Cosmo-Climate-Connection System

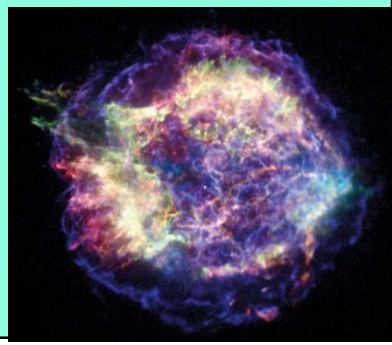
The Earth is a System Open to the Universe.

radiation
(visible light
UV, X-ray)

plasma
(solar wind)

cosmic ray

How is the impact to
weather and climate?

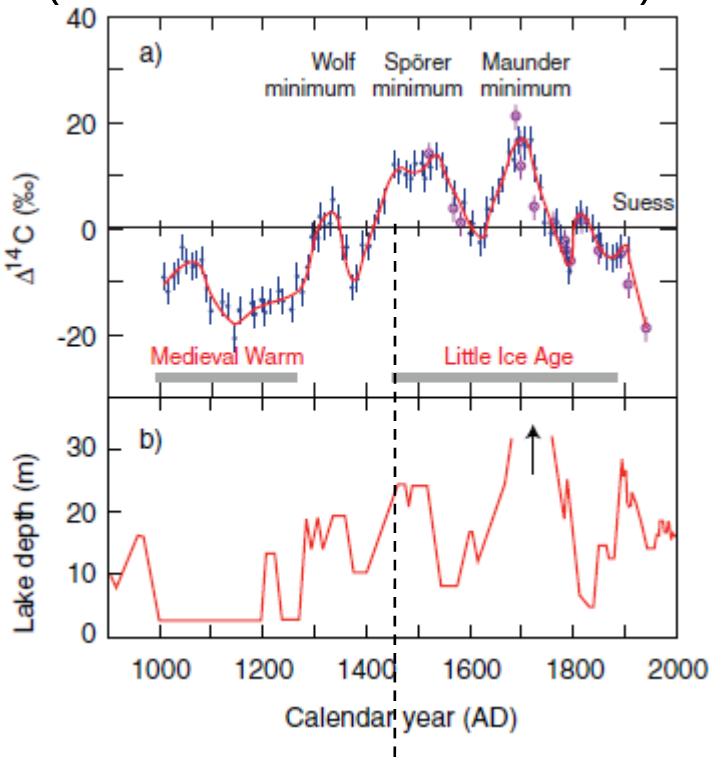


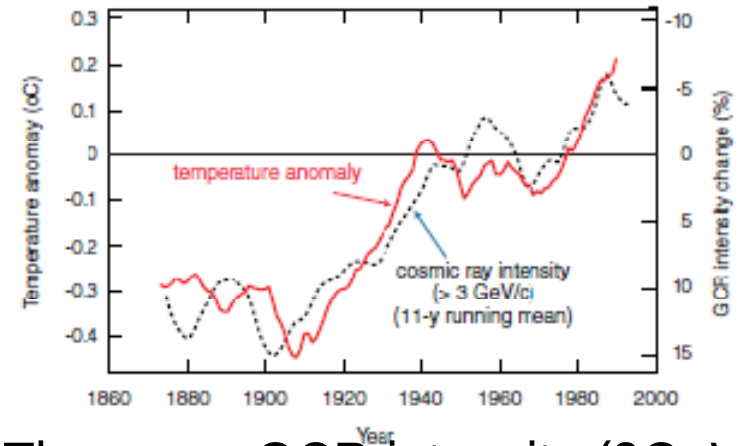
Outline

- Introduction
  - examples of the cosmic and climate connection
  - possible mechanisms
- Cosmic Ray – Cloud connection
  - correlative analyses
  - impact to climate
  - cloud microphysics
- A Future Plan
  - Hierarchical climate model @ the Earth Simulator
- Summary

Correlation b/w GCR and Climate

14C from tree-ring analyses for the last millennium
and the reconstructed depth of Crescent Island Crater Lake
(Verschuren et al. 2000 Nature)





The mean GCR intensity (3GeV/c cutoff, 11y running mean) & SST

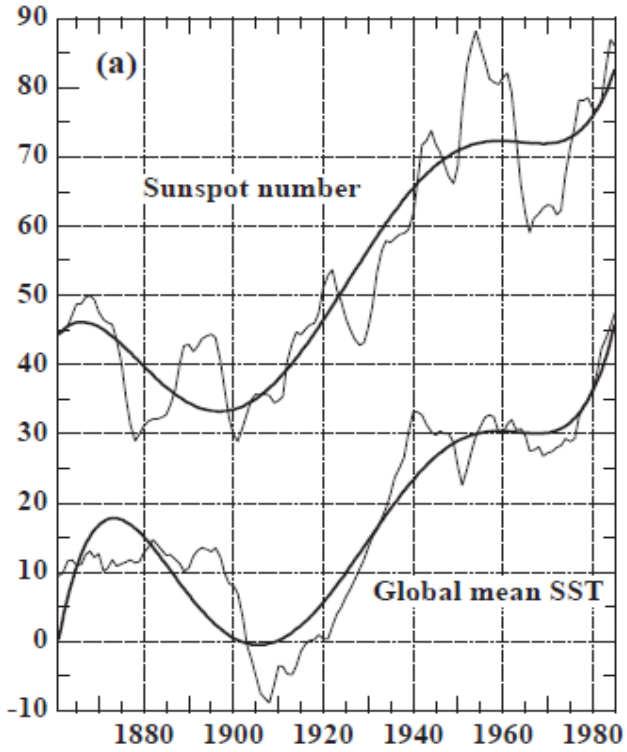
応仁の乱 (the war of Ohnin)
1467-1477

Cosmic ray & Sunspots & Climate

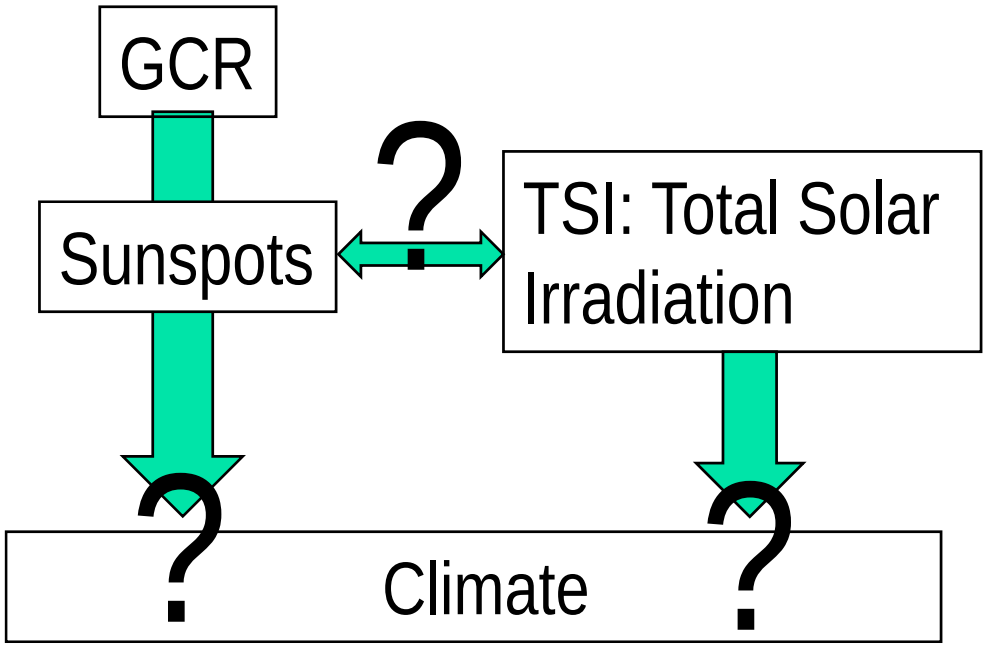
- long-standing issue : William Herschel (1738-1822) suggested that greater sunspot activity would result in warmer earth climates.

