

Klimaets fysik

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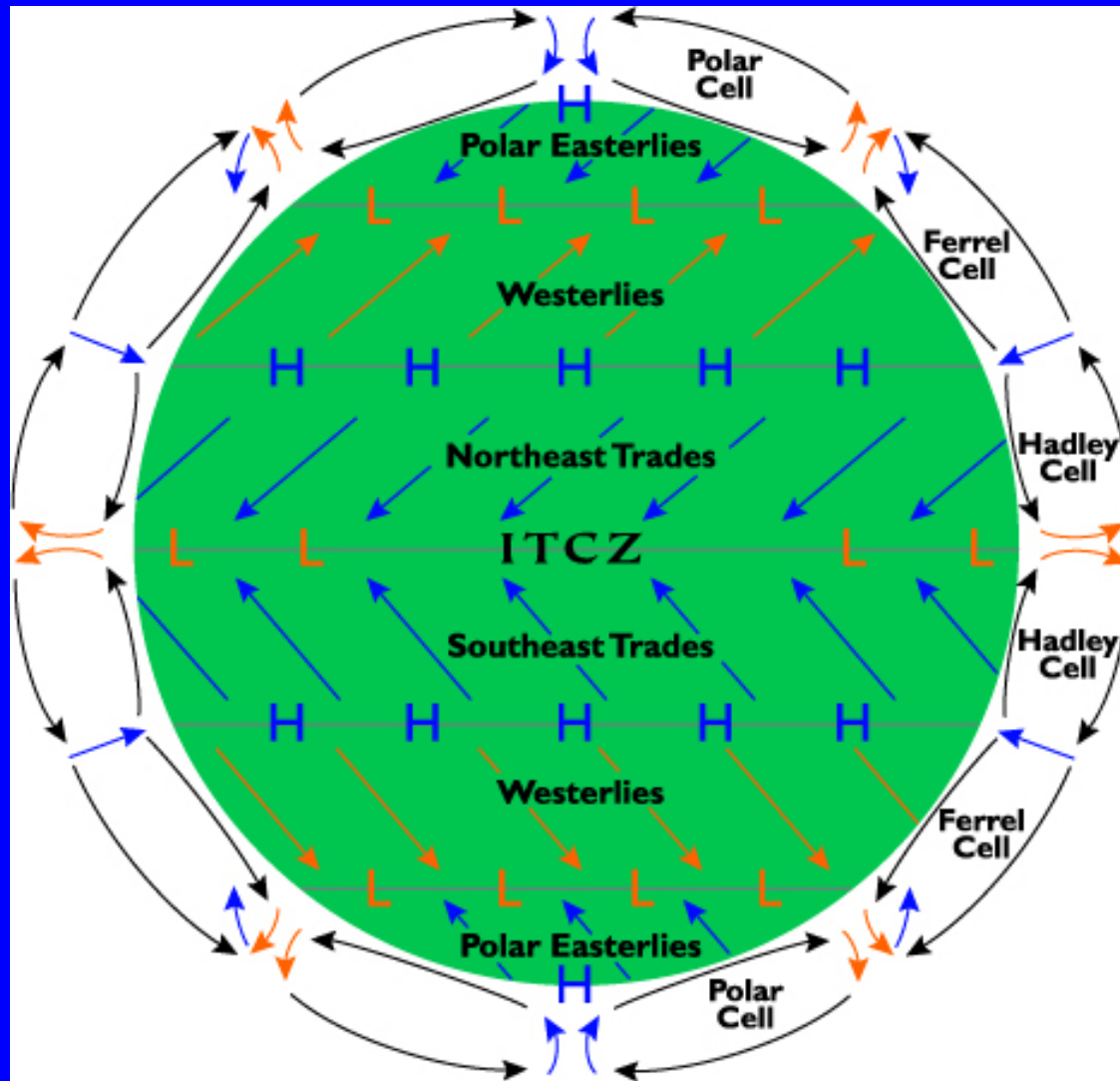
Danmarks Rumcenter



