Mechanism Linking Solar Activity and Climate

Cosmic rays and clouds

Henrik Svensmark, DTU Space

In collaboration with

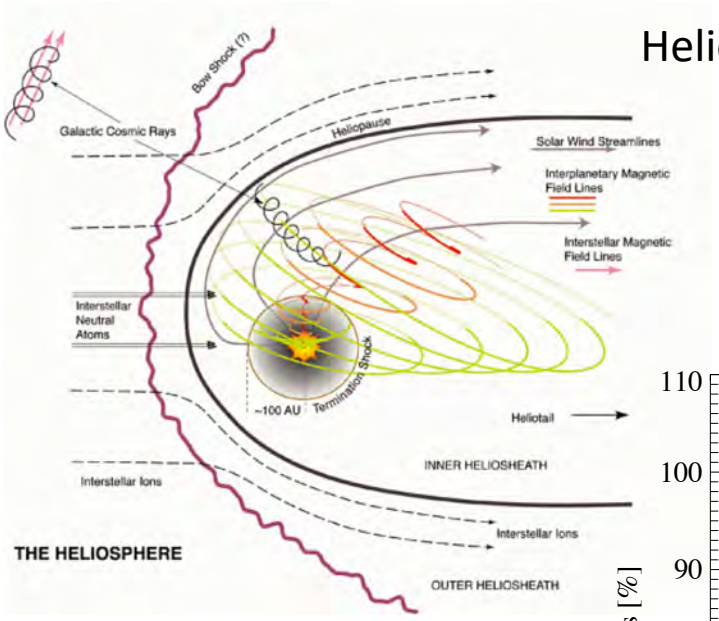
Martin Enghoff, Nir Shaviv, Jacob Svensmark

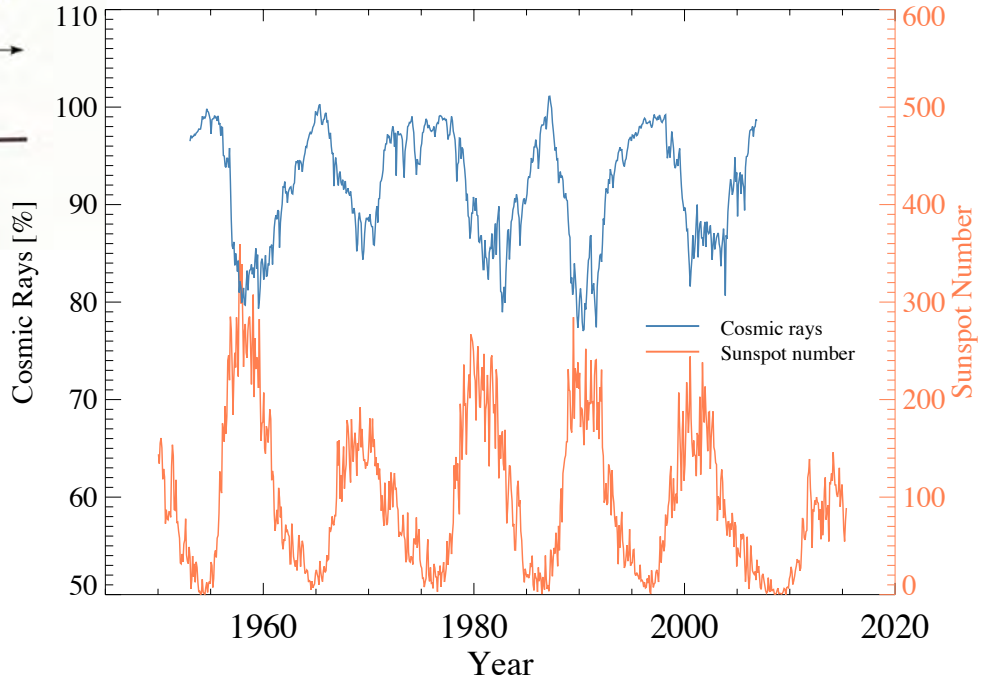
Mechanism Linking Solar Activity and Climate
Cosmic rays and clouds