William Herschel
1738-1822

Relationship b/w Sunspot and SST
（Reid 2000 Space Sci. Rev.）

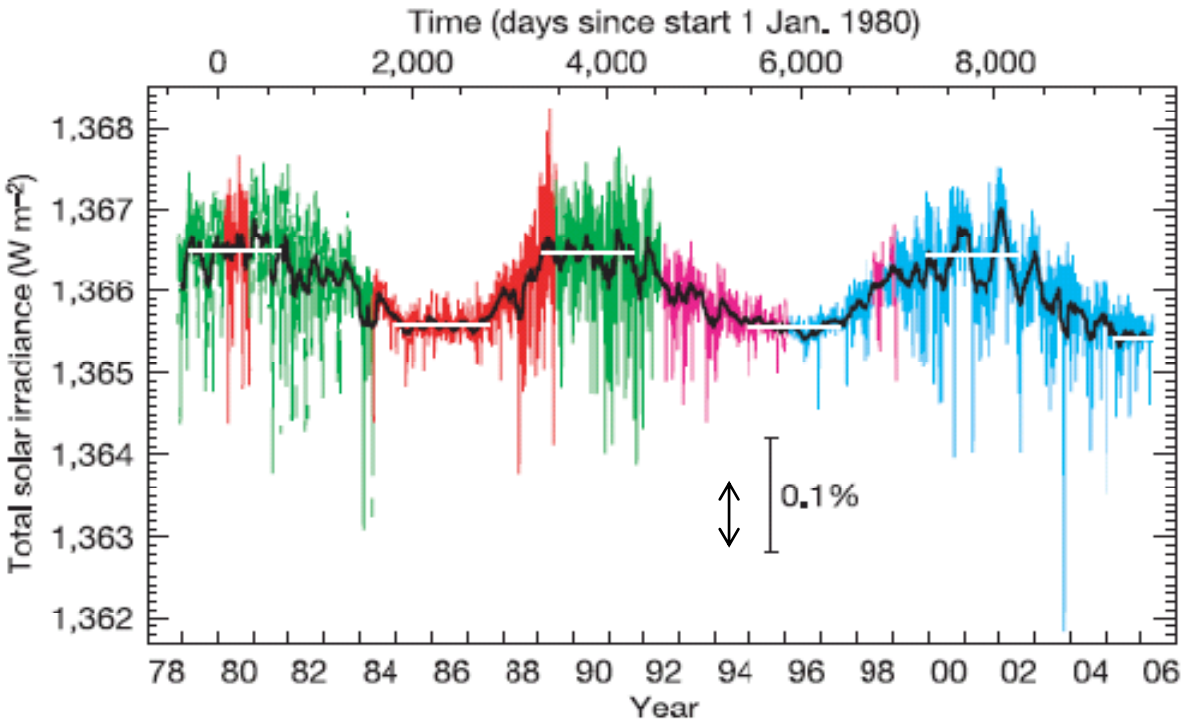


possible mechanisms



Variation in Solar Luminosity

- Foukal et al. (2006, Nature): Variation in the Sun's total luminosity are caused by changing dark (sunspots) and bright (faculae) structures on the solar disk during the 11-year sunspot cycle. The variations are too small to have contributed appreciably to accelerated global warming over the past 30 years.

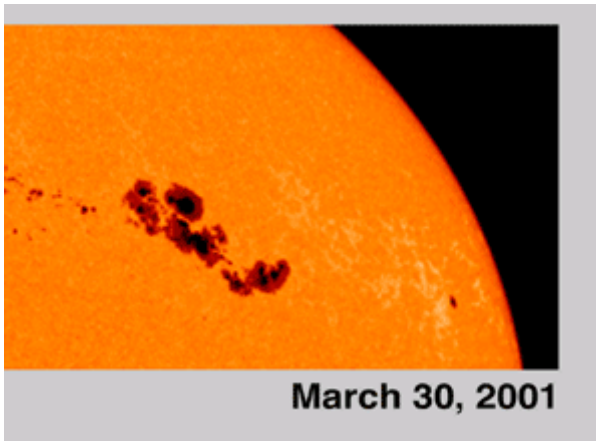


simple black body model

$\delta T/T = \delta I/4I$

$\delta T \sim 6 \times 10^{-4} \times 288/4$

$= 0.04K$ (too small)



GCR & Global Cloud Cover

- Svensmark & Friis-Christensen (1997 JASTP); Marsh & Svensmark (2000, PRL)
- Cloud: International Satellite Cloud Climatology Project (IR detector, global monthly average)
- Cosmic Ray: neutron counts observed at Huancayo (cuttoff rigidity 12.91 GeV)

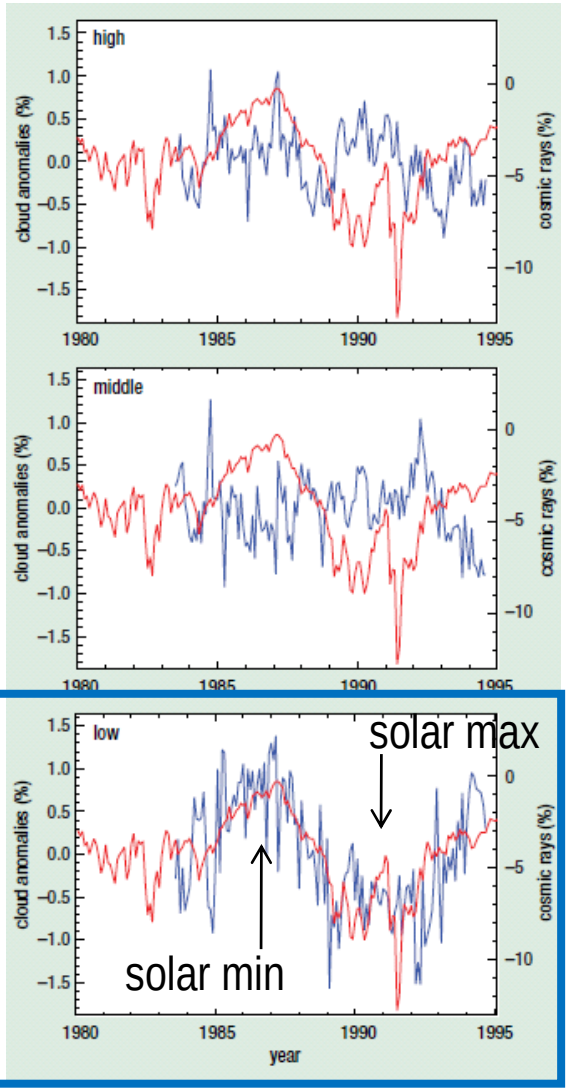
high

440hPa (6.5km)

middle

680hPa (3.2km)