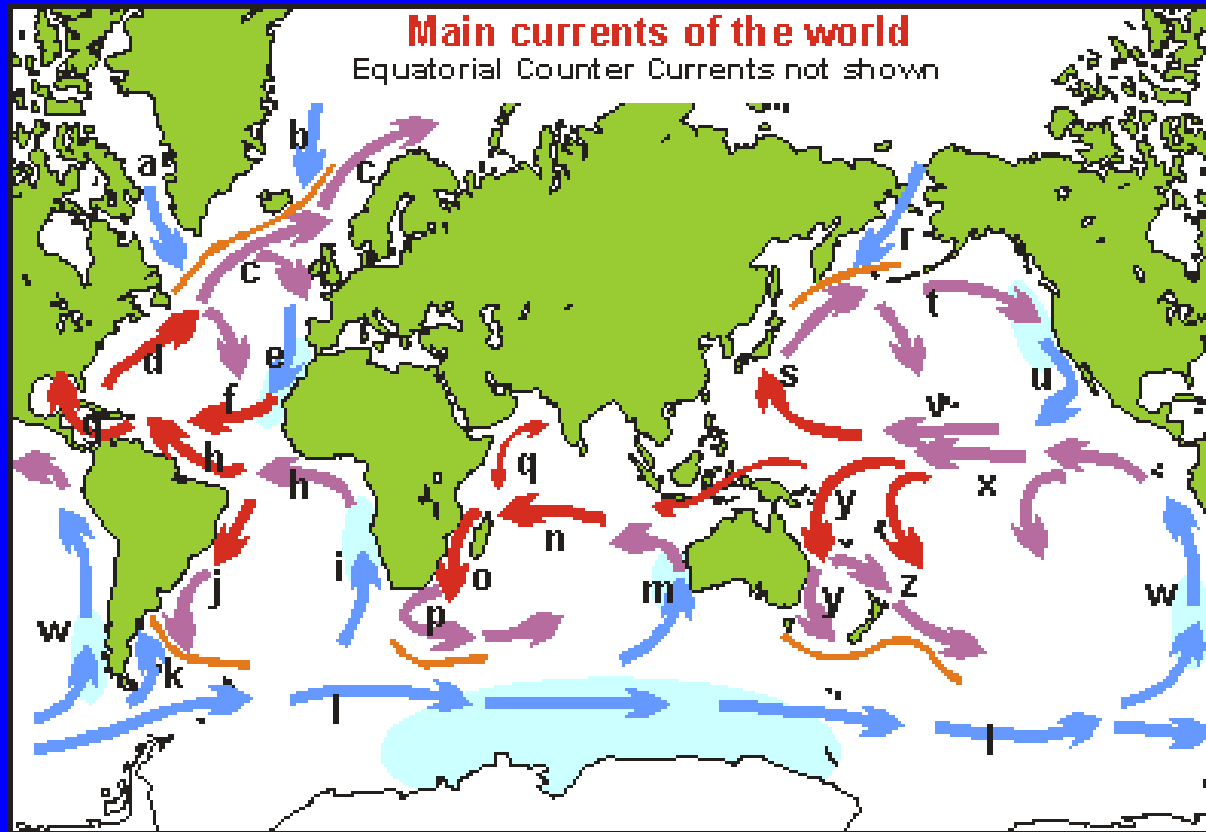
Århus, 27. januar 2006



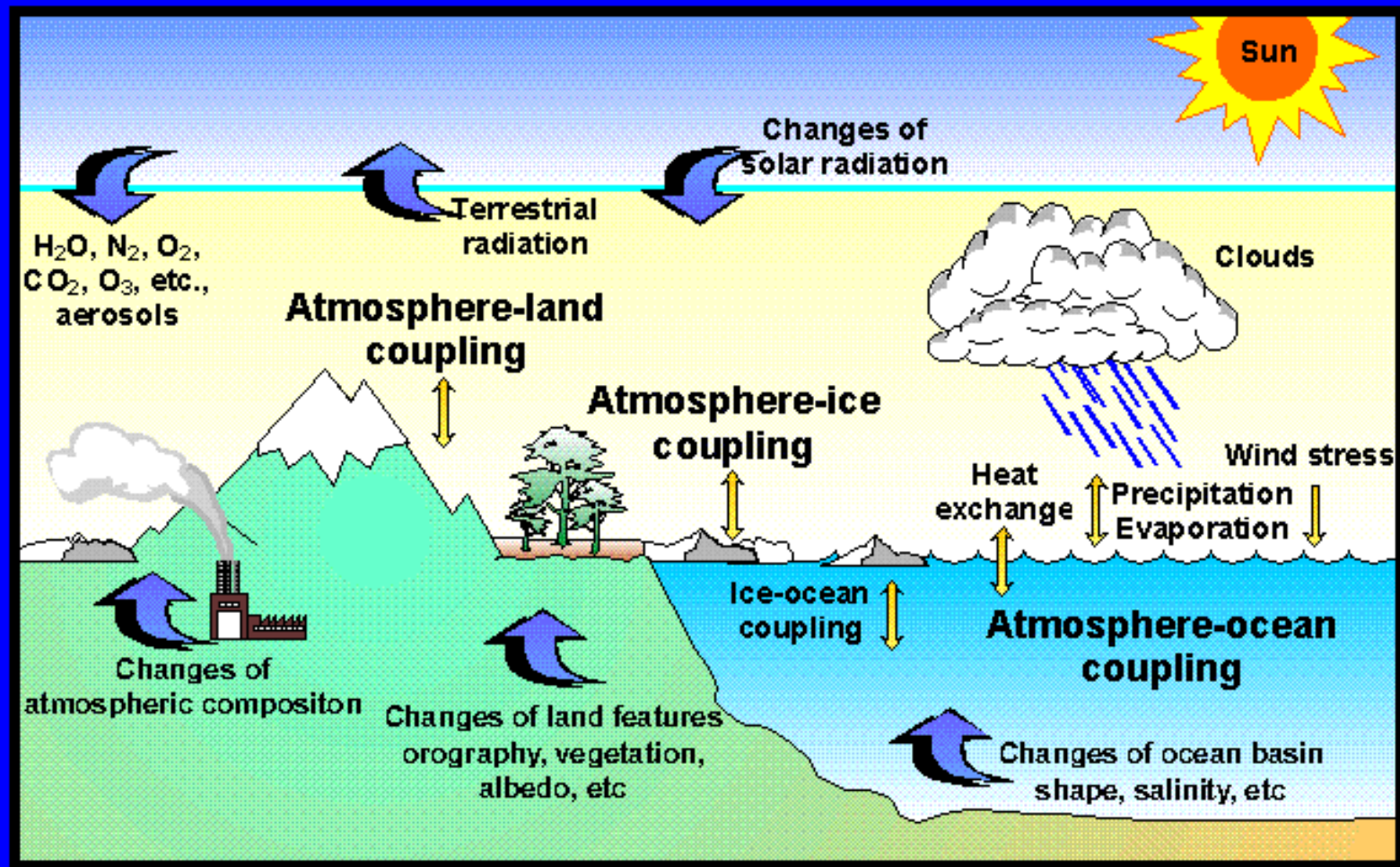
Strømninger i atmosfæren



Strømninger i havet



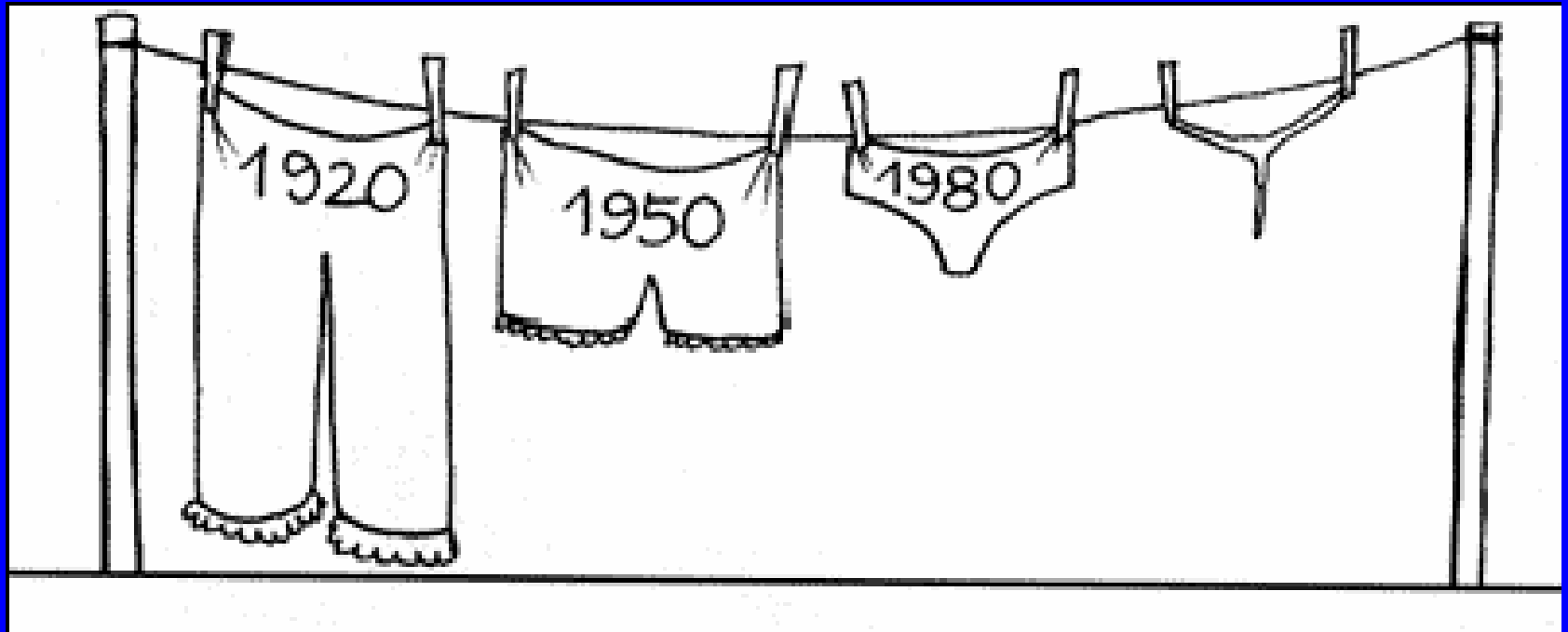
Klimasystemet



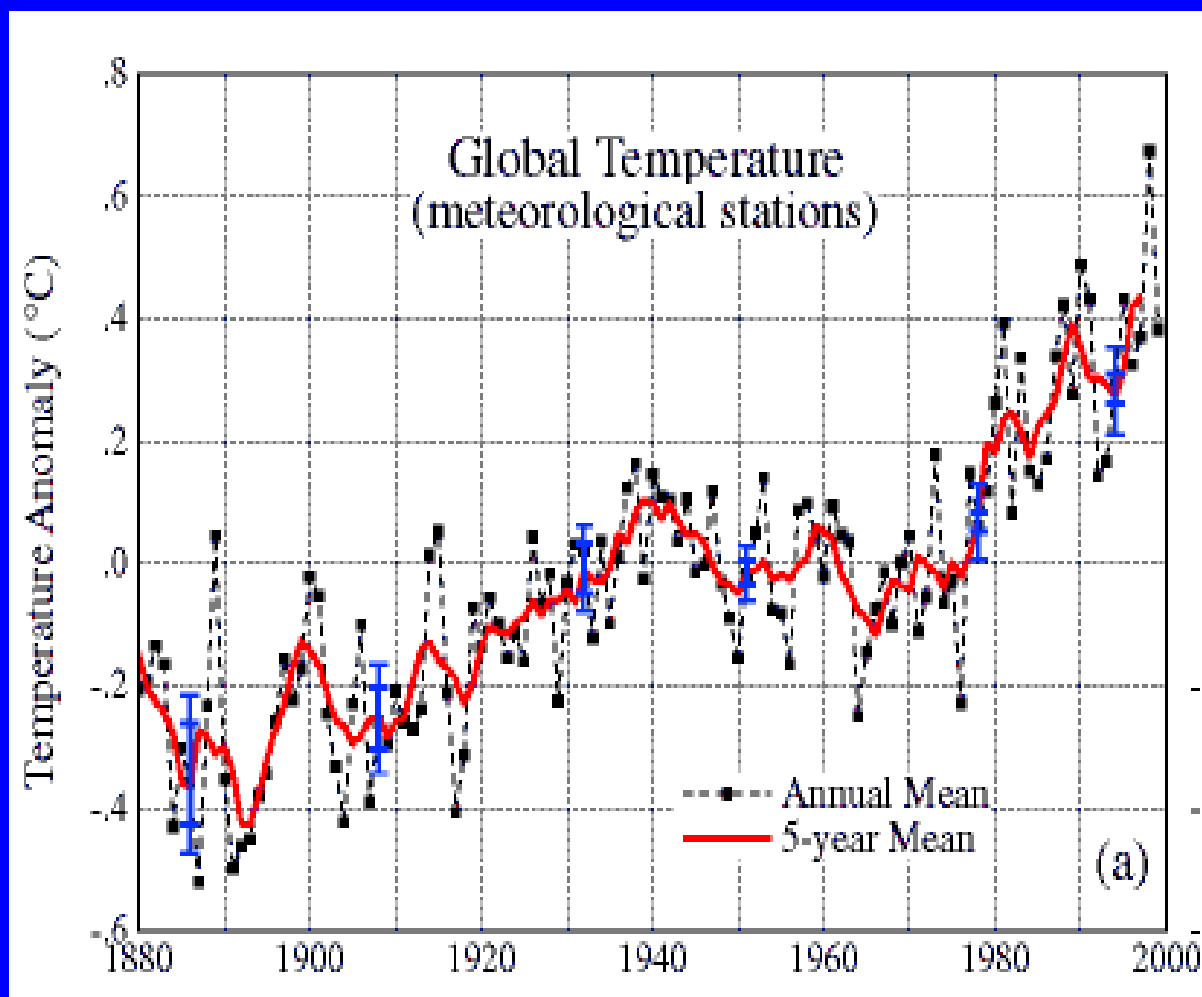
Global opvarmning?