- Cosmic rays and clouds
- Physical mechanism between ionization and cloud formation
- Further empirical evidence

Supernova explosions happens for heavy stars (> $8M_{sun}$)

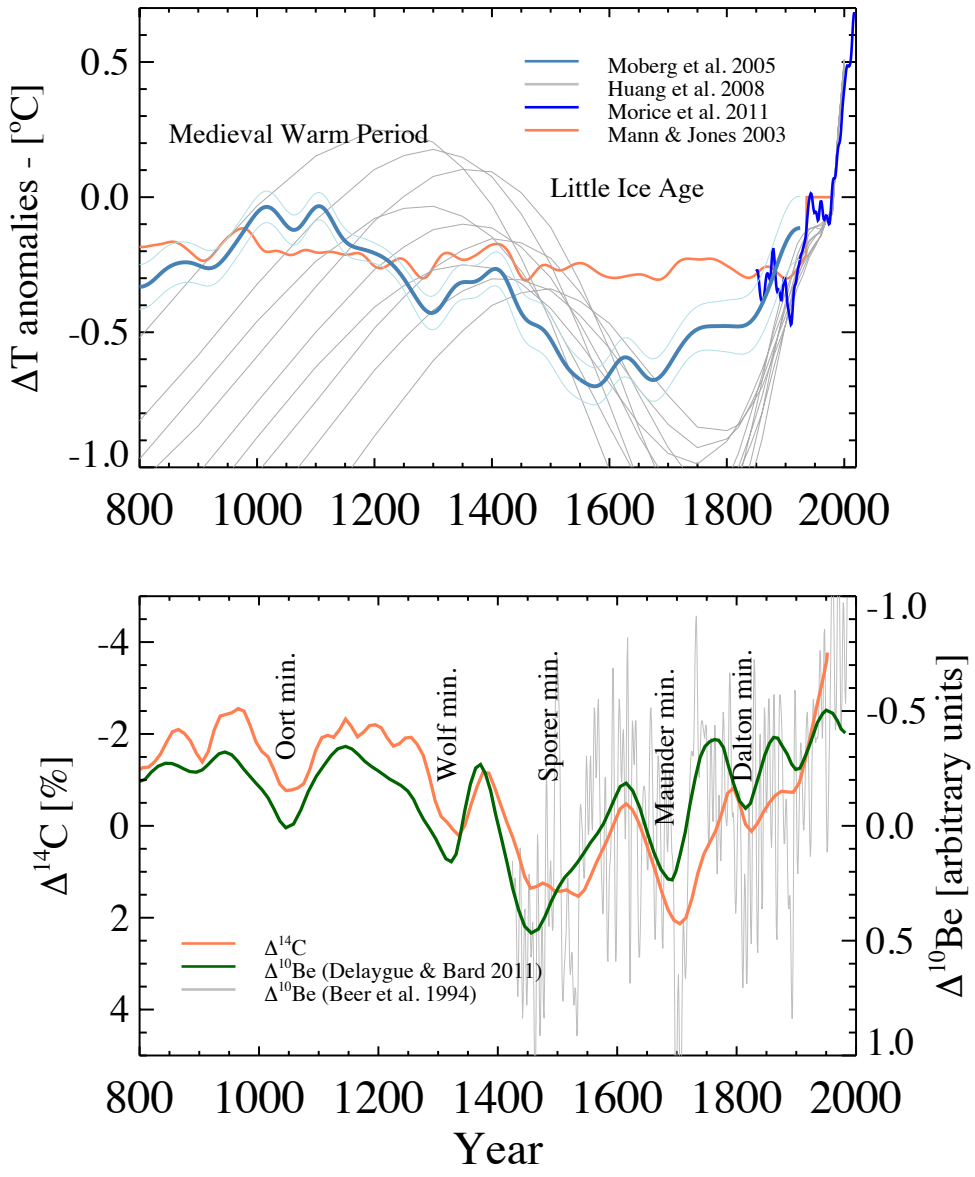
Heliosphere, Cosmic Rays and Solar Activity