low

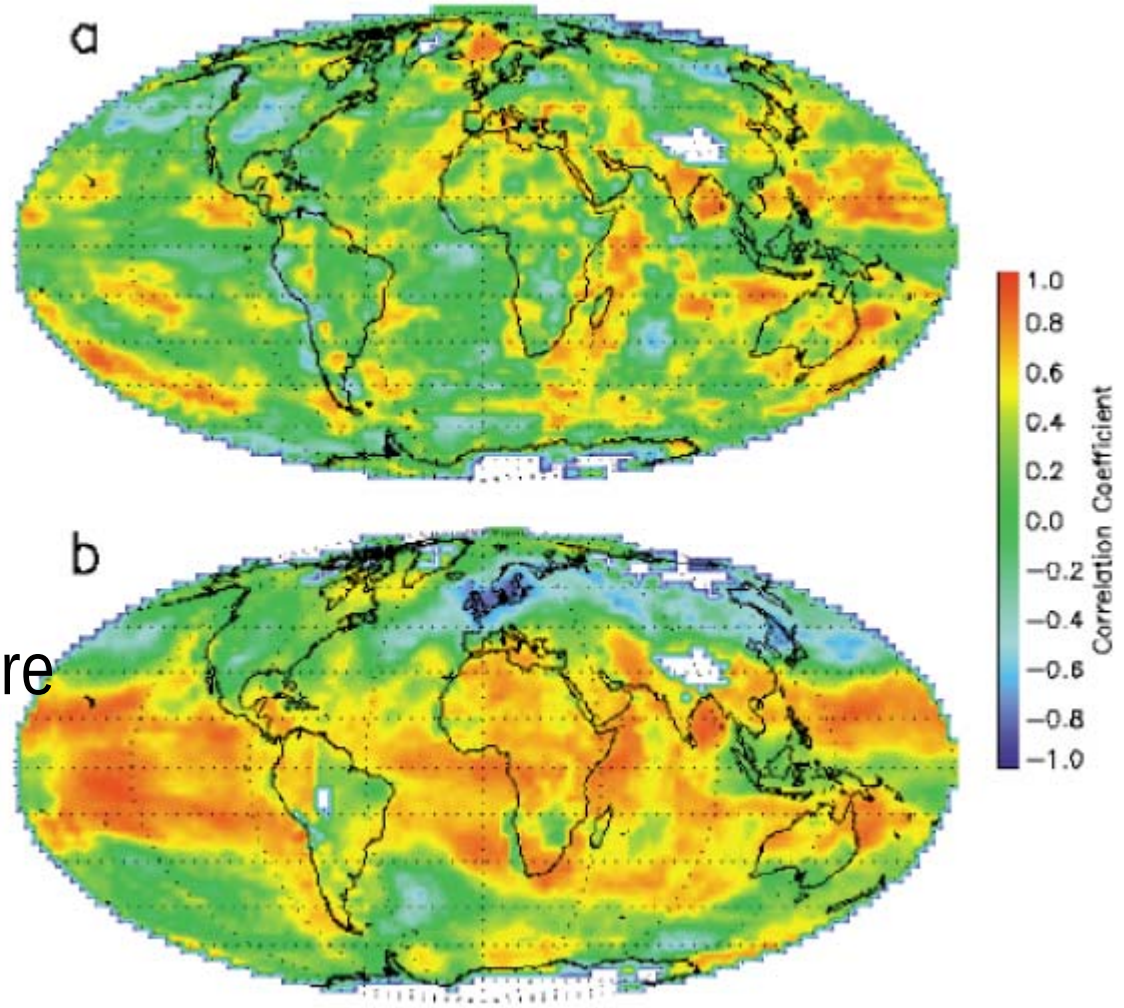


good correlation b/w GCR & low cloud

Correlation Maps: GCR & low Cloud

GCR & cloud cover correlated mainly in Ocean

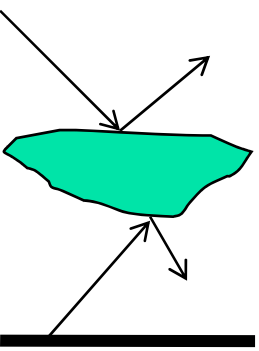
GCR & cloud temperature correlated mainly in Tropics



Radiative Forcing due to Clouds

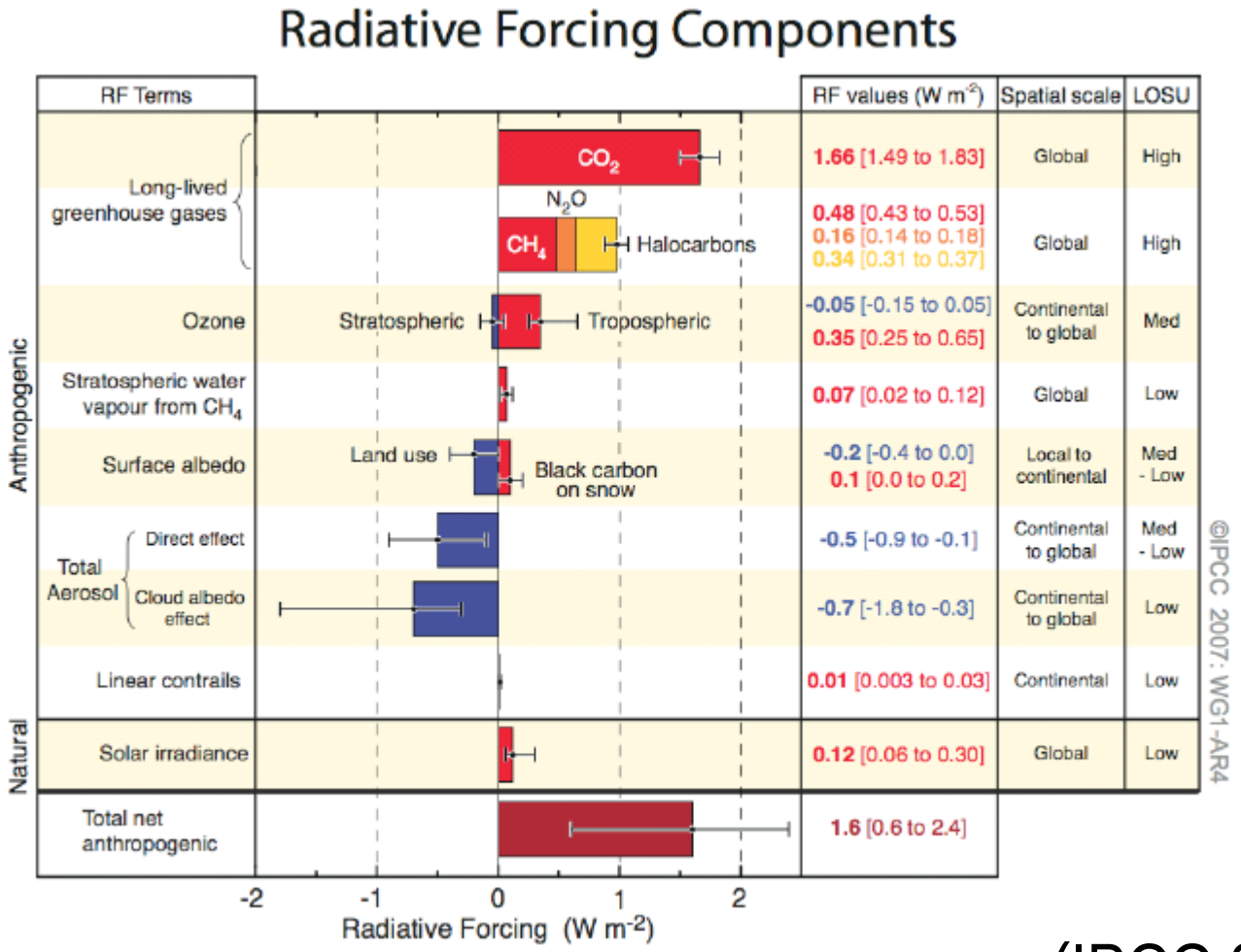
- low cloud cover variation ~ 1.7% (absolute)
  ~ 6% to low cloud
- forcing change ~ 6%x17W/m^2 ~ -1W/m^2

Table 1: Global annual mean forcing due to various types of clouds, from the Earth Radiation Budget Experiment (ERBE) [21].