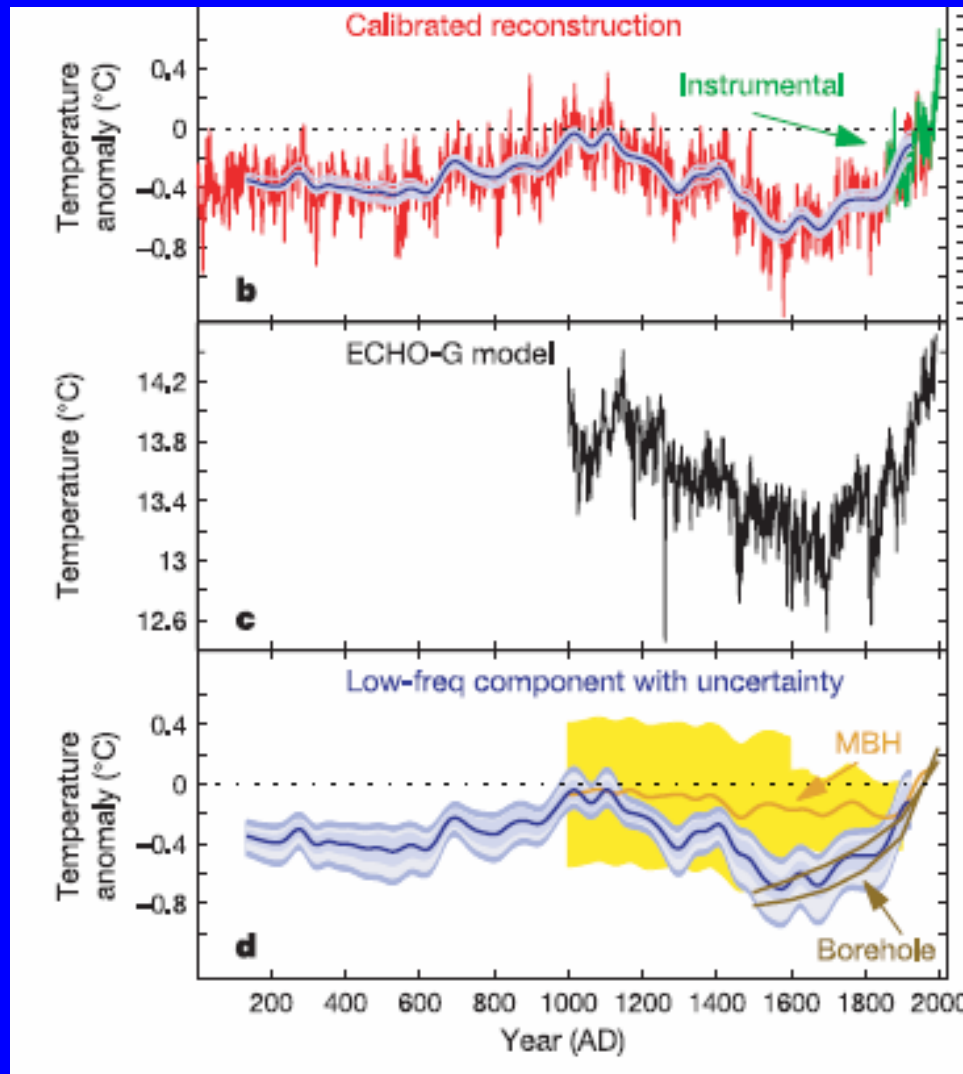
Flere indikationer



Den globale overfladetemperatur siden 1880

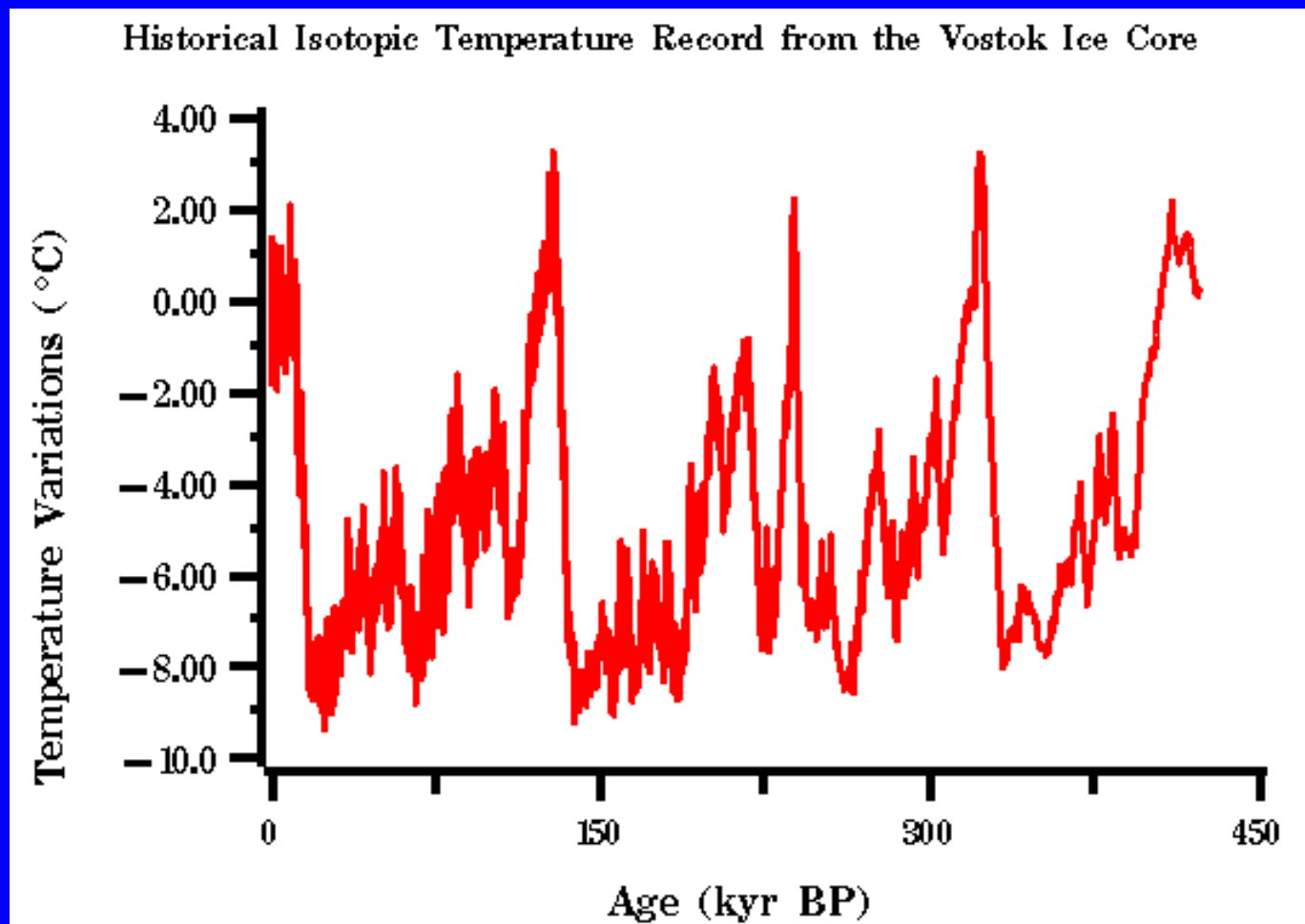


Global temperature 0-2000

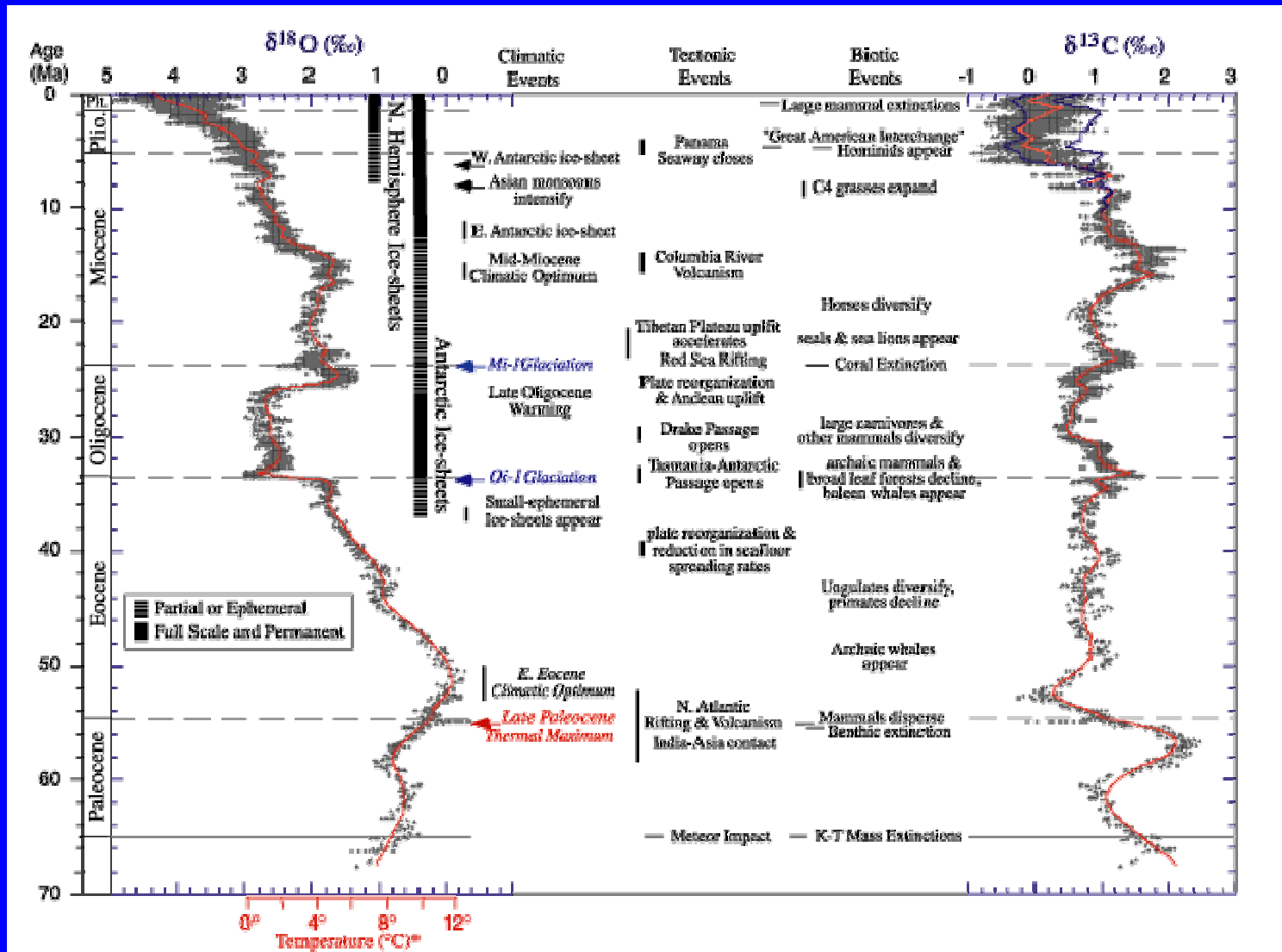


Moberg: Nature 2005

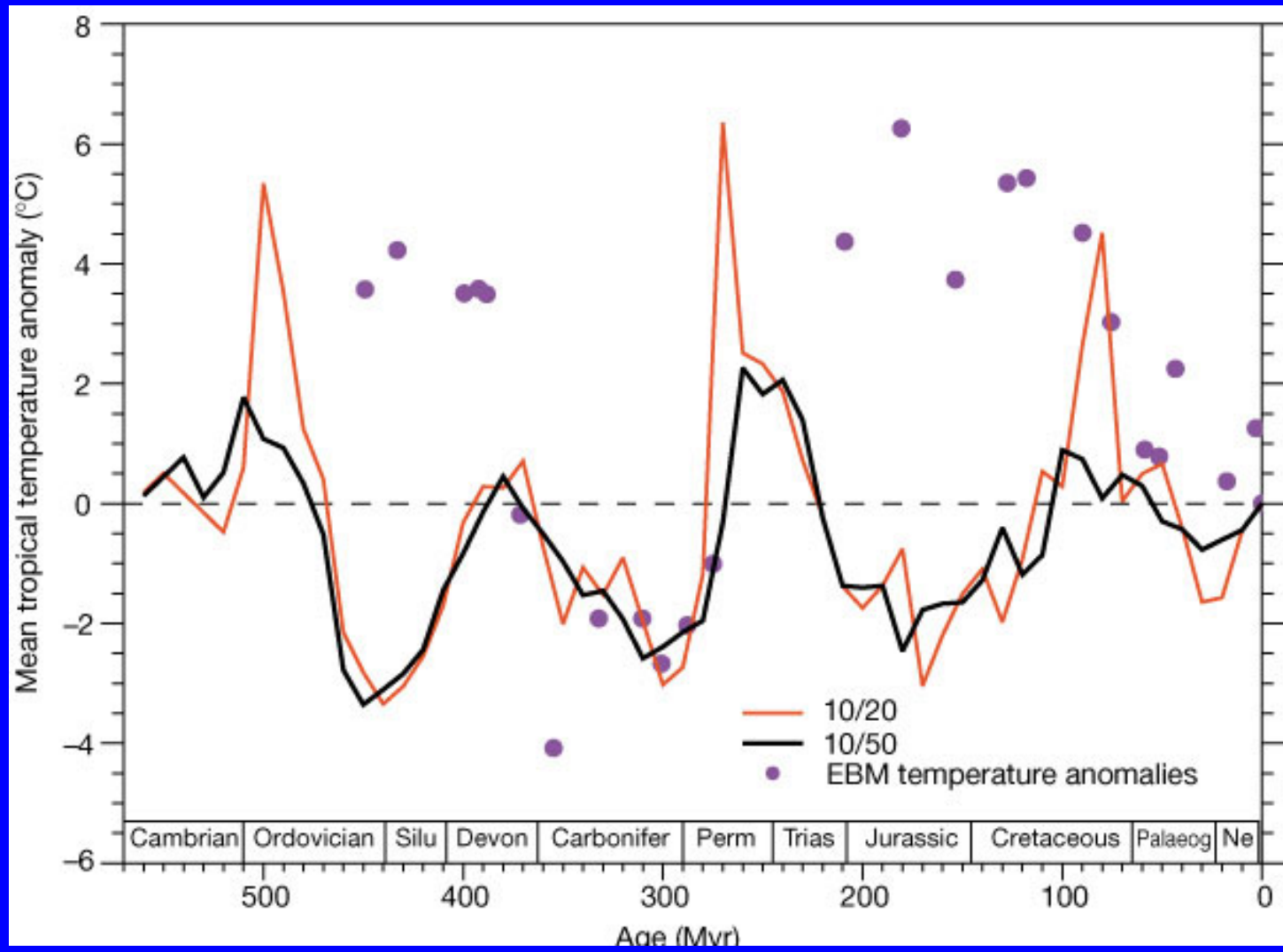
Temperaturen gennem 450.000 år



Temperaturen gennem 70 mio. år

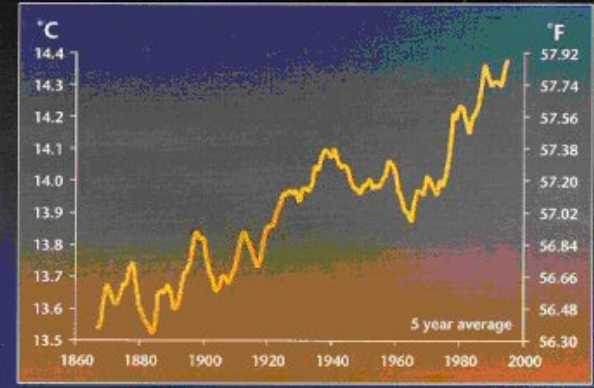


Temperaturen gennem 600 mio. år

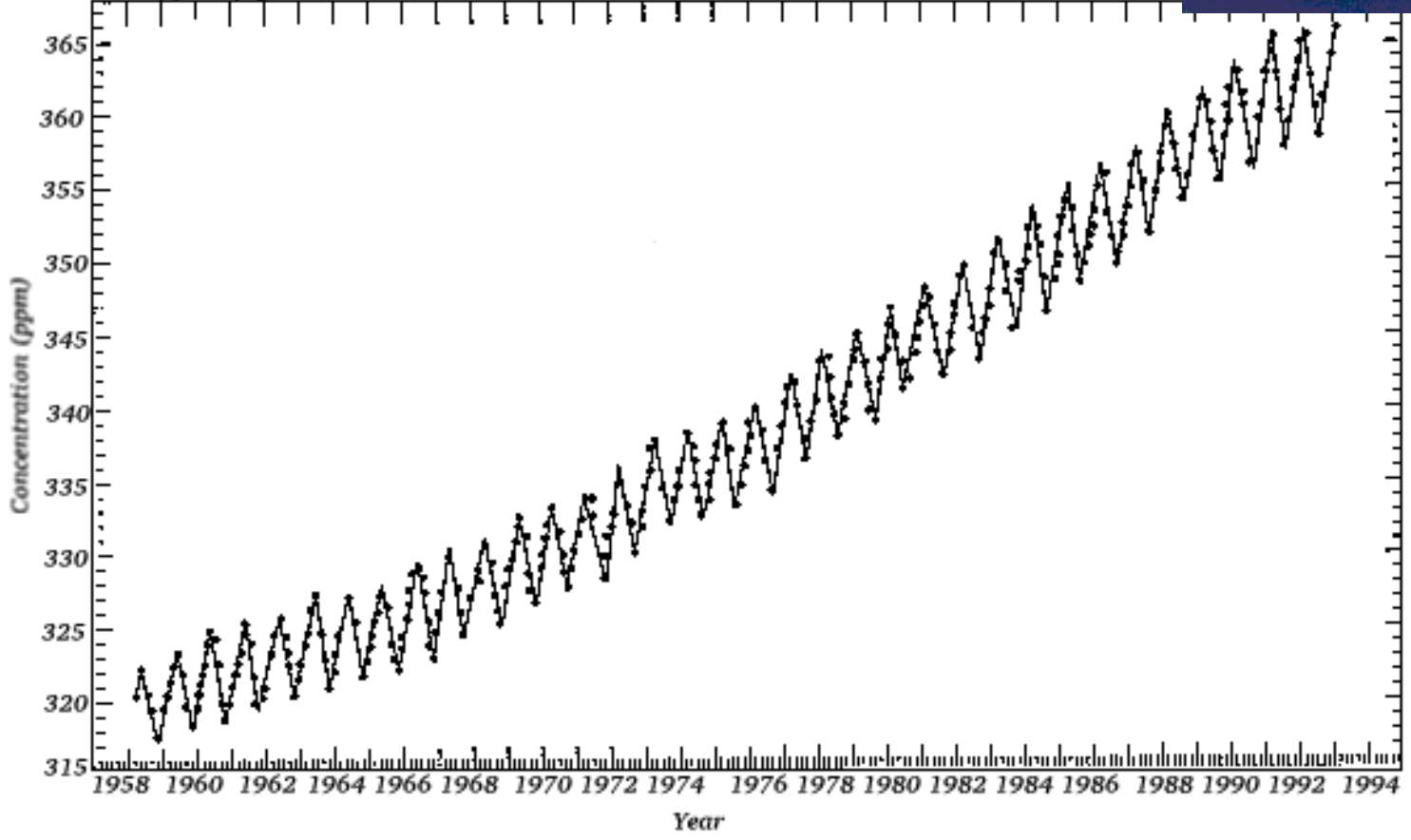


CO2 i atmosfæren 1958 - 1994

Global Average Temperature

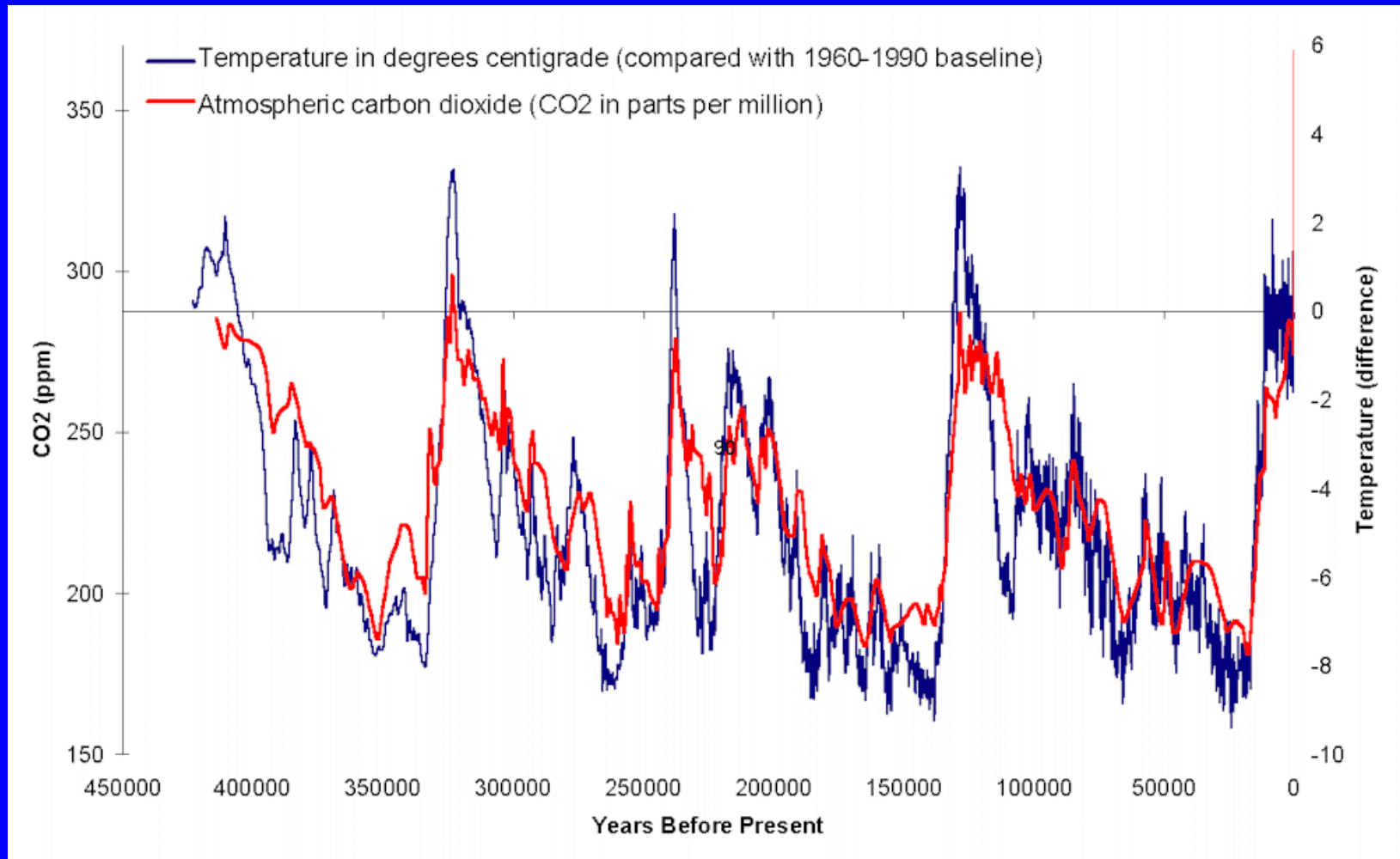