Cosmic rays in the atmosphere

Cosmic rays and climate over the last millennium



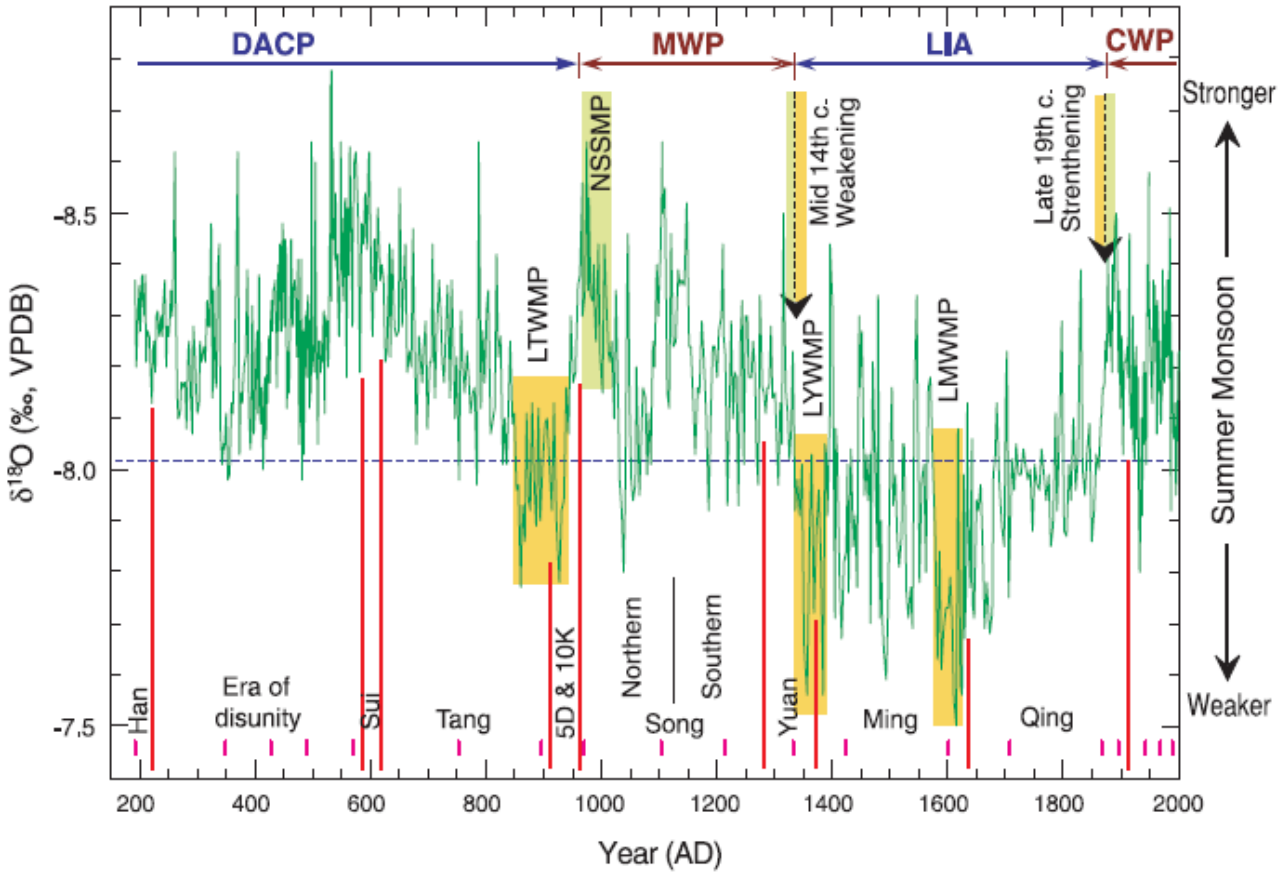
Low Cosmic ray flux
Warmer Climate