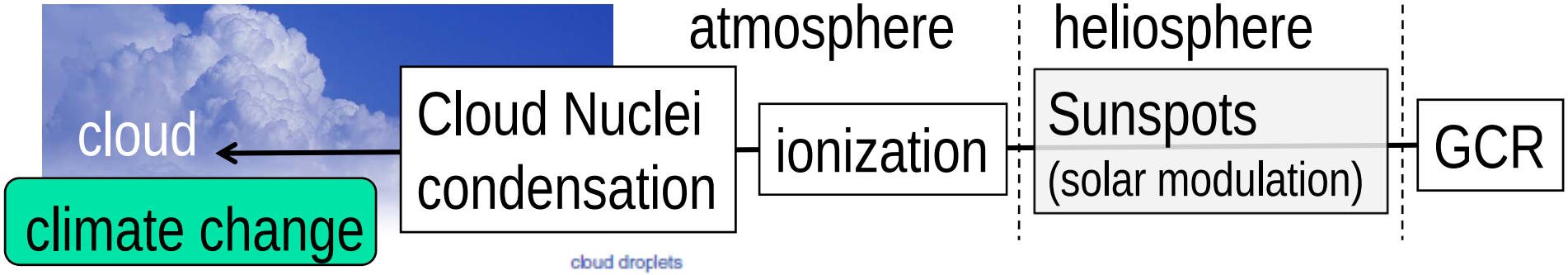
Parameter		High clouds		Middle clouds		Low clouds	Total
		Thin	Thick	Thin	Thick	All	
Global fraction	(%)	10.1	8.6	10.7	7.3	26.6	63.3
Forcing (relative to clear sky):							
Albedo (SW radiation)	(Wm^{-2})	-4.1	-15.6	-3.7	-9.9	-20.2	-53.5
Outgoing LW radiation	(Wm^{-2})	6.5	8.6	4.8	2.4	3.5	25.8
Net forcing	(Wm^{-2})	2.4	-7.0	1.1	-7.5	-16.7	-27.7

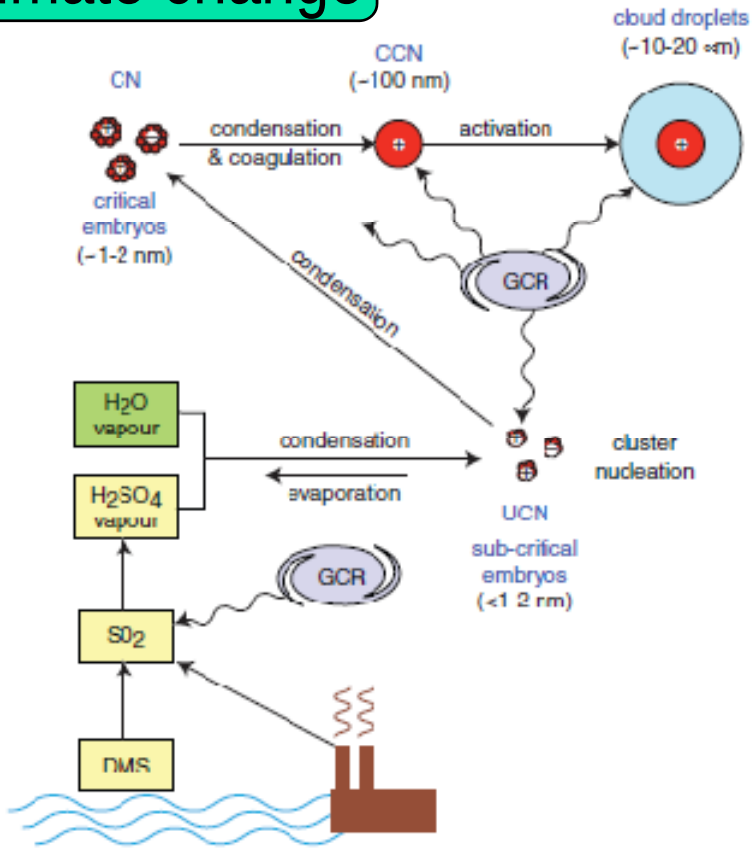
Anthropogenic Radiative Forcing

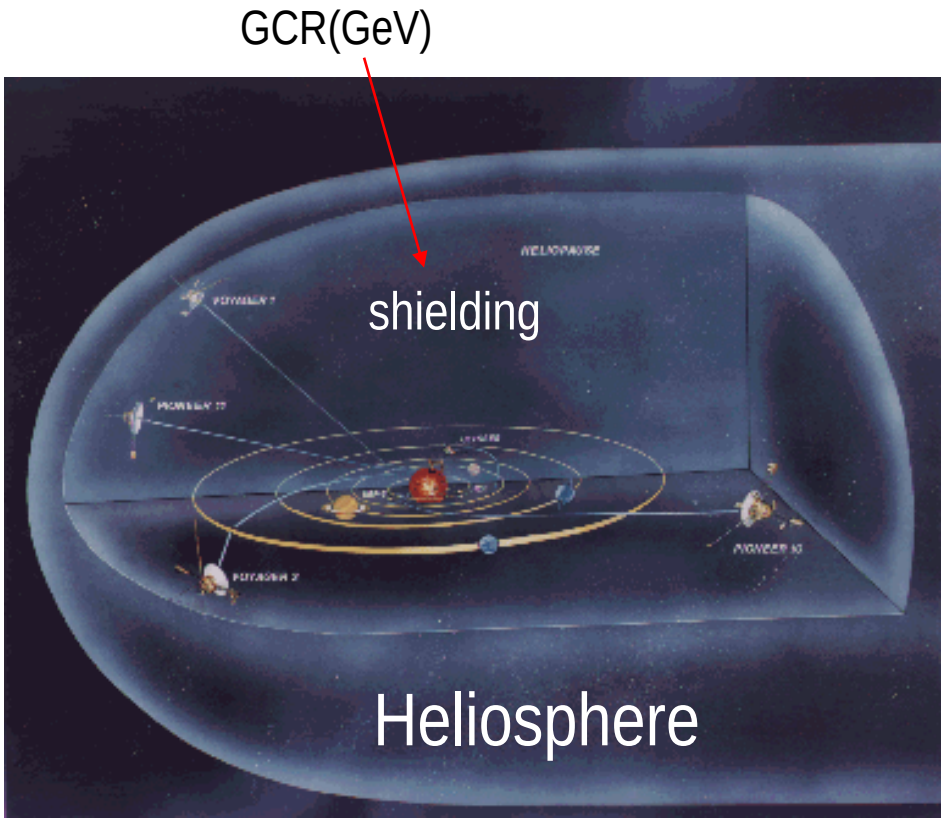


(IPCC 2007)

