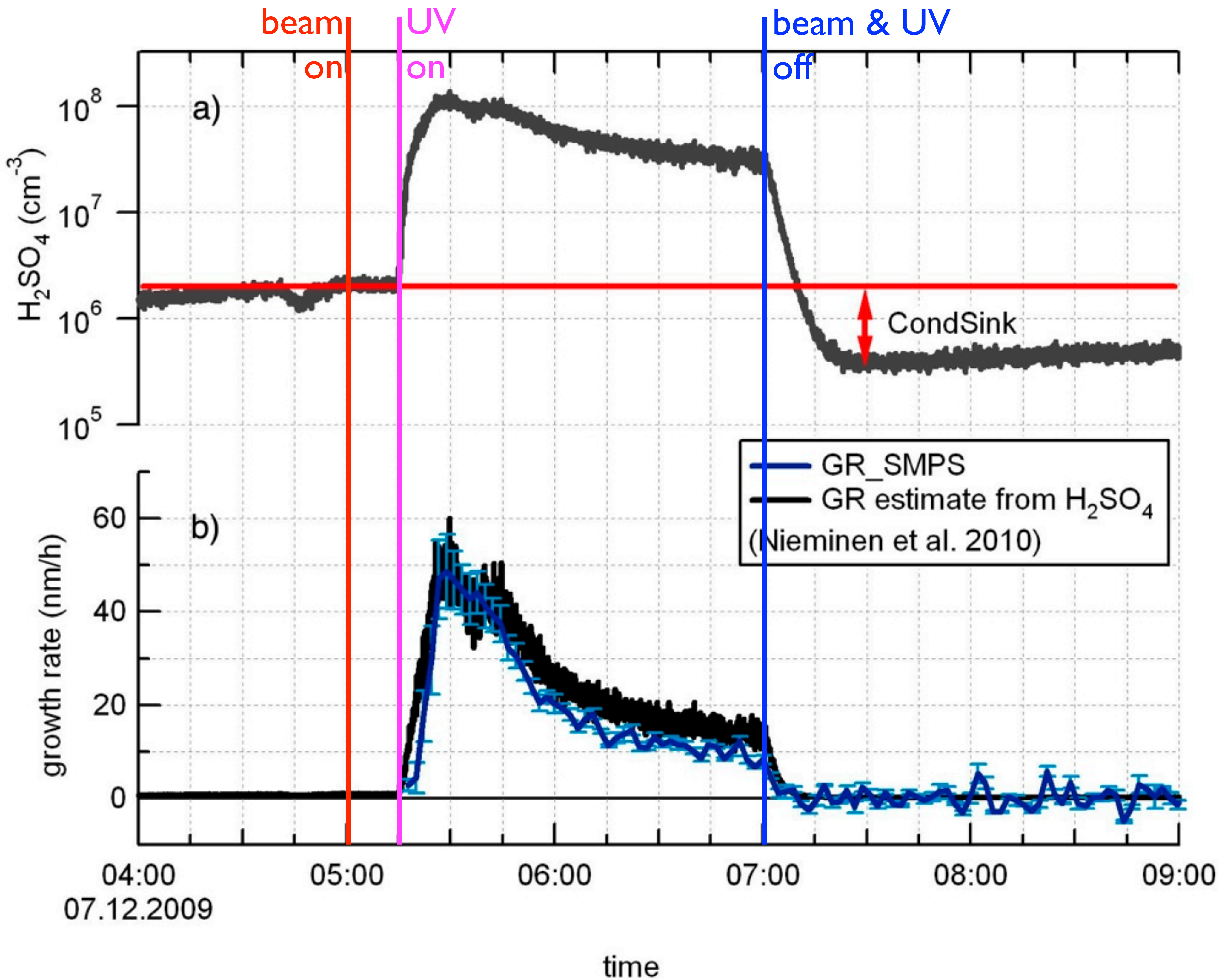
Ion-induced nucleation banana plots

negative clusters

positive clusters



Aerosol growth rates



Conclusions

- Climate has continually varied in the past, and the causes are not well understood - especially on the 100 year timescale relevant for today's climate change
- Strong evidence for solar-climate variability, but no established mechanism. A cosmic ray influence on clouds is a leading candidate
- CLOUD at the CERN PS has begun to investigate the cosmic ray-cloud mechanism in a controlled laboratory experiment.
- CLOUD showed excellent technical performance in the first run in Dec 2009 and has already made important new observations, which are in preparation for publication
- The question of whether - and to what extent - the climate is influenced by solar/cosmic ray variability remains central to our understanding of anthropogenic climate change