Mauna Lau Observatory, Hawaii
Monthly average CO2 concentration

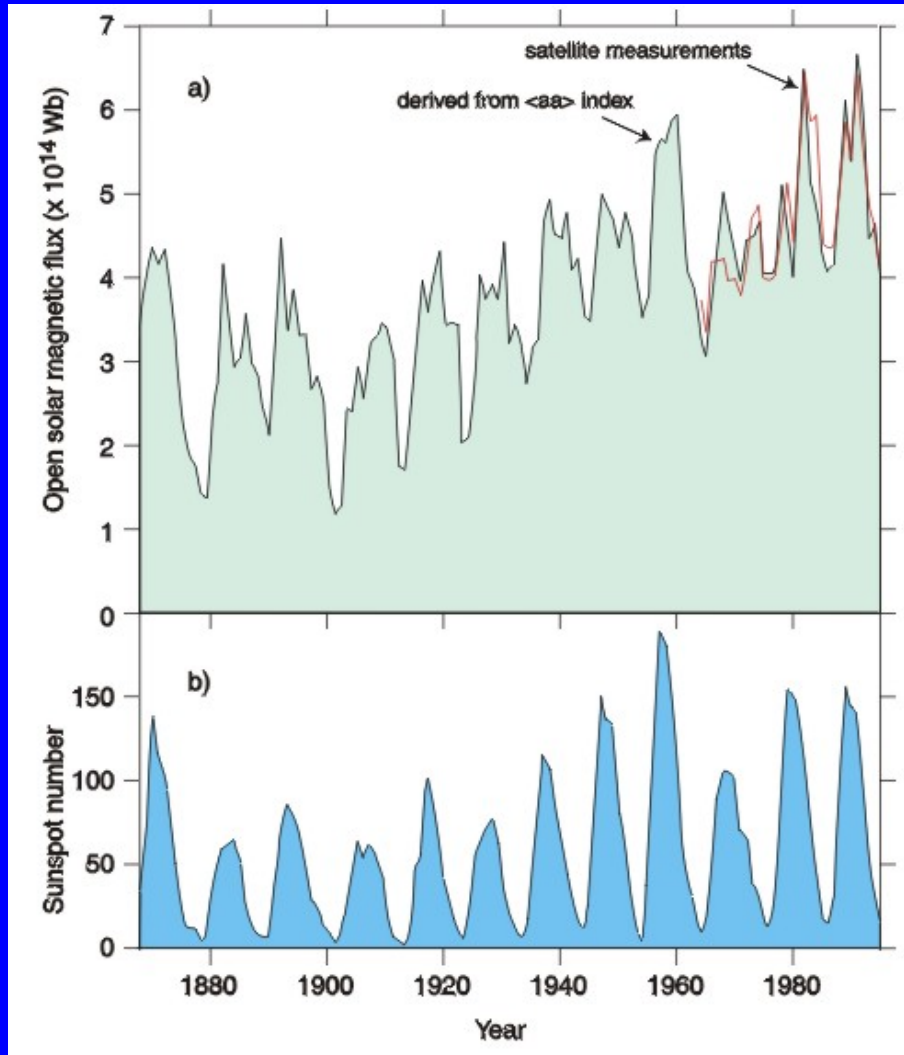


CO2 i atmosfæren

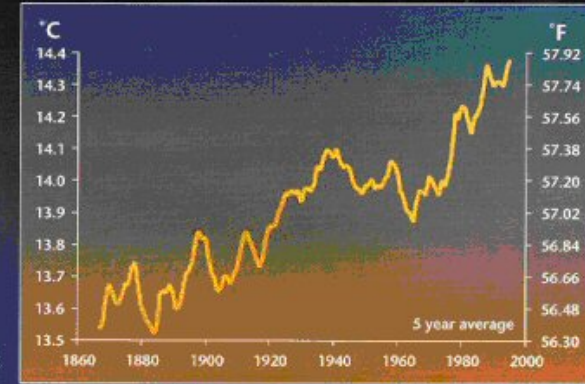
De sidste 450.000 år



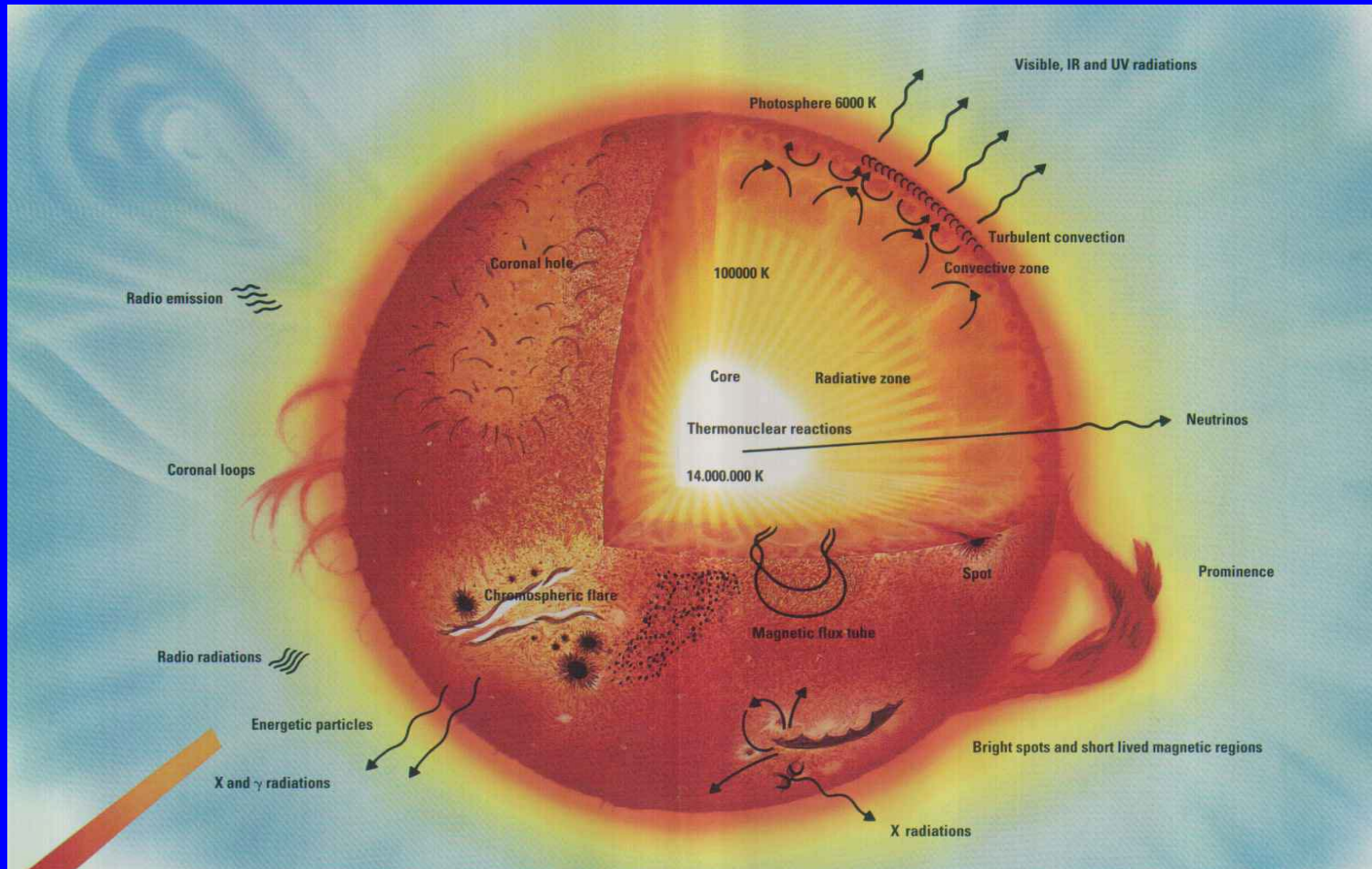
Solaktivitet de sidste 150 år



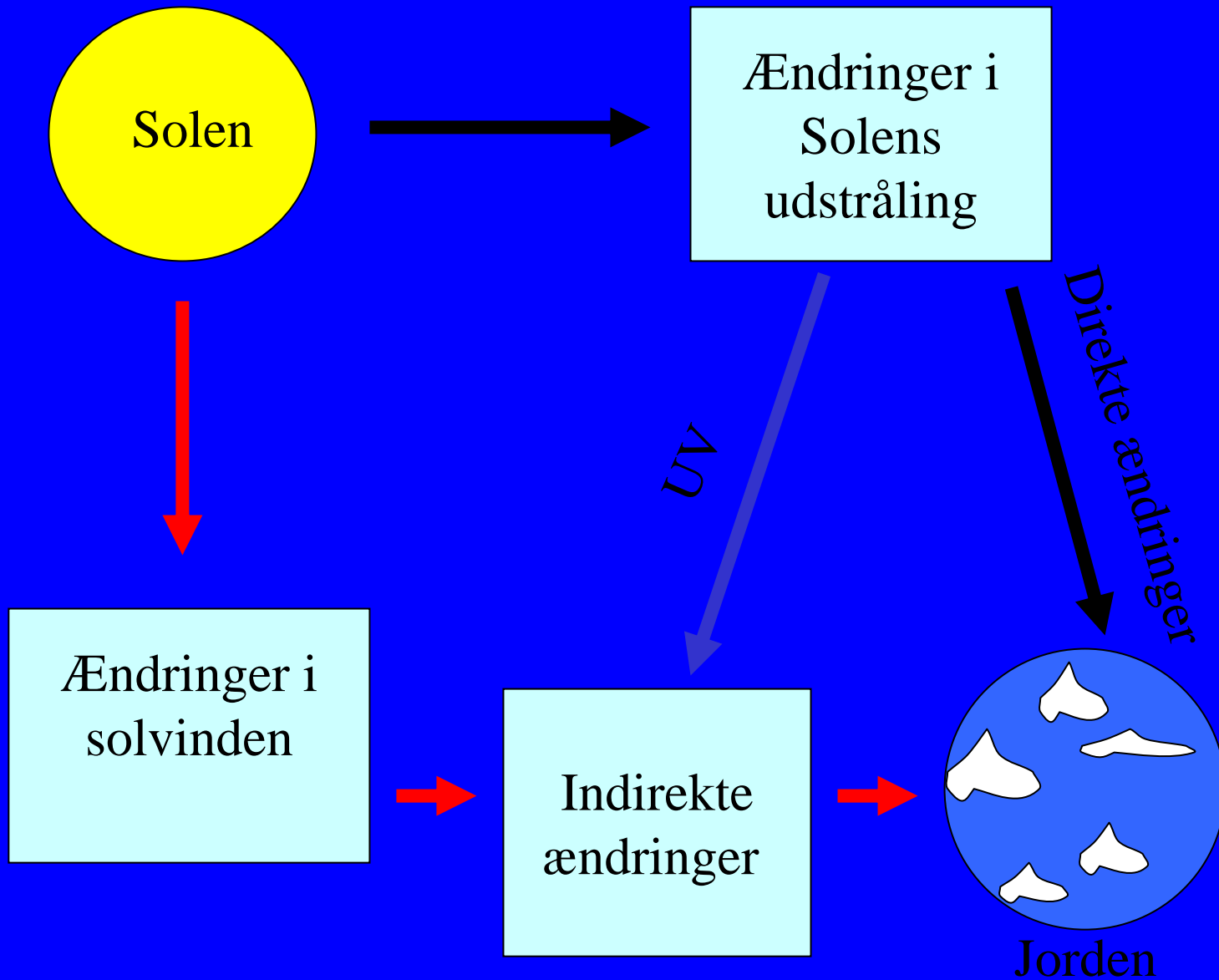
Global Average Temperature



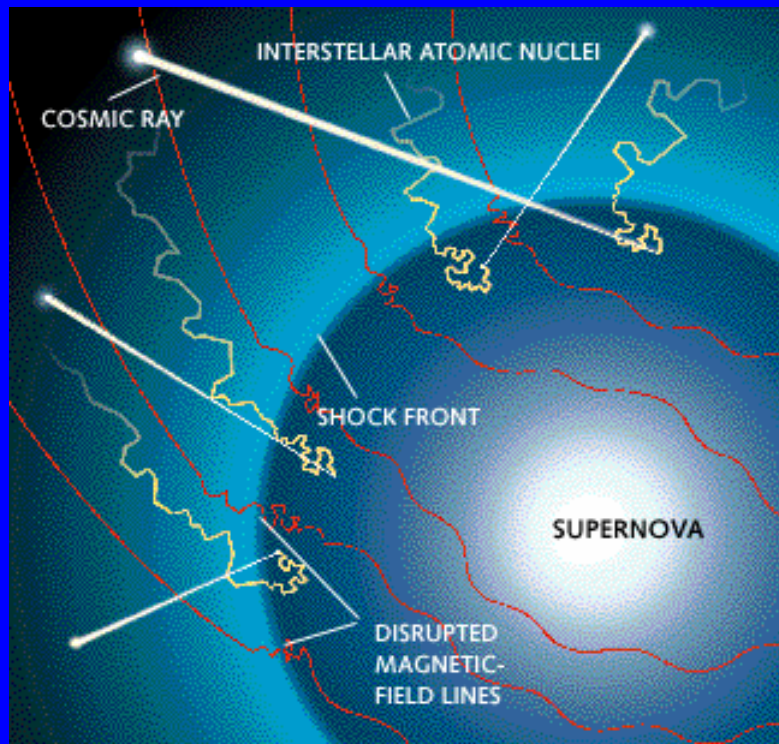
En aktiv sol



Solaktivitet og Jordens atmosfære



Produktion af kosmiske stråler



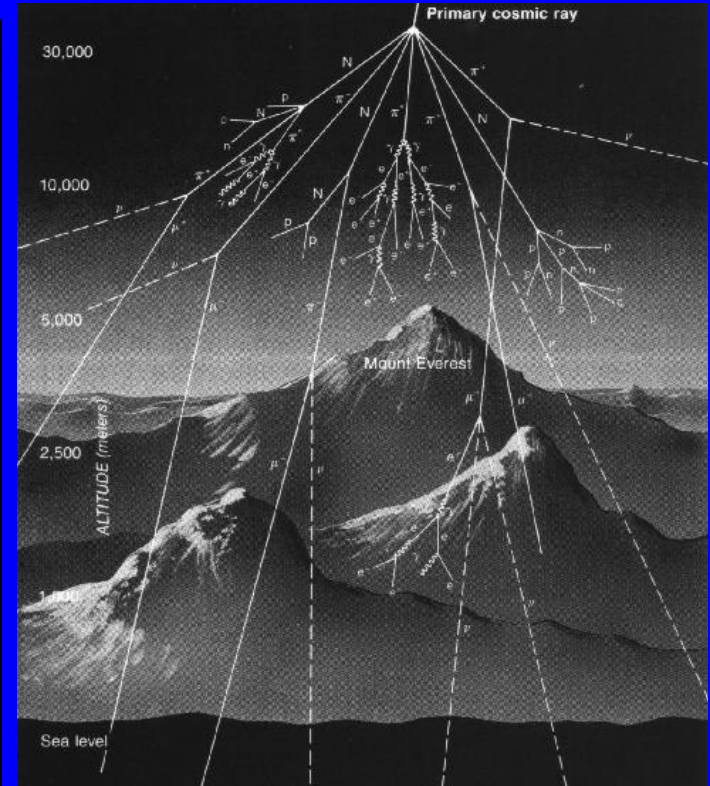
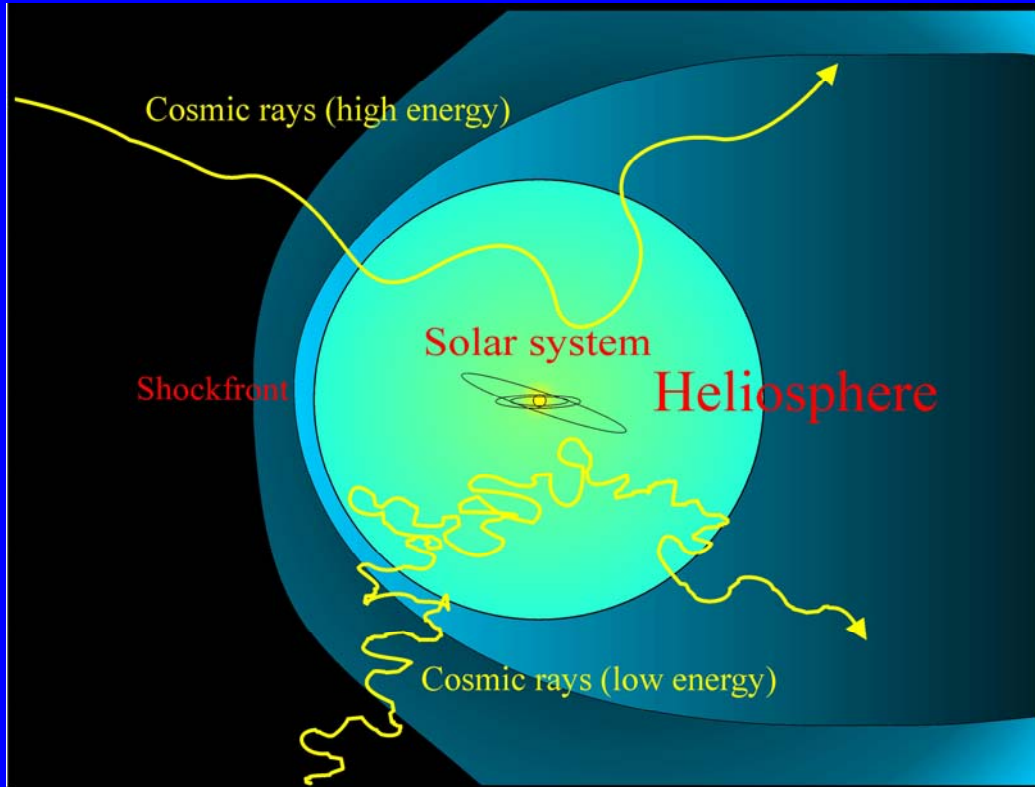
~ 100 MeV – 10 GeV
(10^{20} eV)