High Cosmic ray flux
Colder Climate

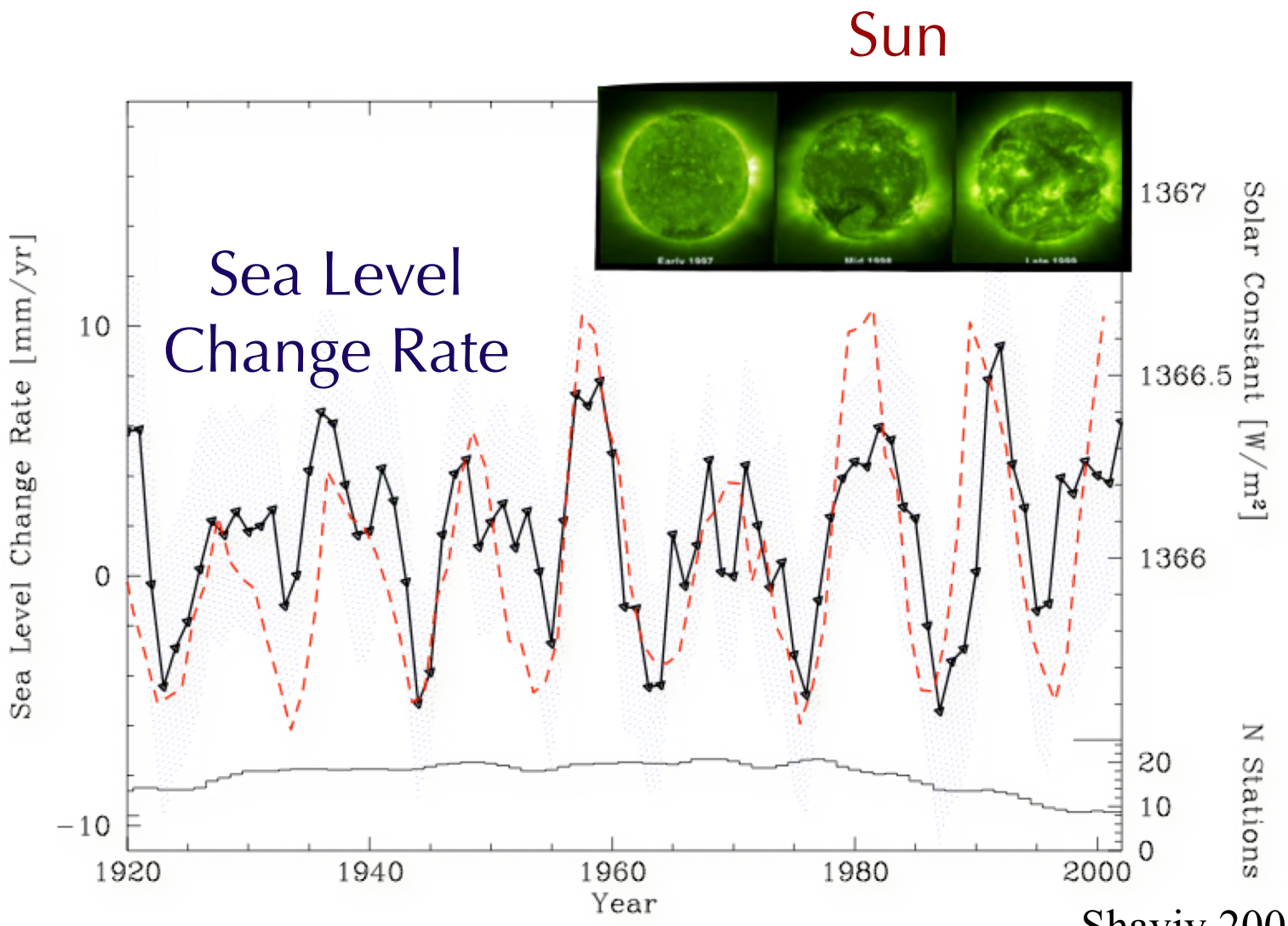
A Test of Climate, Sun, and Culture Relationships from an 1810-Year Chinese Cave Record