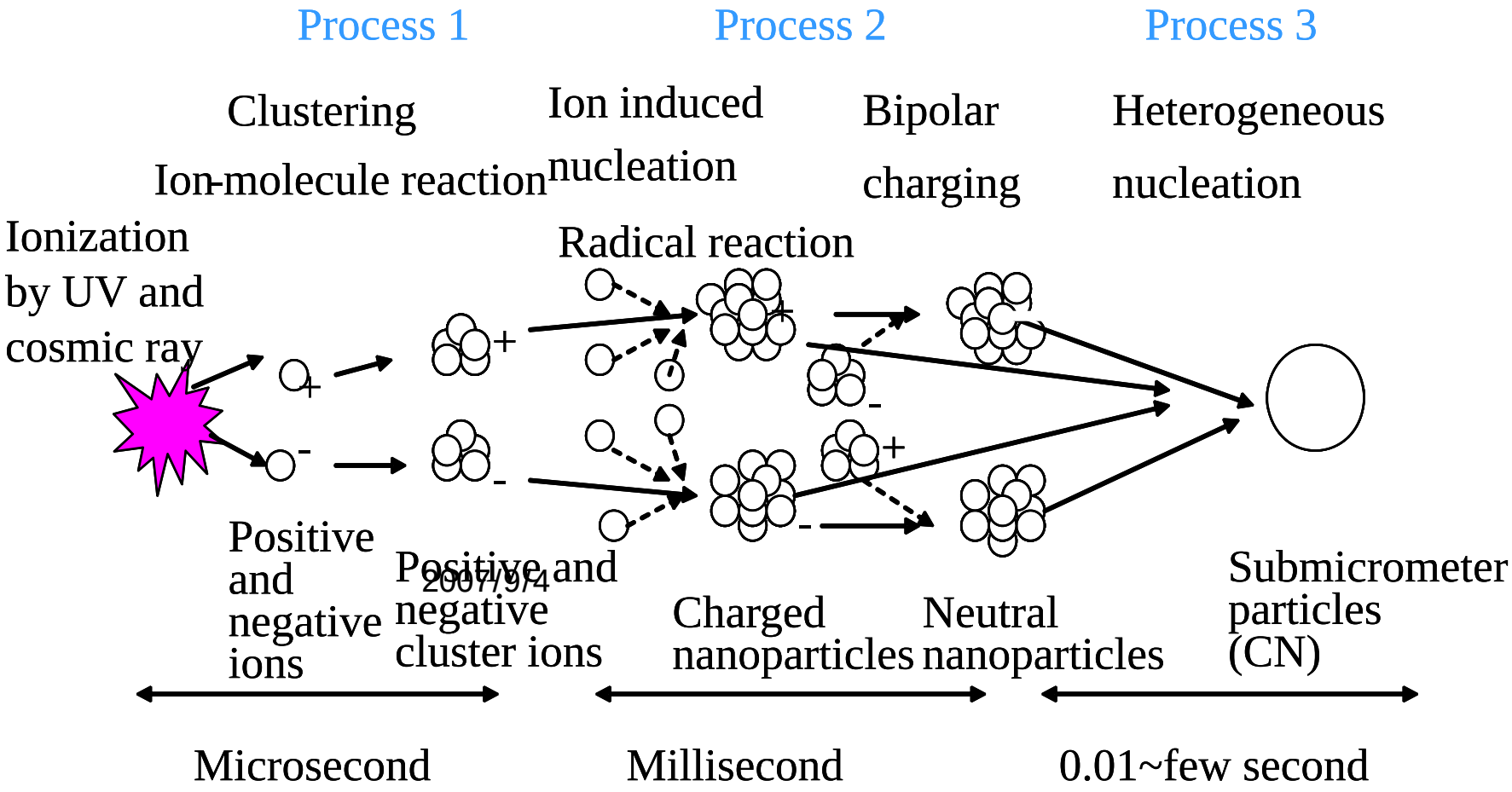
Cosmic Ray-Cloud Connection Hypothesis





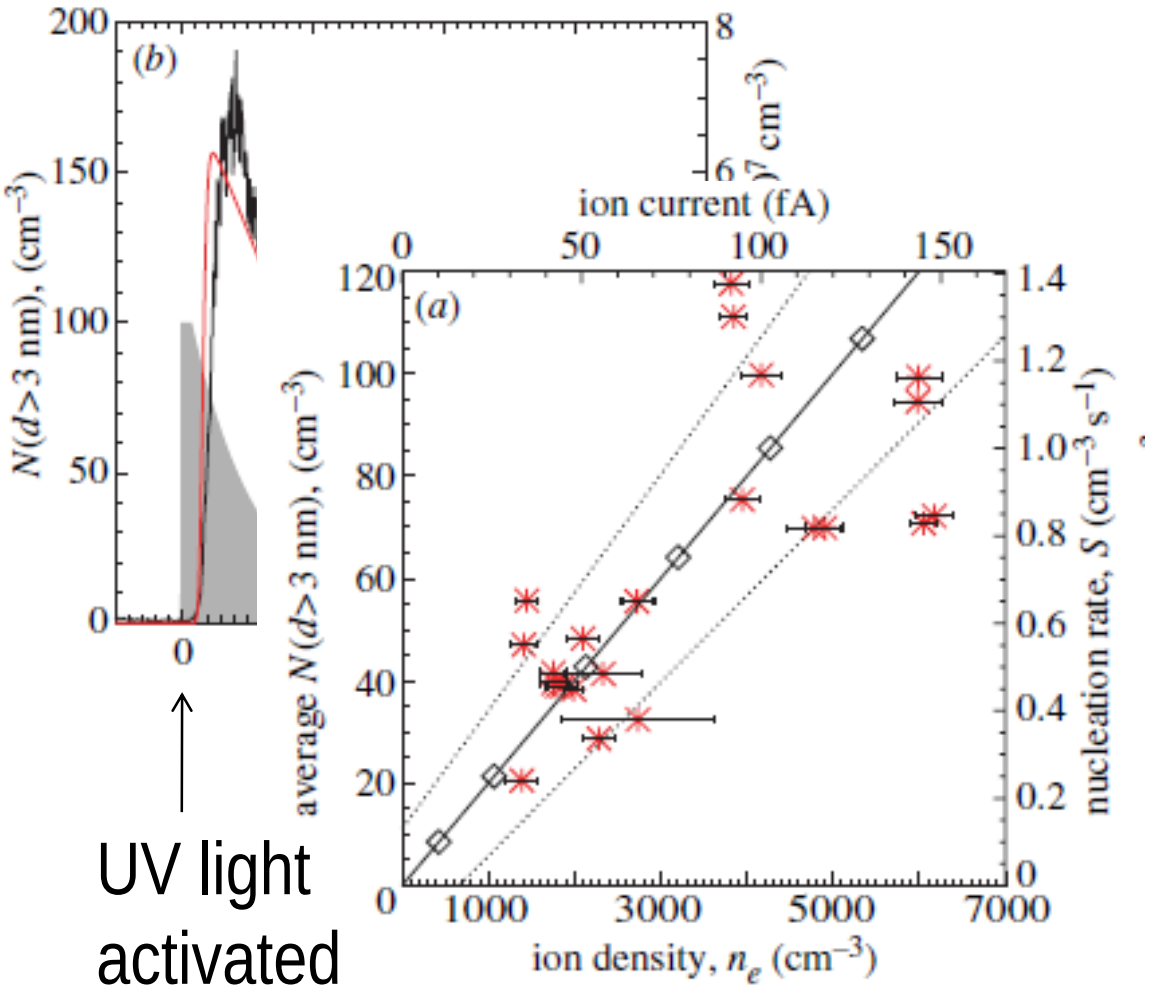


Ion Mediated Nucleation Model



Experiments of Ion Mediated Condensation

- Svensmark et al. (2007)



UV light activated

UV light (photo-ionizing)

fresh air
H_2O, O_3, SO_2
(gases)

H_2SO_4 (liquid)
condensation?

reactive chamber

CLOUD Experiments at CERN

- study of the effects of relativistic ionizing particles on cloud microphysics (Kirkby)