89 % p

10 % α

1 % tunge elementer, e

Heliosfæren og kosmiske stråler



Ved overfladen: $\sim 100 \mu / m^2 / s$

Energier ved toppen af Jordens atmosfære

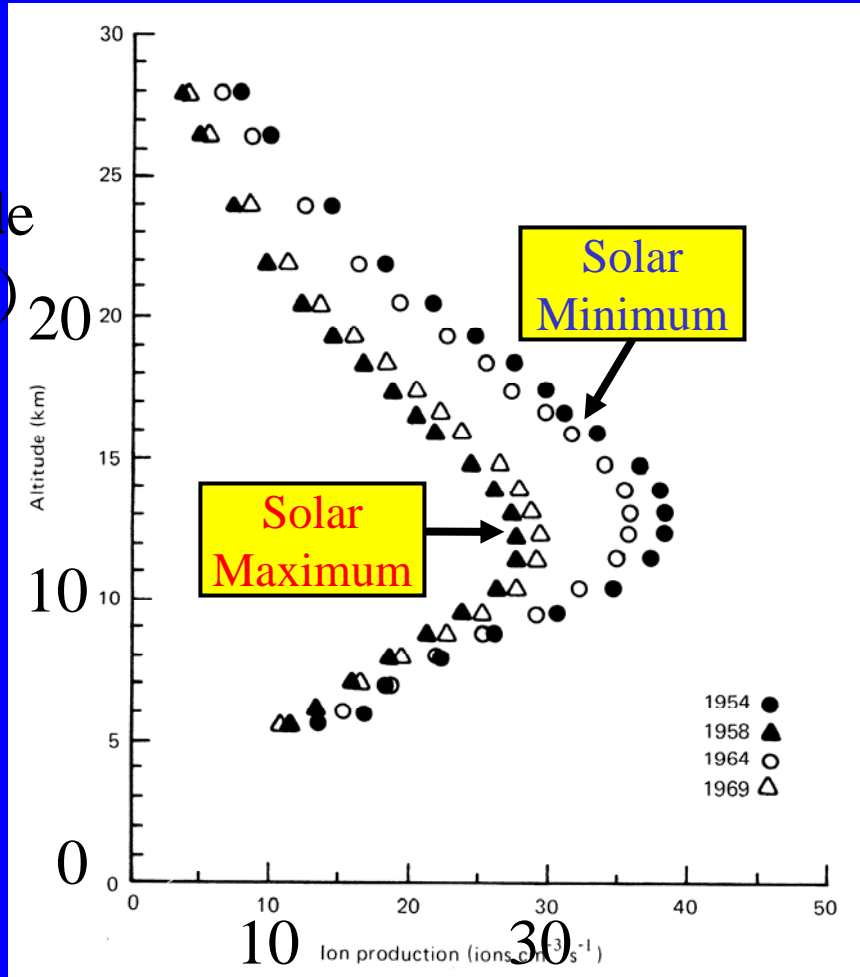
- Solen $\sim 340 \text{ W/m}^2$
- 11-årige Solcyklus
 $\sim 0.34 \text{ W/m}^2$
- Kosmiske stråler
 $\sim 10^{-5} \text{ W/m}^2$

**Der må være en
forstærkning, hvis
kosmiske stråler skal
påvirke klimaet**

**Kollisioner med molekyler i atmosfæren
producerer bl.a. C-14 og Be-10**

Dannelse af ioner pga. kosmisk stråling

Højde
(km)



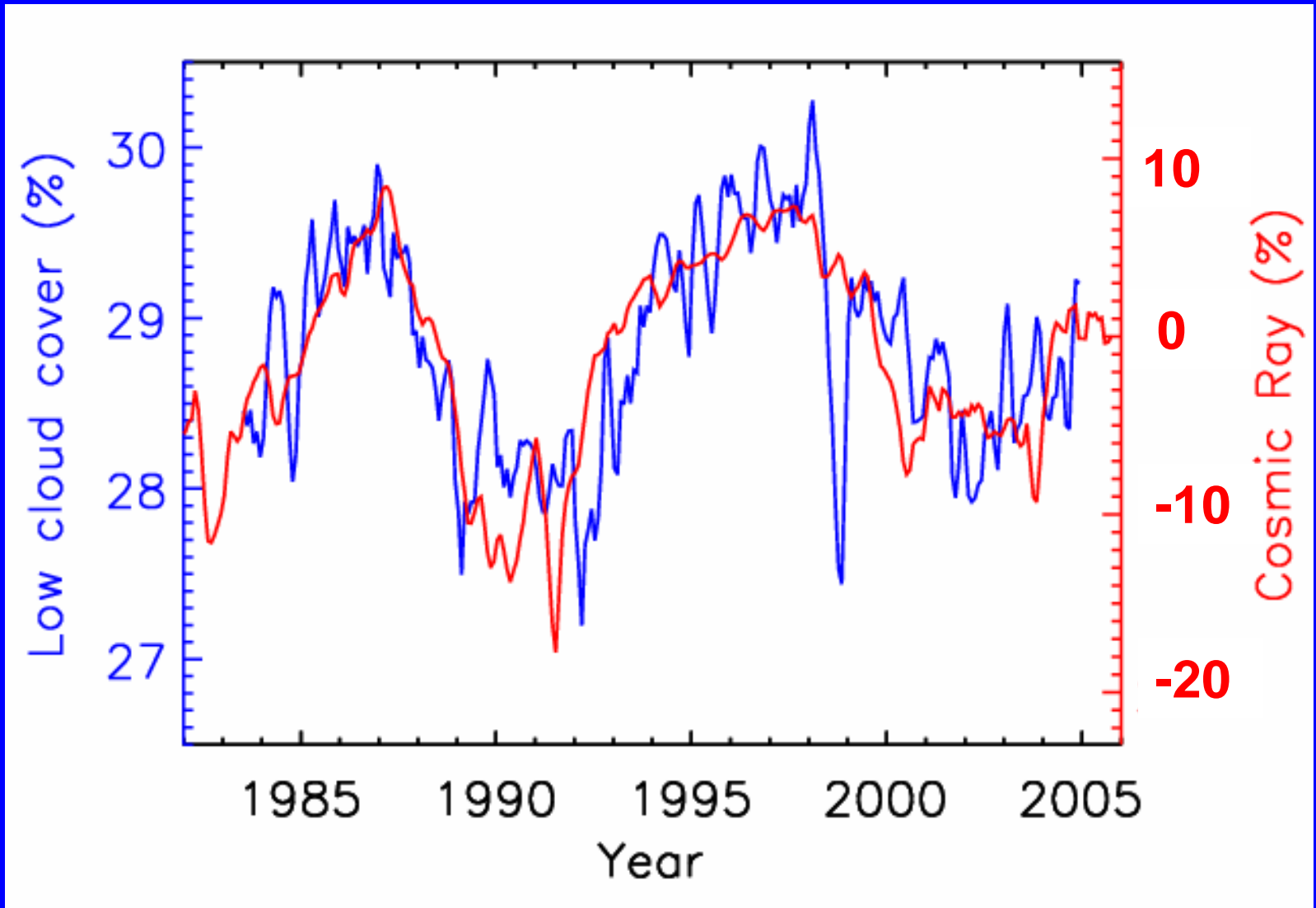
Ion-par/cm³/s

“The meteorological variable subject to the largest solar-cycle modulation in the dense layers of the atmosphere is the atmospheric ionisation produced by cosmic rays.”

E.P. Ney, Nature, 1959.

$n = 500-3000 \text{ ion-par/cm}^3$

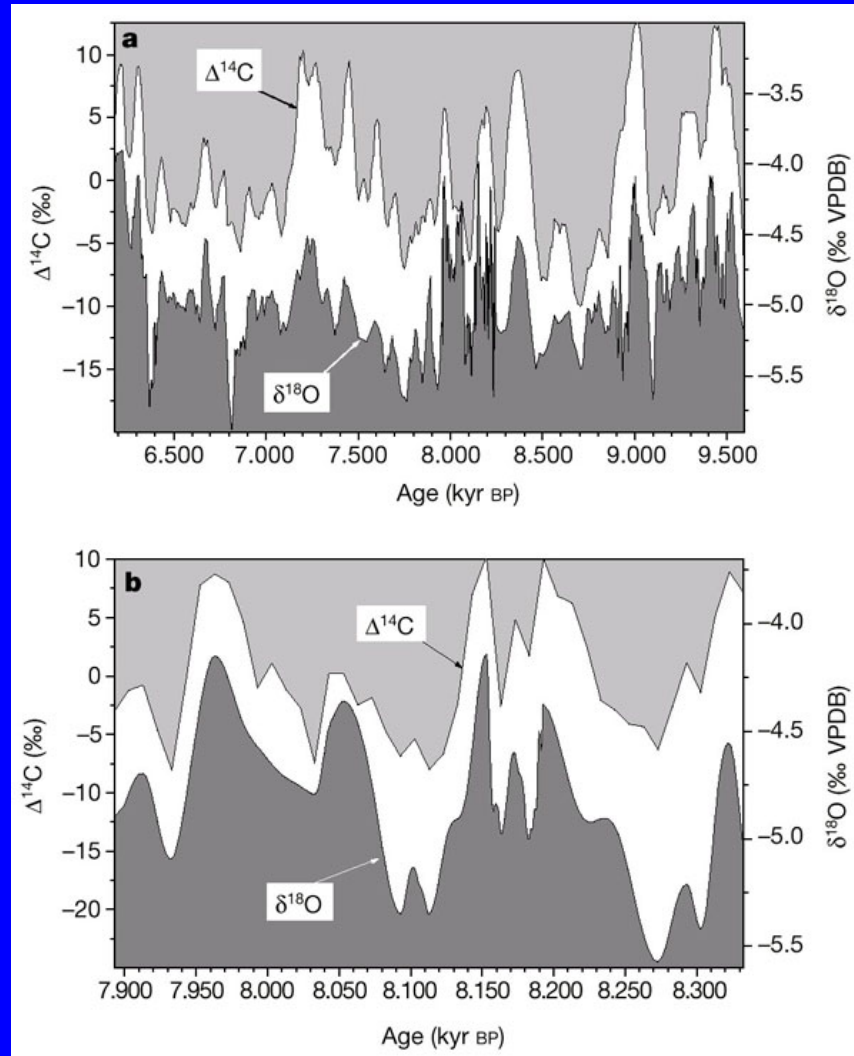
Udbredelsen af lave skyer og mængden af kosmisk stråling



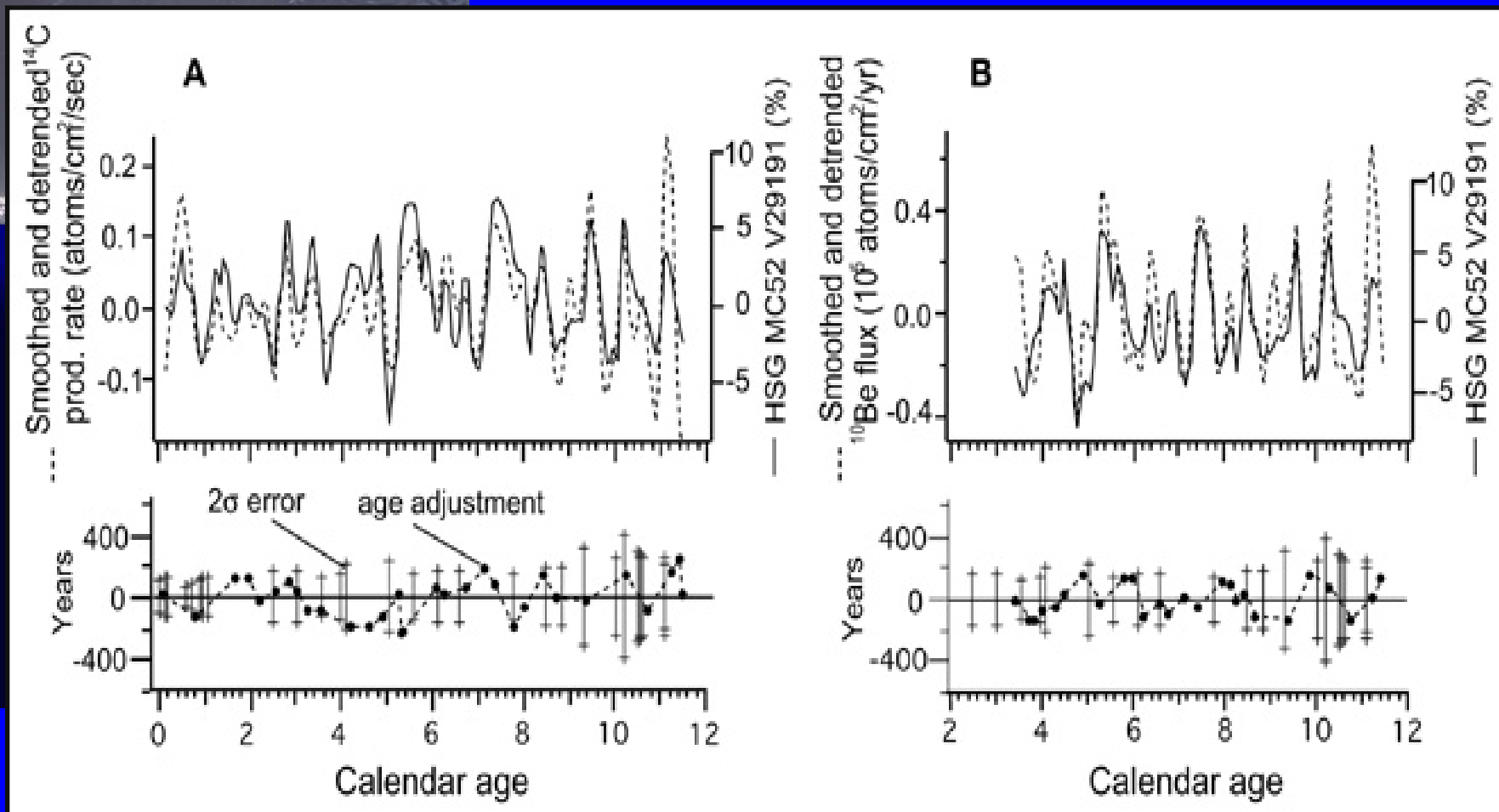
Marsh og Svensmark, PRL (2000), opdateret 2005

Temperatur og kosmisk stråling 9500-6500 f.Kr.