Pingzhong Zhang,[1] Hai Cheng,[2*] R. Lawrence Edwards,[2] Fahu Chen,[1] Yongjin Wang,[3] Xunlin Yang,[1] Jian Liu,[4] Ming Tan,[5] Xianfeng Wang,[2] Jinghua Liu,[1] Chunlei An,[1] Zhibo Dai,[1] Jing Zhou,[1] Dezhong Zhang,[1] Jihong Jia,[1] Liya Jin,[1] Kathleen R. Johnson[6]

7 NOVEMBER 2008 VOL 322 **SCIENCE** www.sciencemag.org

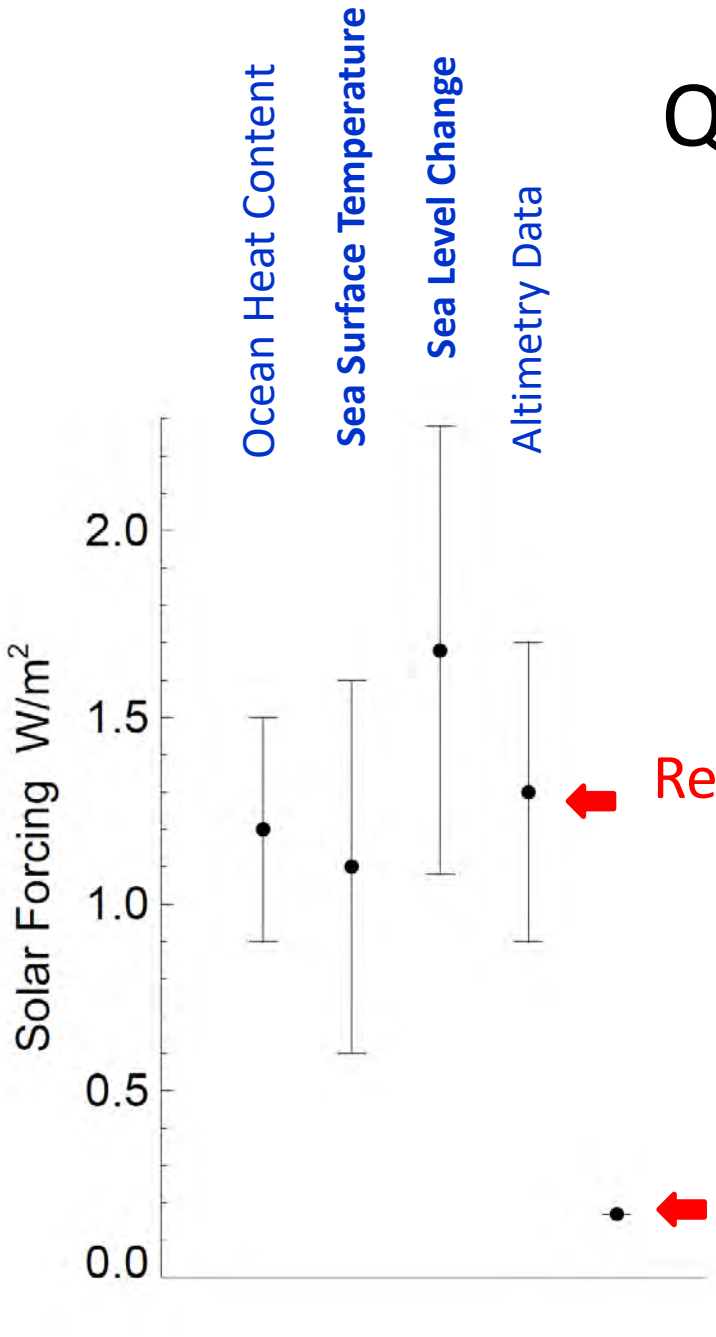


Quantifying the Solar impact:



Shaviv 2008

Quantifying Solar Forcing over 11 years

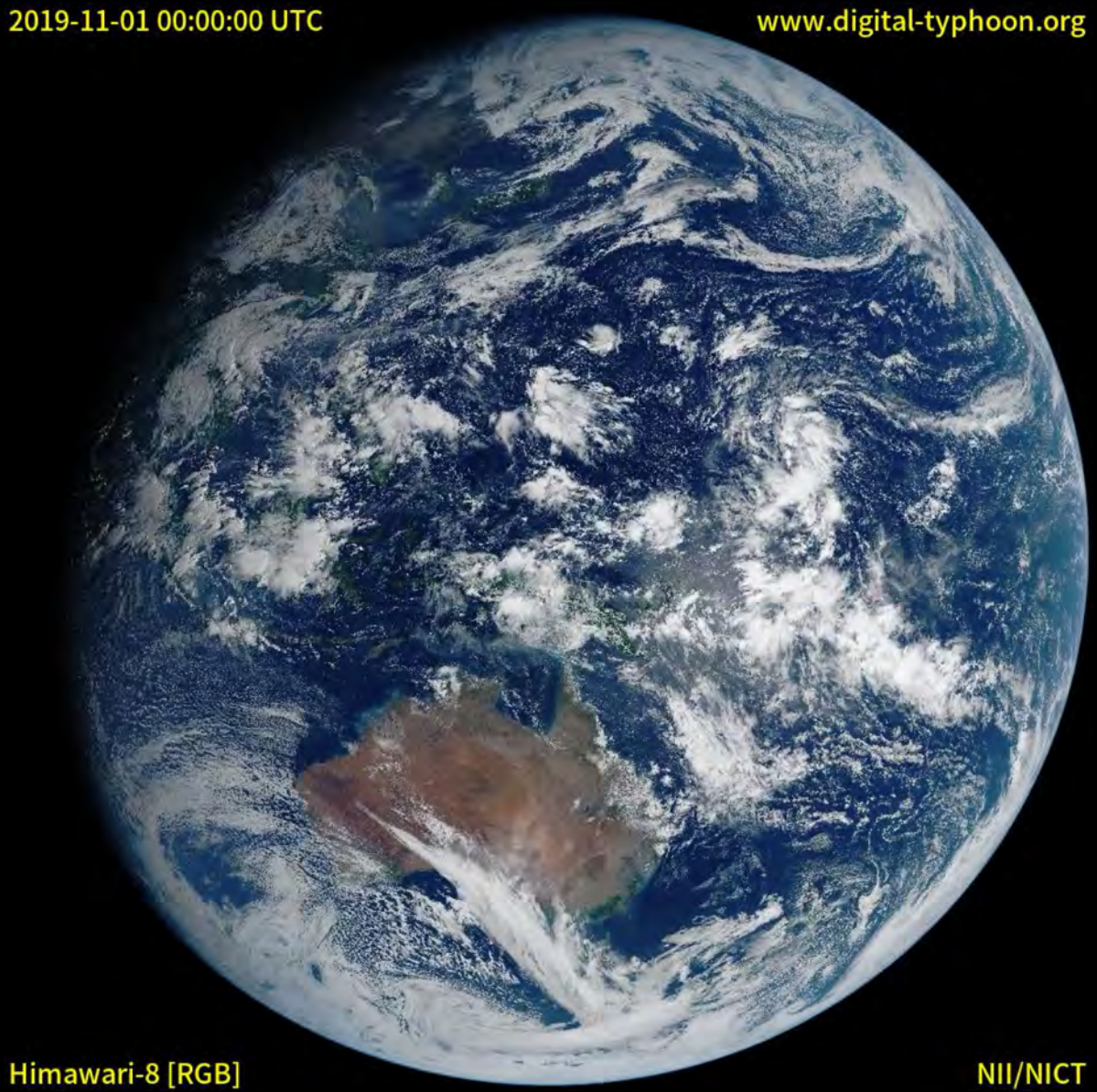


Require an amplification mechanism

Total Solar Irradiance

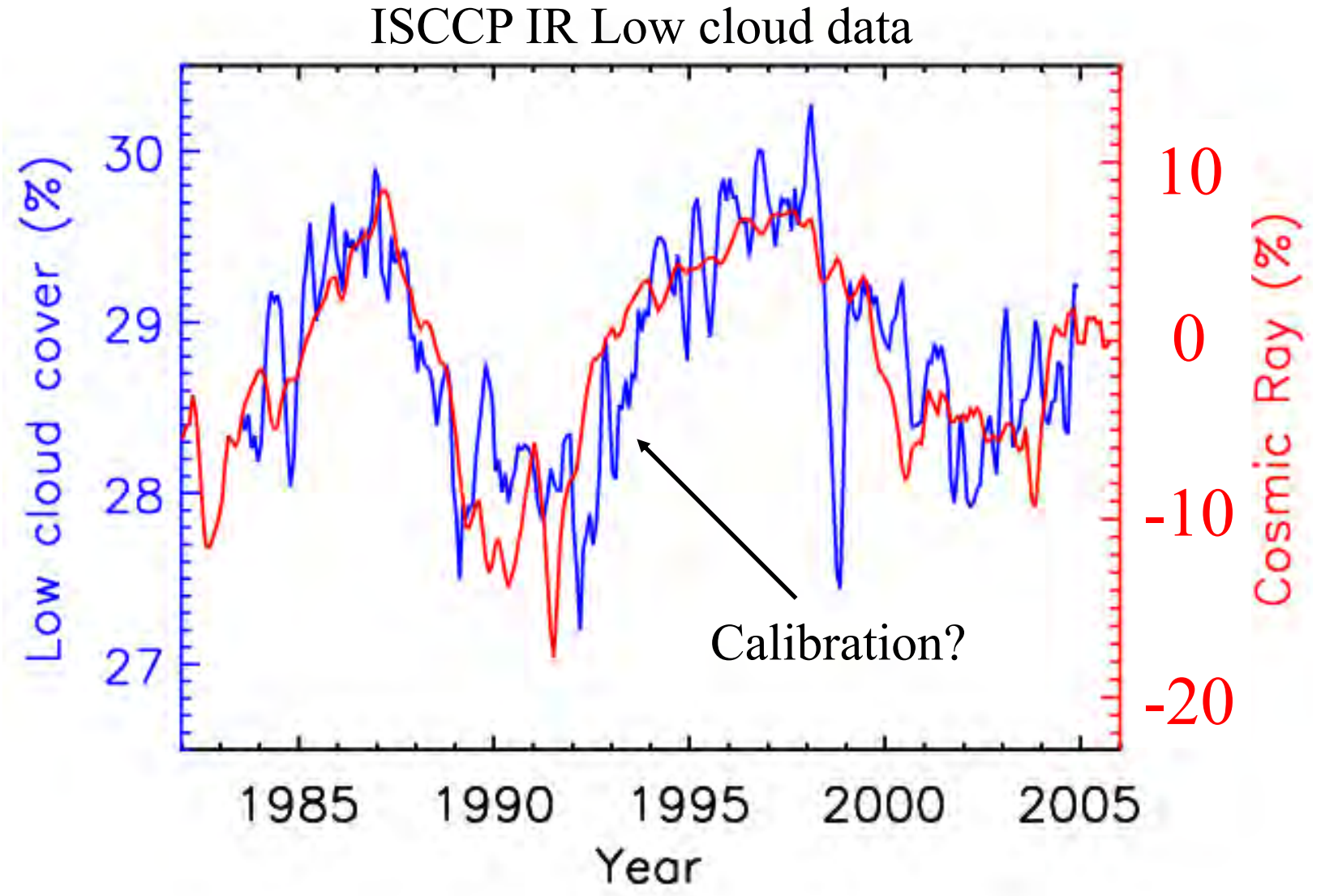