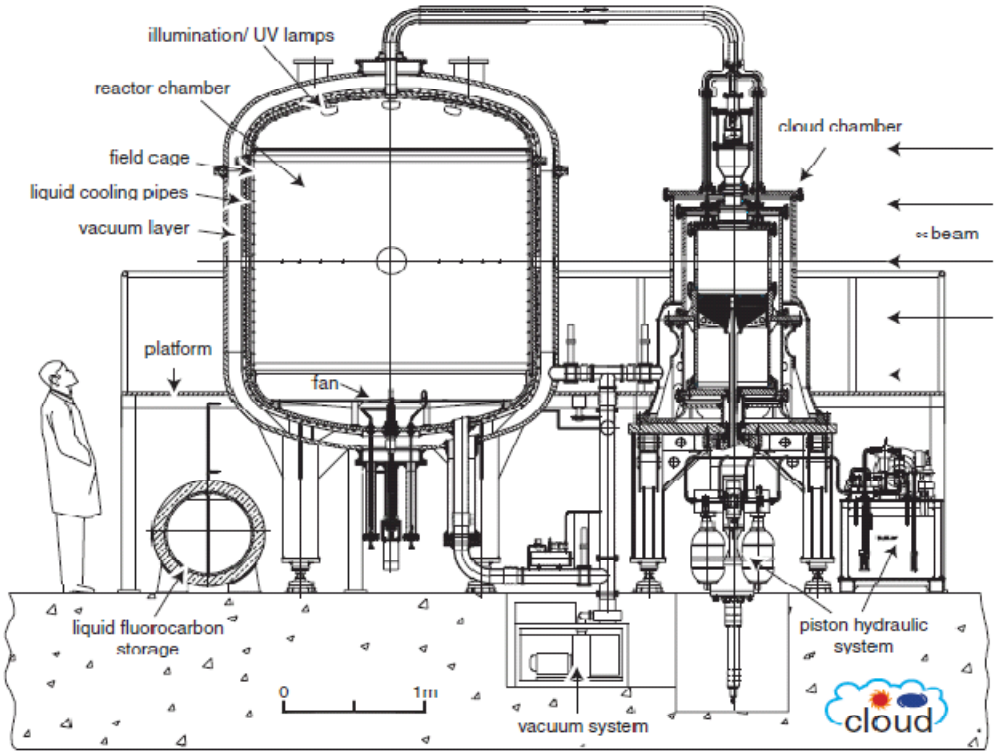
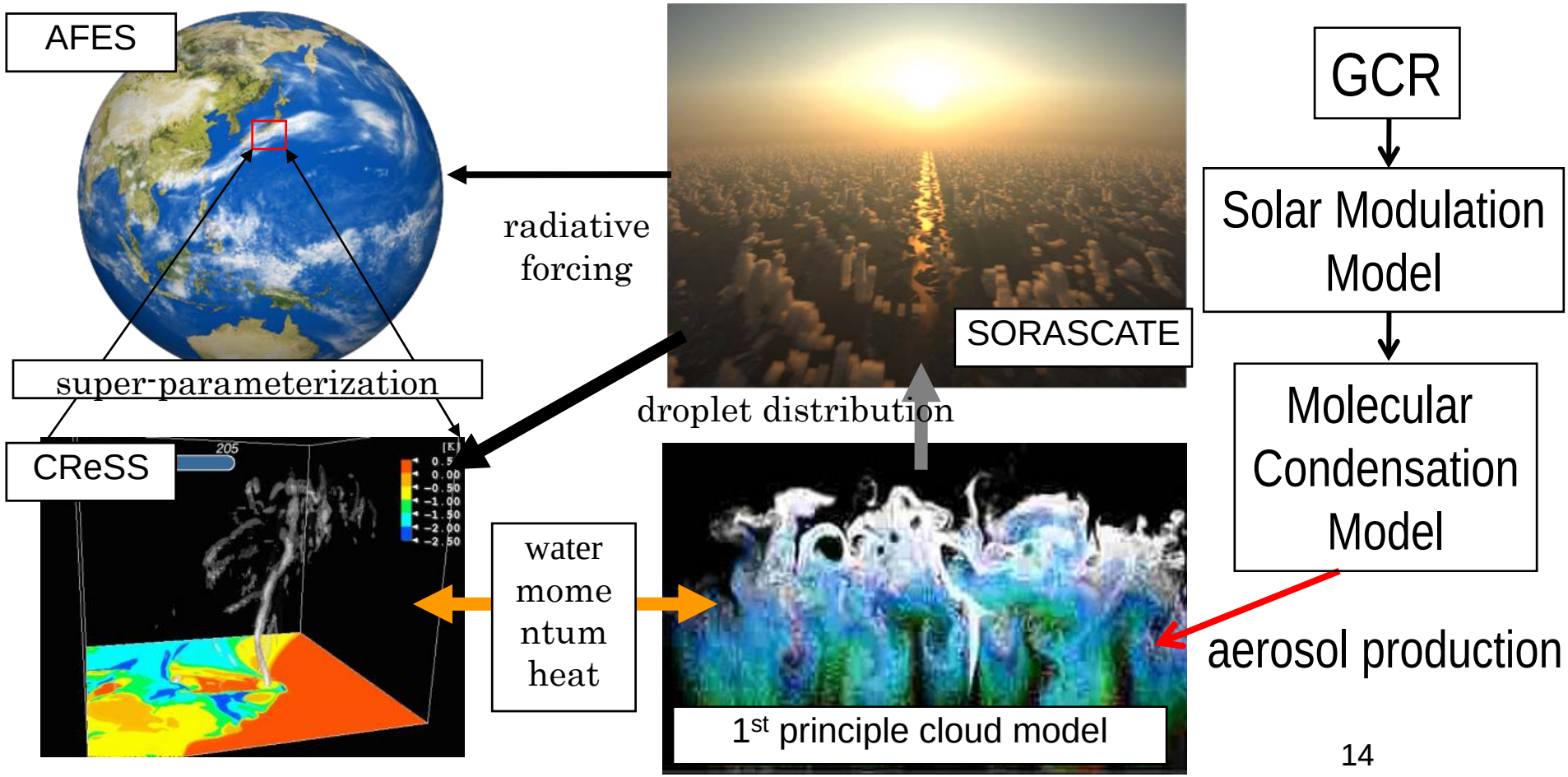


Fig. 43: Vertical section through the CLOUD facility showing the 0.5 m cloud chamber and 2 m reactor chamber. The beam counters are not shown.

2006 press release
2007 prototype data
2010 first beam data

GCR-Climate Connection Model

- The Earth Simulator Center plans to develop a new type of hierarchical climate model.