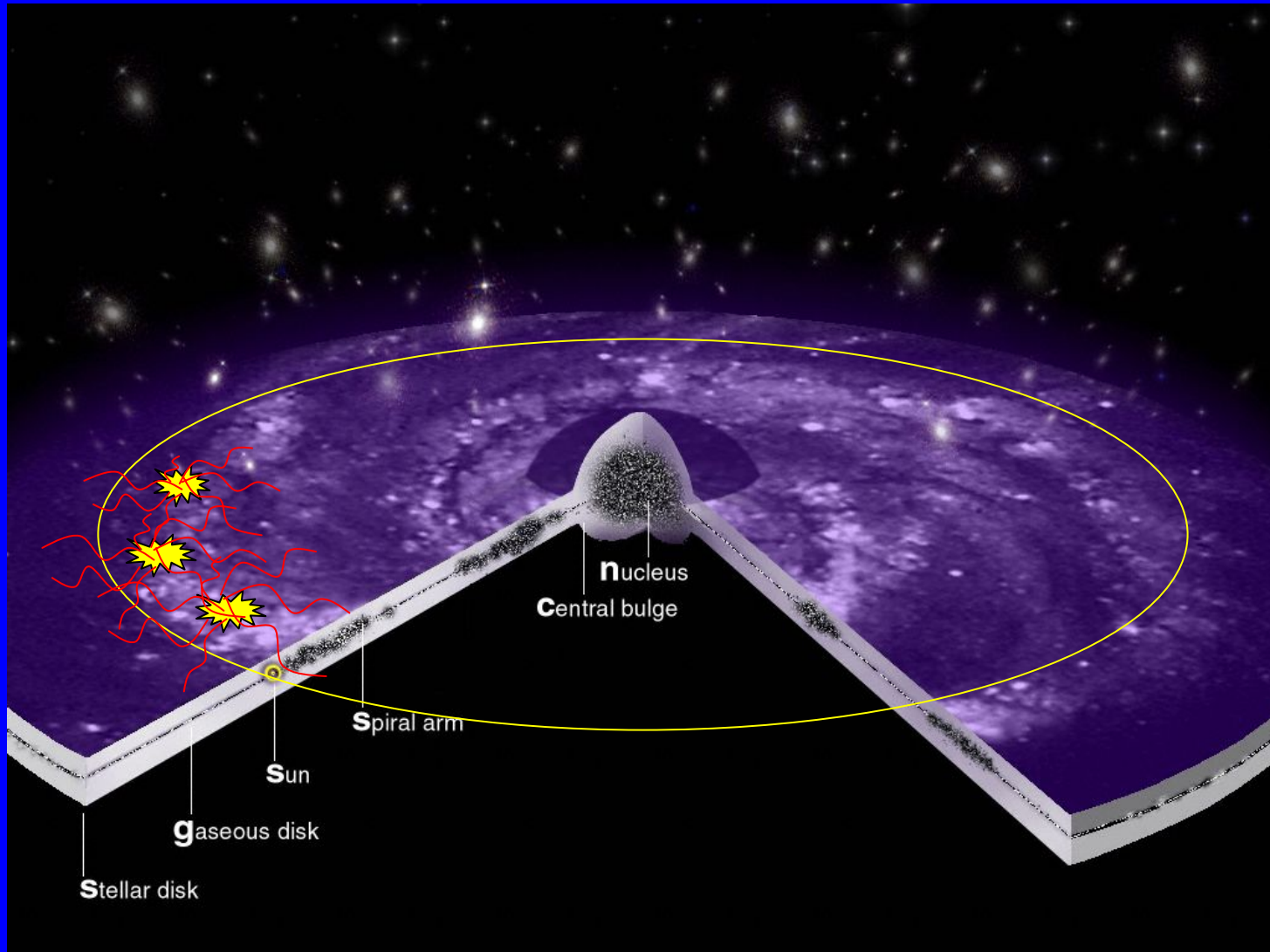
Dannelse af stalagmitter i en grotte i det nordlige Oman.



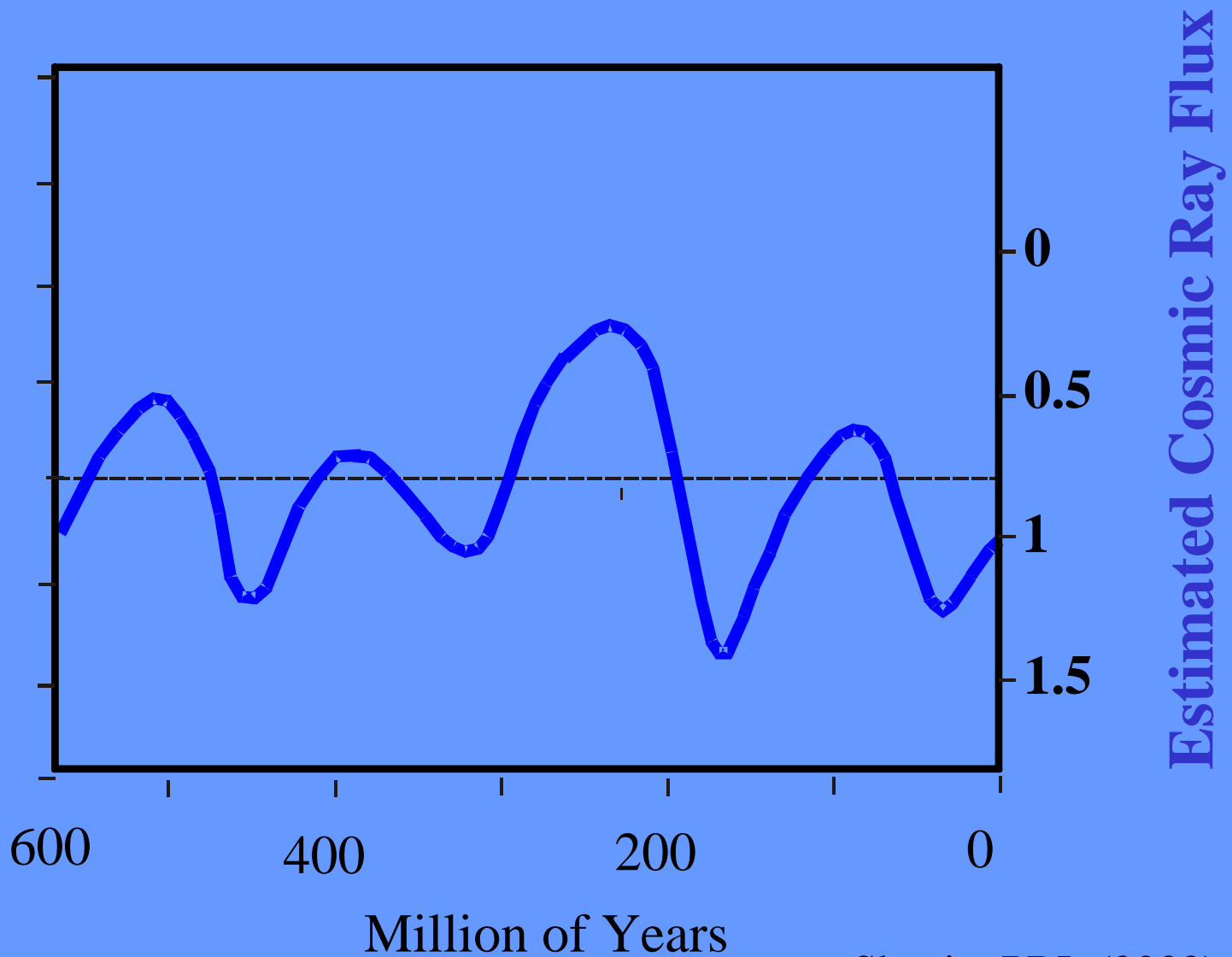
Hyppighed af isbjerge i Nordatlanten sammenholdt med sol-aktivitet gennem 12.000 år



Mælkevejen, super novaer og kosmisk stråling



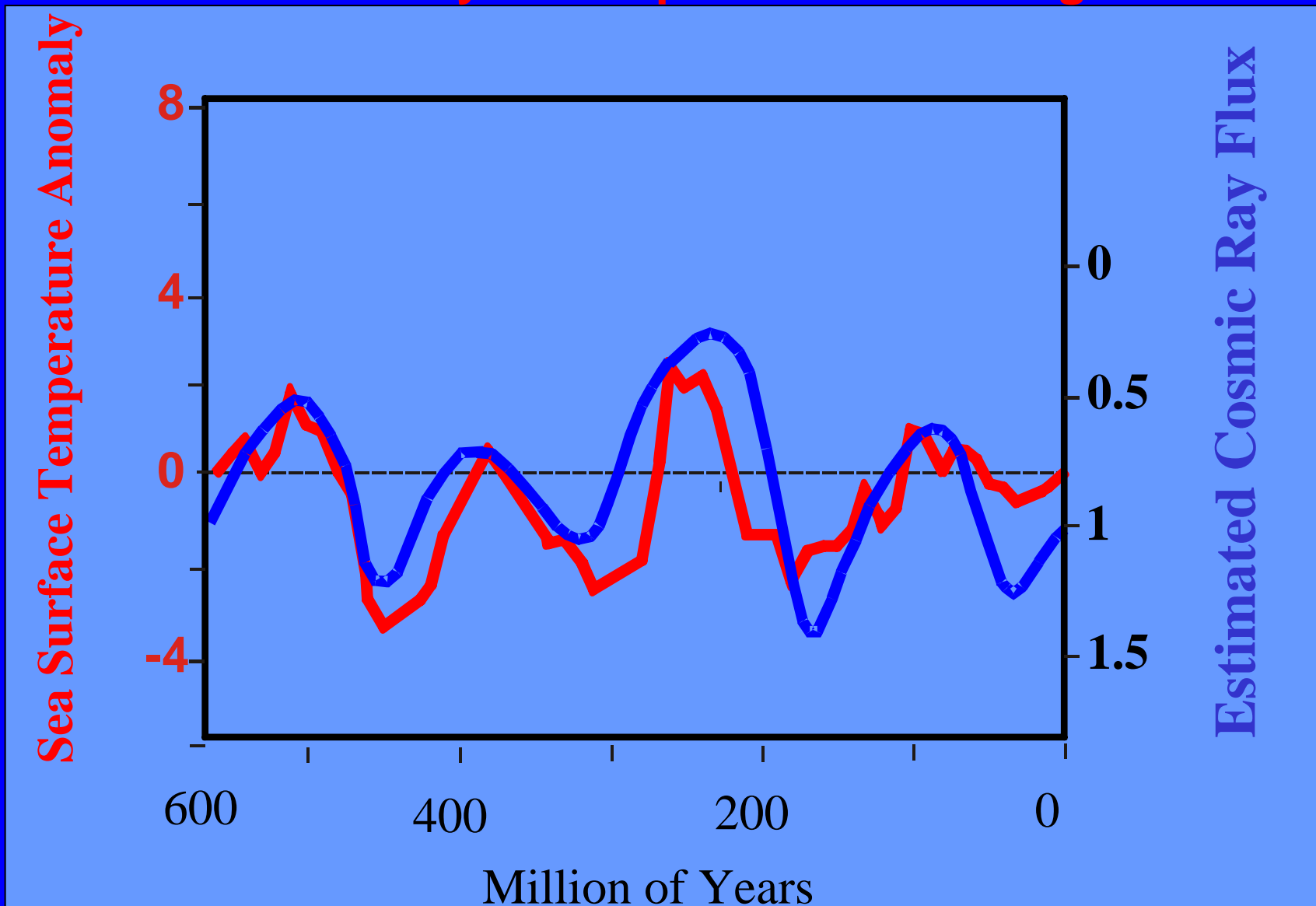
Cosmic rays and spiral arm crossing



Shaviv, PRL (2002)

°C

Cosmic rays and spiral arm crossing



Shaviv & Veizer

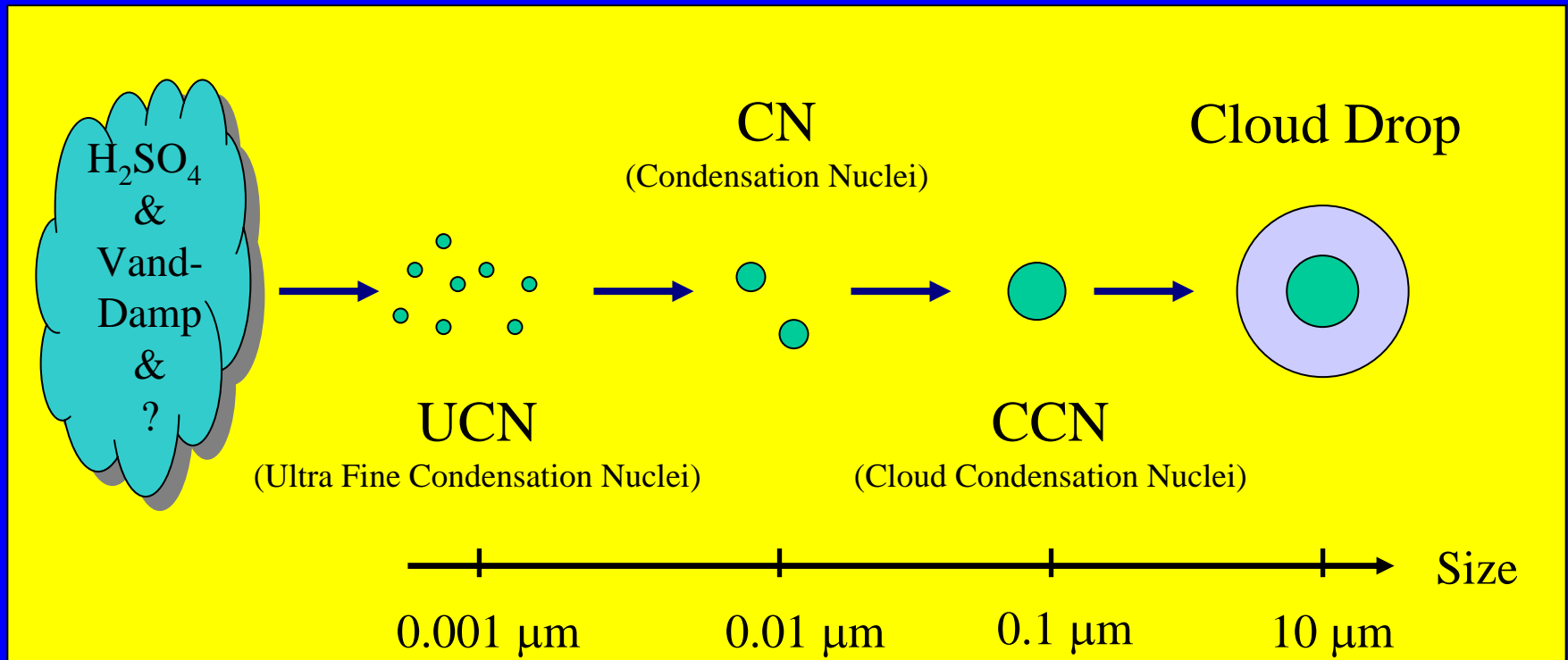
Hvordan påvirker skyerne klimaet?