Fluid-Particle Cloud Model

Navier-Stokes eq.

$$\rho \frac{D\vec{\mathbf{v}}}{Dt} = -\nabla P - (\rho + \rho_w)\vec{\mathbf{g}} + \lambda\rho\nabla^2\vec{\mathbf{v}},$$

momentum

$$P = \rho R_d T,$$

$$\frac{D\theta}{Dt} = -\frac{L}{c_p \Pi} S_v + \kappa\nabla^2\theta,$$

heat

$$\frac{D\rho}{Dt} = -\rho\nabla\cdot\vec{\mathbf{v}},$$

$$\frac{Dq_v}{Dt} = S_v.$$

vapor

Particle in Cell

Super-Droplet Method

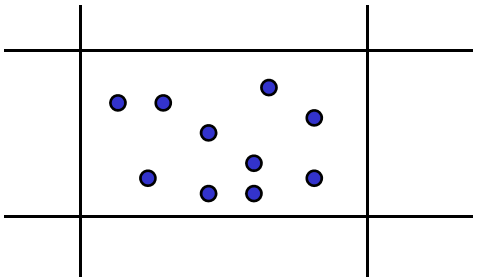
$\vec{u} = \vec{u}_t(M, g, \vec{v})$ Köhler curve

$$R\dot{R} = \left\{ S - (1 + \frac{a}{R} - \frac{b}{R^3}) \right\} / (F_k + F_d)$$

$$S_v = \sum_i 4\pi R_i^2 \dot{R}_i \rho$$

MC ⇒ collision

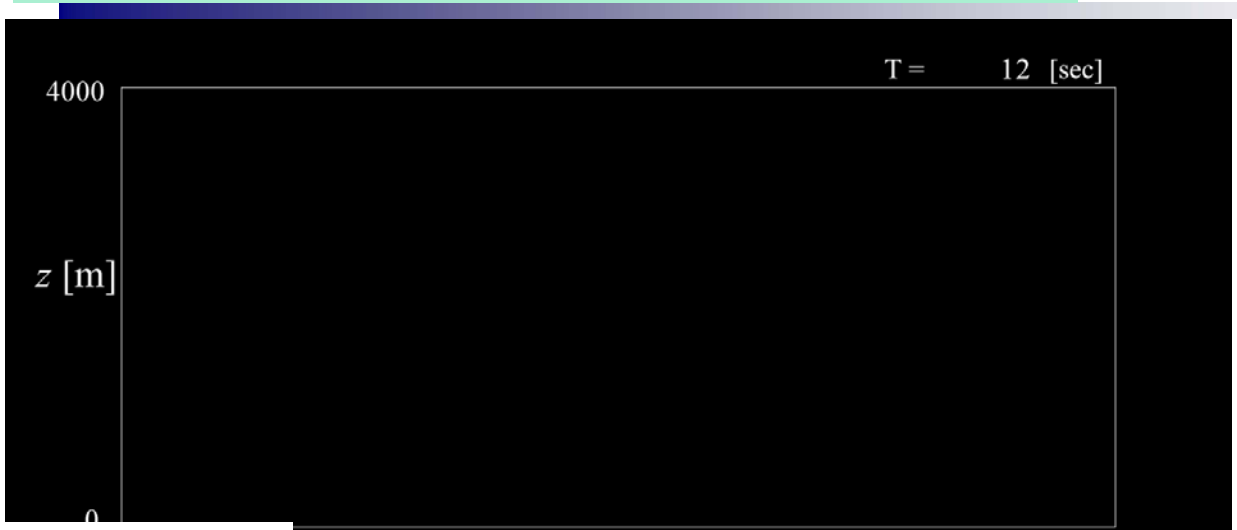
fluid for atmospheric variables



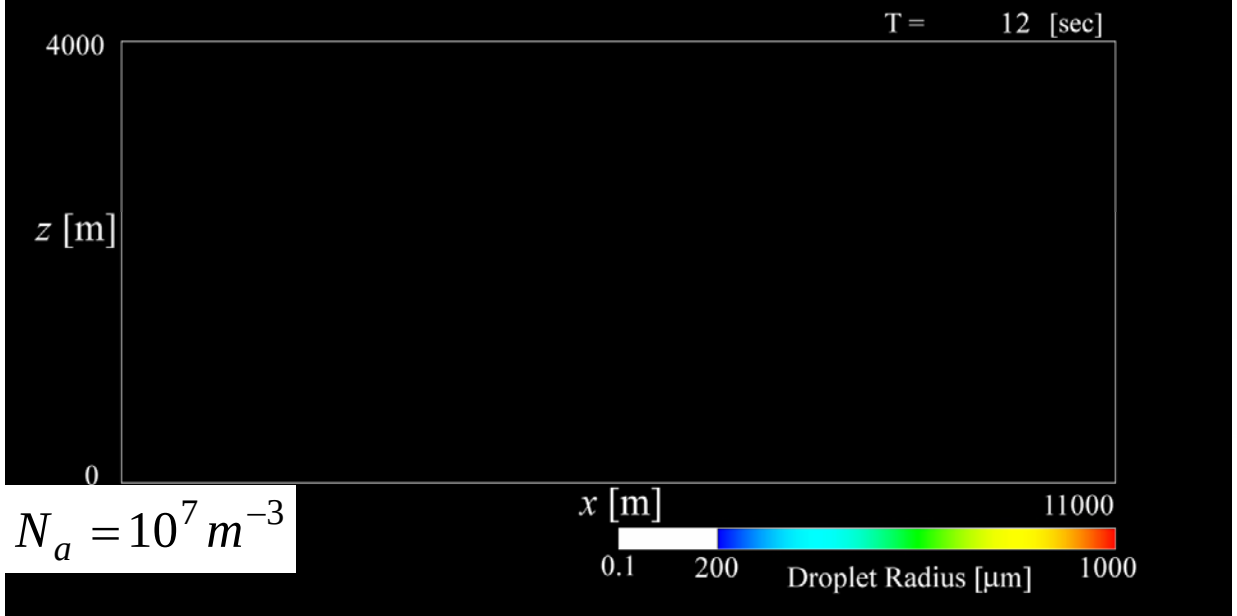
particles for aerosol and droplet

Cloud lifetime and precipitation are sensitive to the number of aerosol.

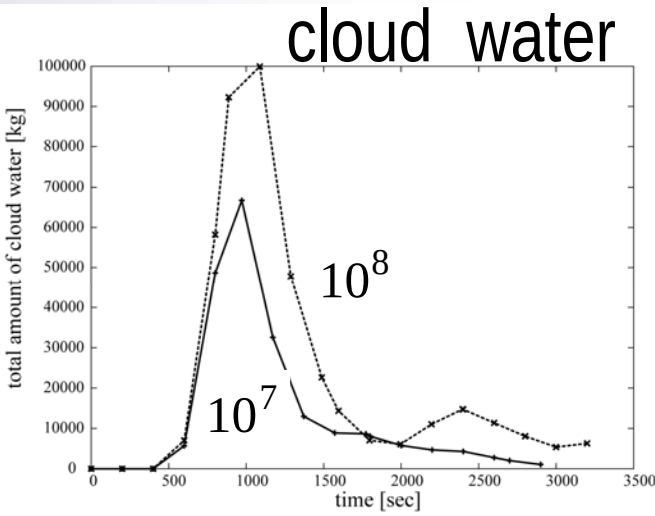
& Precipitation

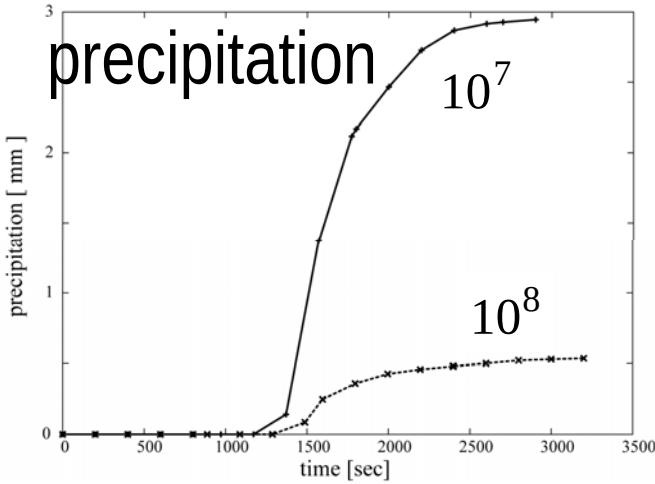


$N_a = 10^8\, m^{-3}$



$N_a = 10^7\, m^{-3}$





time(sec)