- Tilbageholder **lange** bølgelængder
- Reflekterer **korte** bølgelængder

Radiative Properties of Clouds

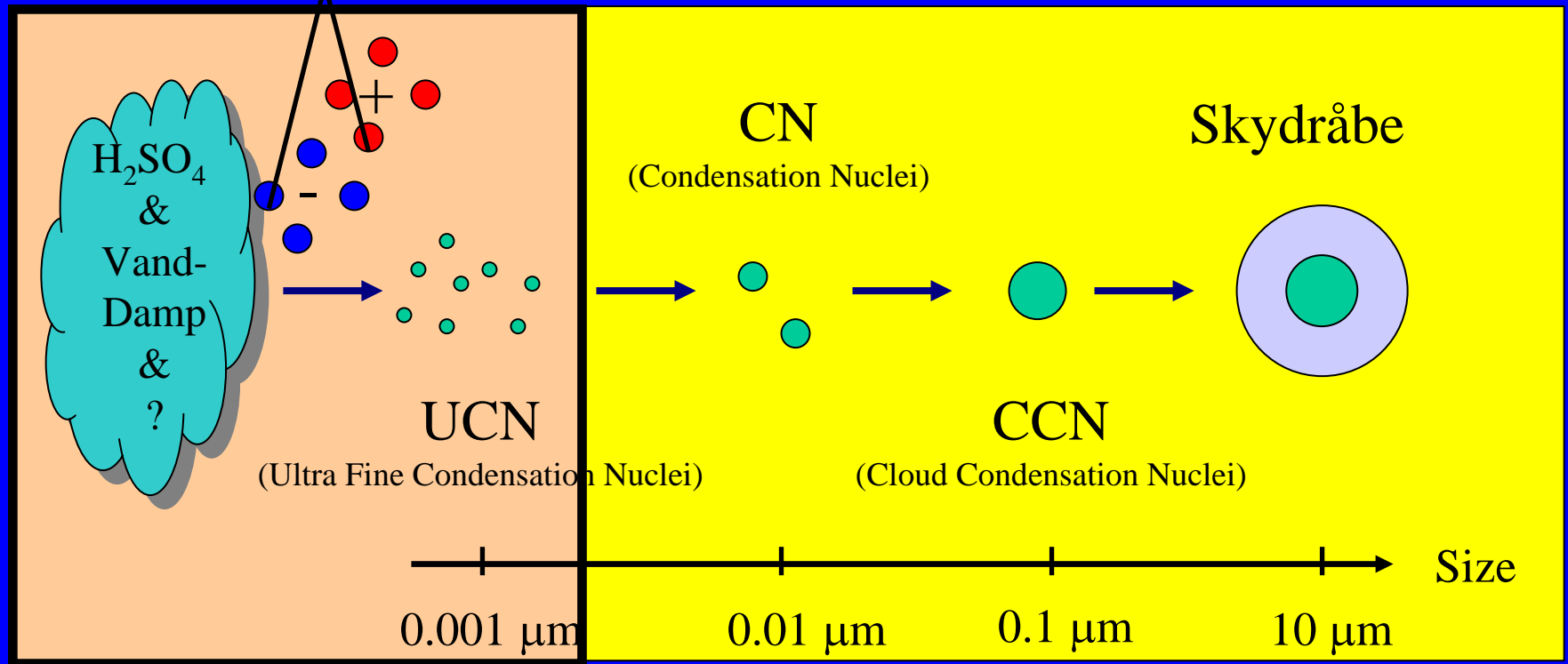
	High Clouds		Middle Clouds		Low Clouds	Total
	Thin	Thick	Thin	Thick	All	
Global Fraction %	10.1	8.6	10.7	7.3	26.6	63.3
Net Cloud Forcing Wm^{-2}	2.4	-7.0	1.1	-7.5	-16.7	-27.7

Dannelse af aerosoler



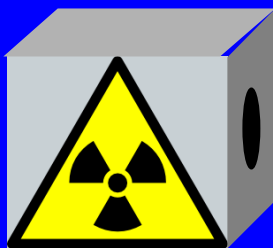
Dannelsen af små nye partikler er ikke forstået

Dannelse af aerosoler

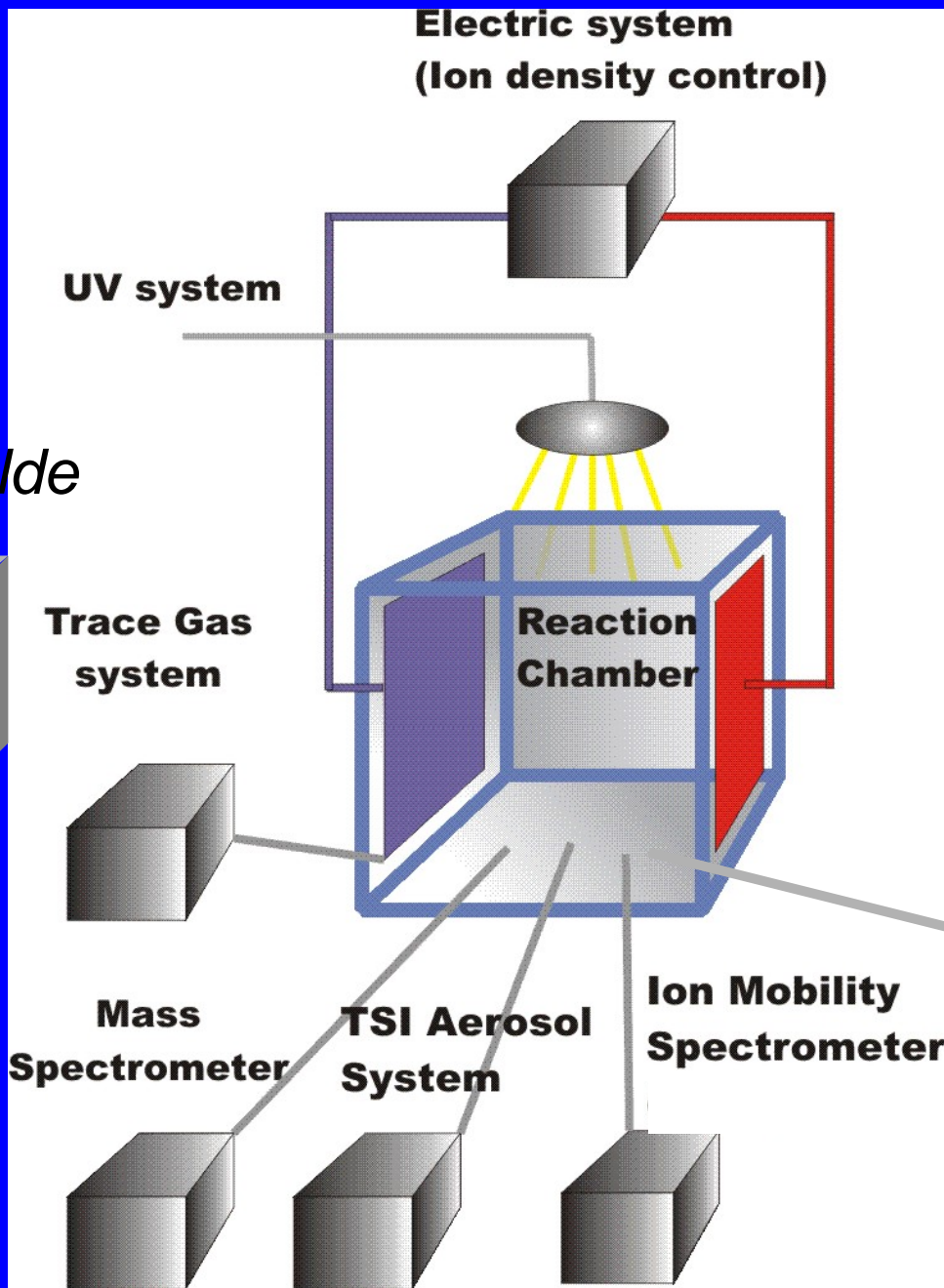


Betydningen af ioner?

Gamma Kilde



SO₂
O₃
H₂O



Gamma Kilde



*Muon detector
Radon detector*

Particle counter

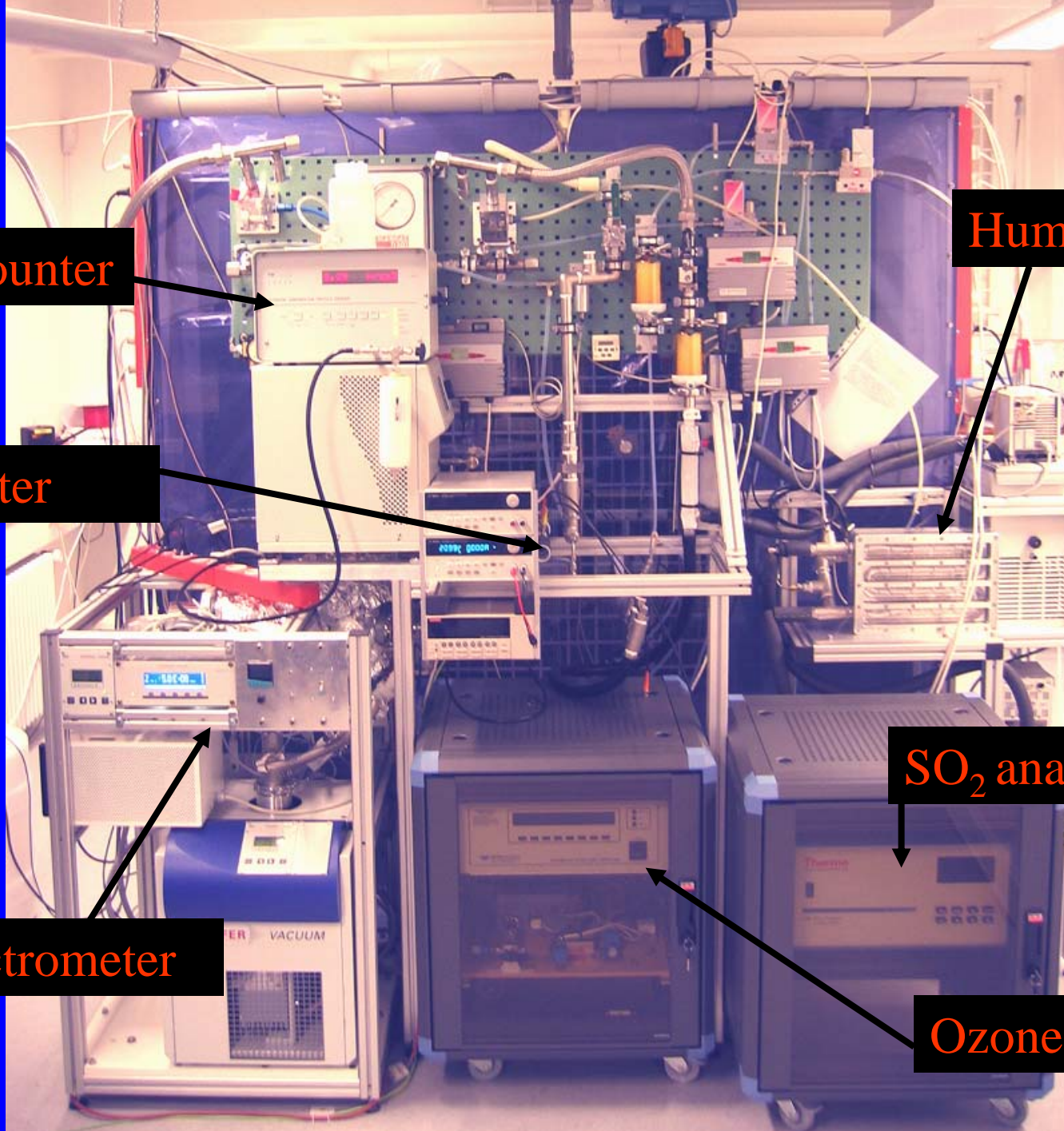
Ion counter

Humidifier

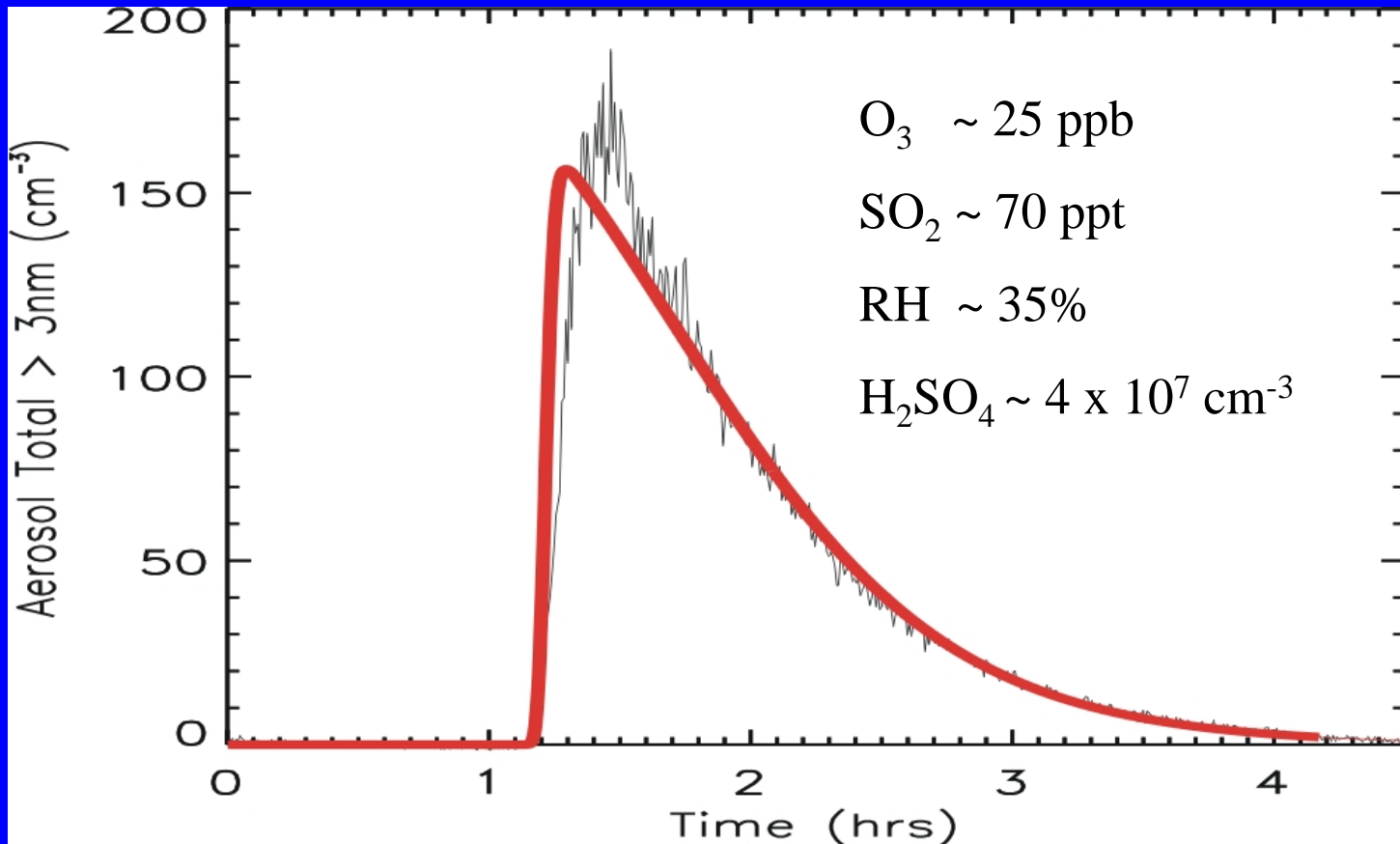
SO₂ analyzer

Mass spectrometer

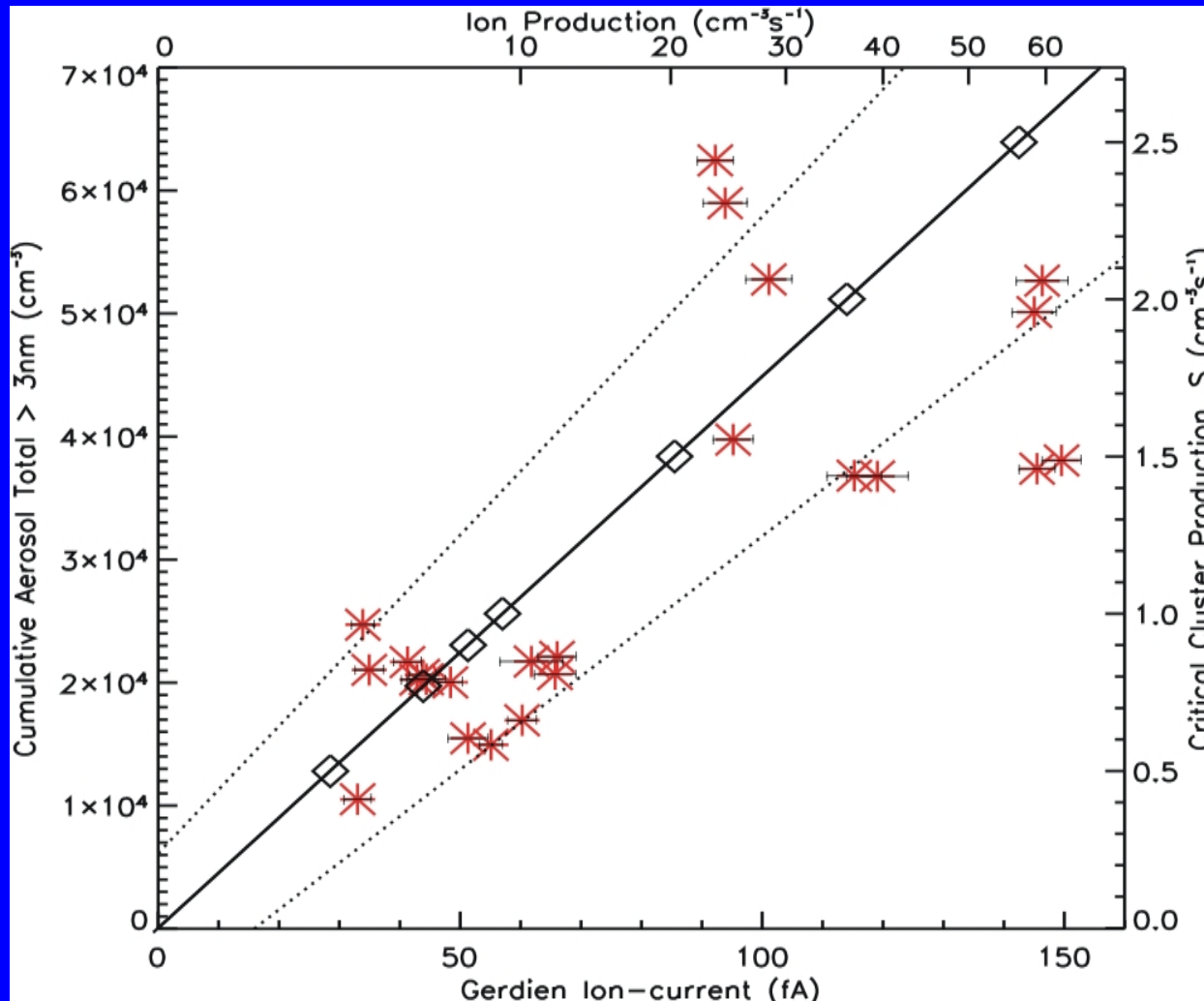
Ozone analyzer



Aerosol dannelselse efter UV belysning

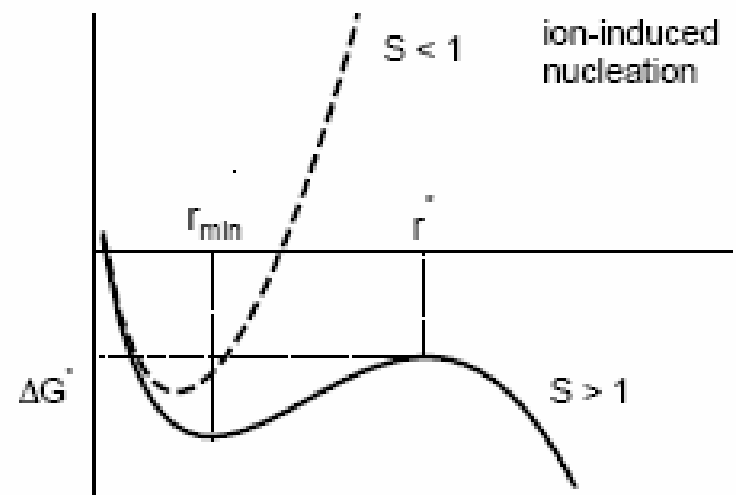
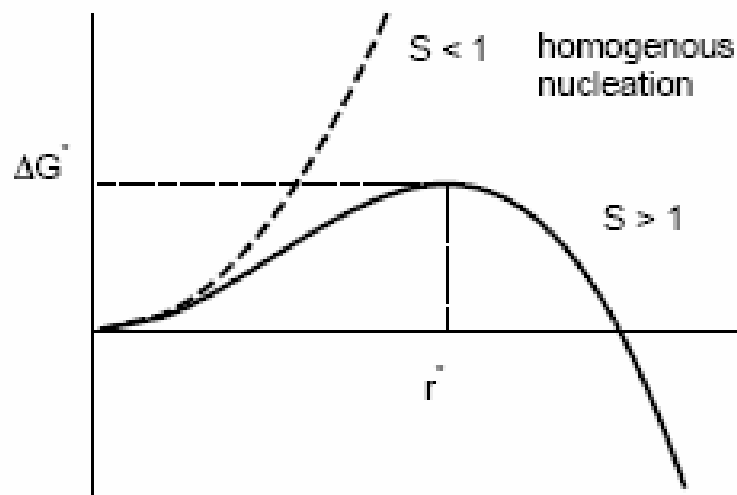


Aerosol dannelse og iontæthed



Svensmark, Pedersen, Marsh, Enghoff, Uggerhøj (2006)

Homogen og ion-induceret nukleation



Konklusioner

Partikler fra rummet ser ud til at påvirke Jordens klima på tidsskalaer fra år til mia. af år.

Mælkevejens histore kan være af betydning for Jordens udvikling

Det er ikke den eneste årsag til klimaændringer

Den fysiske mekanisme, der forbinder kosmiske stråler med klimaet er ikke forstået i detaljer

Observationer og eksperimenter tyder på, at mekanismen eksisterer og at den involverer ioner, små klynger samt skydannelse

Eksperiment ved CERN (afventer godkendelse i marts 2006)

CLOUD

Omkring 60 forskere
fra 10 lande

2006 Opbygning

2009 Første
eksperimenter

Sep/okt 2006 6 ugers
beamtid til
testeksperimenter

Forår 2007
yderligere 6 ugers
beamtid

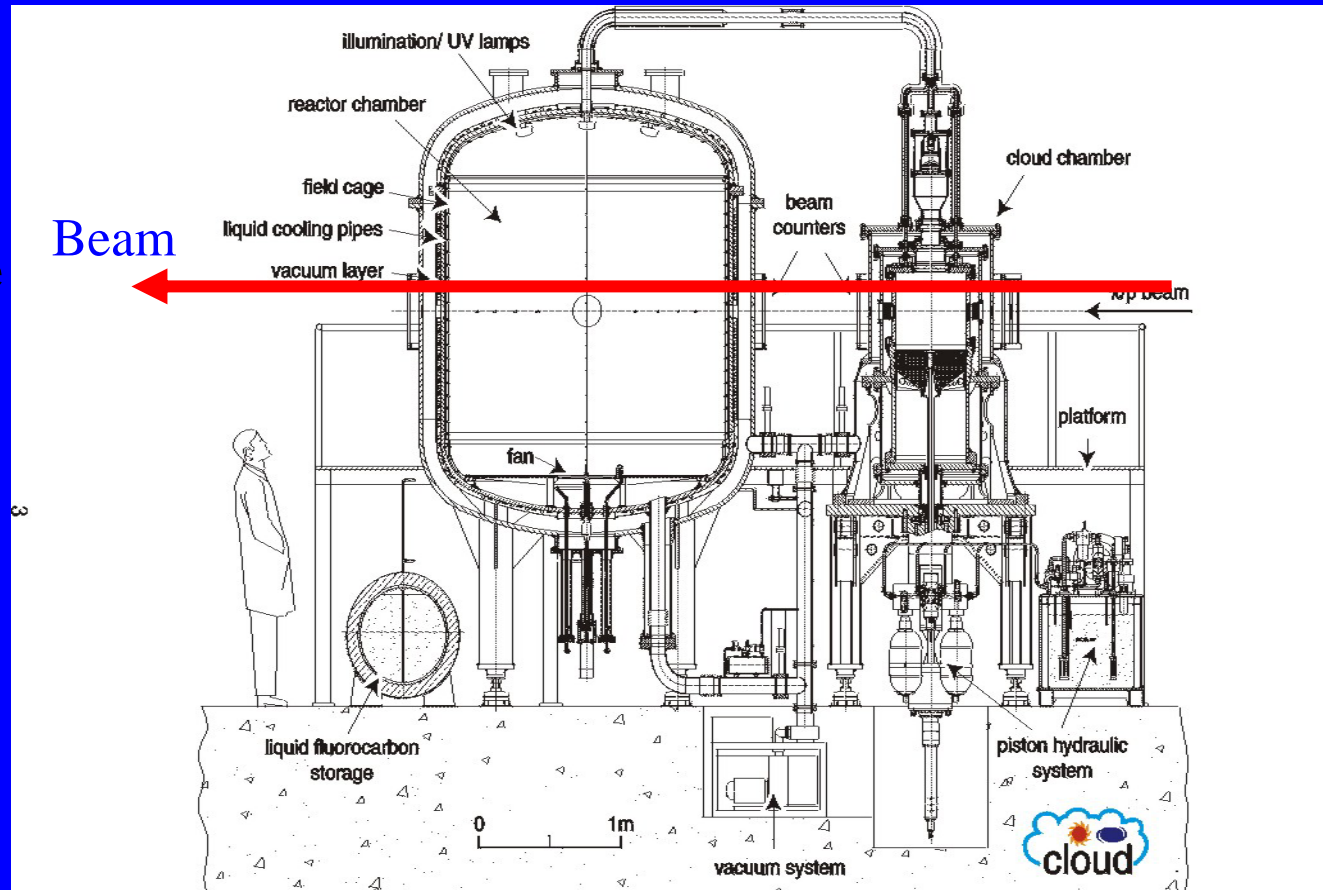


Figure 2: Vertical section showing the cloud chamber and the new reactor chamber. The latter combines the functions of the original buffer expansion tank and flow reactor chamber, and replaces them.

Medarbejdere:

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Sun-Climate Research