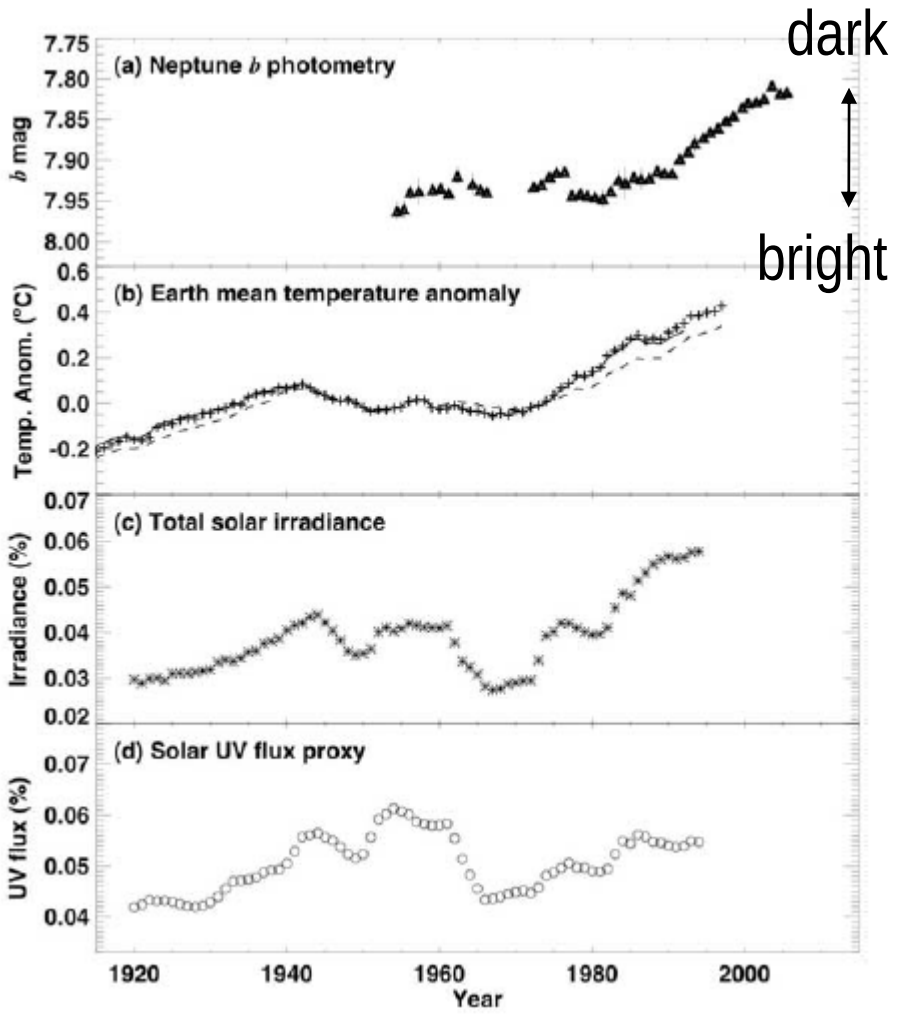
Summary

- There are several evidences, which indicate the correlation b/w the GCR intensity and the climate proxies.
- Recently, it was found that GCR may be correlated with the low cloud cover mainly in ocean.
- The ion mediated nucleation (IMN) of CCN is a possible explanation of the GCR-cloud connection.
- CLOUD experiment at CERN has been started to examine the IMN mechanism.
- In the Earth Simulator Center, a new simulation work project is now planned to reveal the causal relationship b/w GCR and climate.

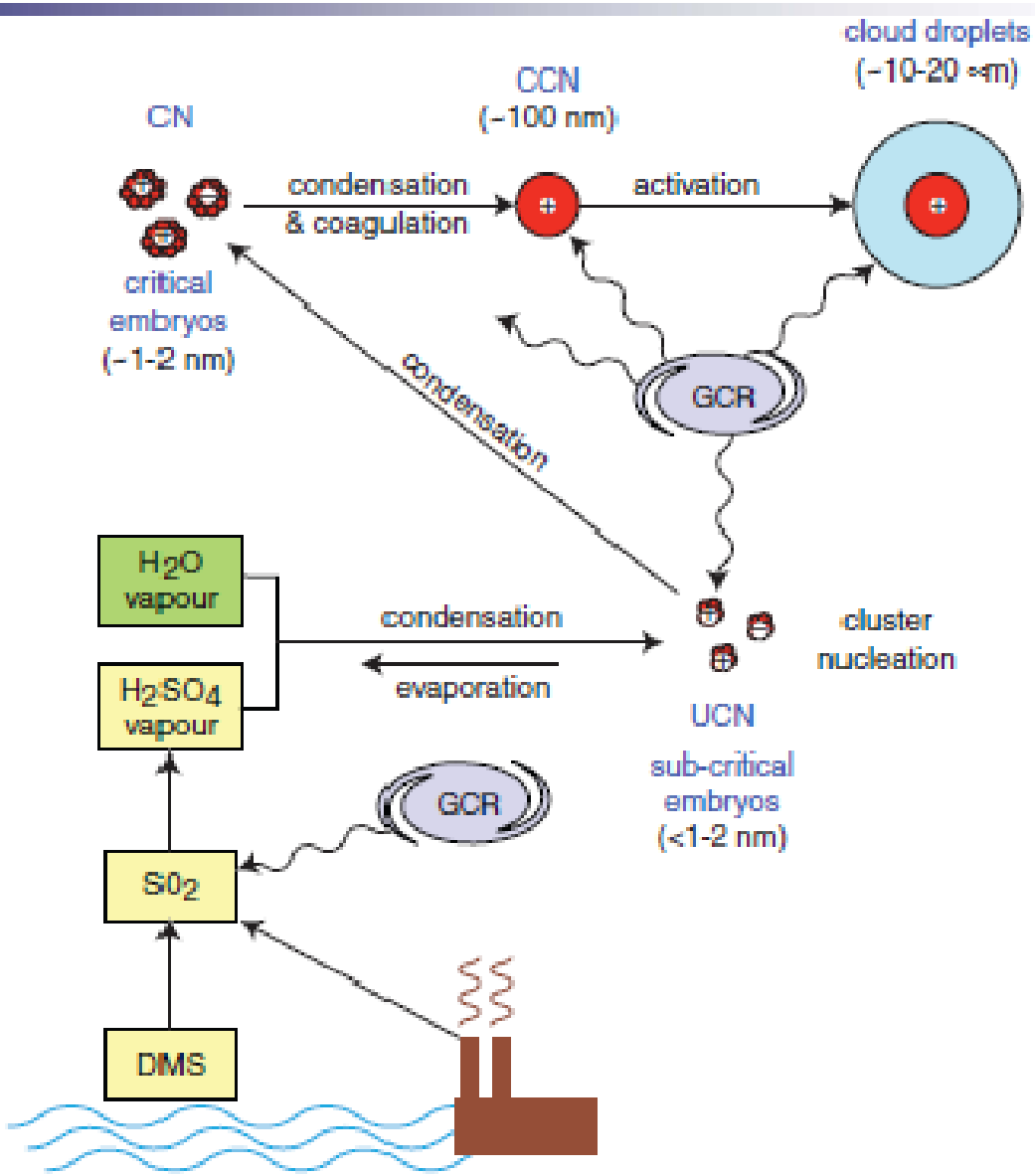
Earth and Neptune Climate

- Hammel and Lockwood 2007

If changing brightness and temperatures of two different planets are correlated, then some planetary climate changes may be due to variations in the solar system environment.



Ionization Mediated Condensation



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