Shaviv, 2008

How can STARS influence Climate?



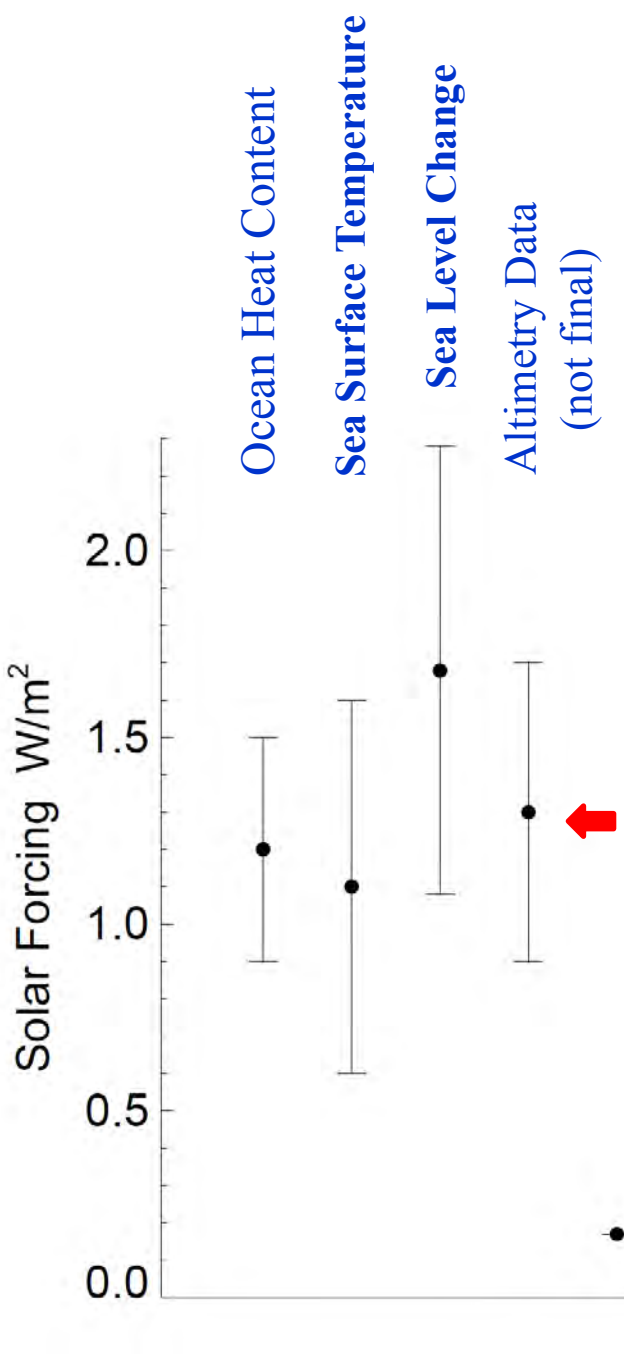
Net effect of clouds is to cool the Earth by about 30 W/m^2

Link between Low Cloud Cover and Galactic Cosmic Rays?
Solar cycle variation



Svensmark & Friis-Christensen, JASTP 1997, Svensmark, PRL 1998, Marsh & Svensmark, PRL, 2000. (update 2005)

Quantifying Solar Forcing over 11 years



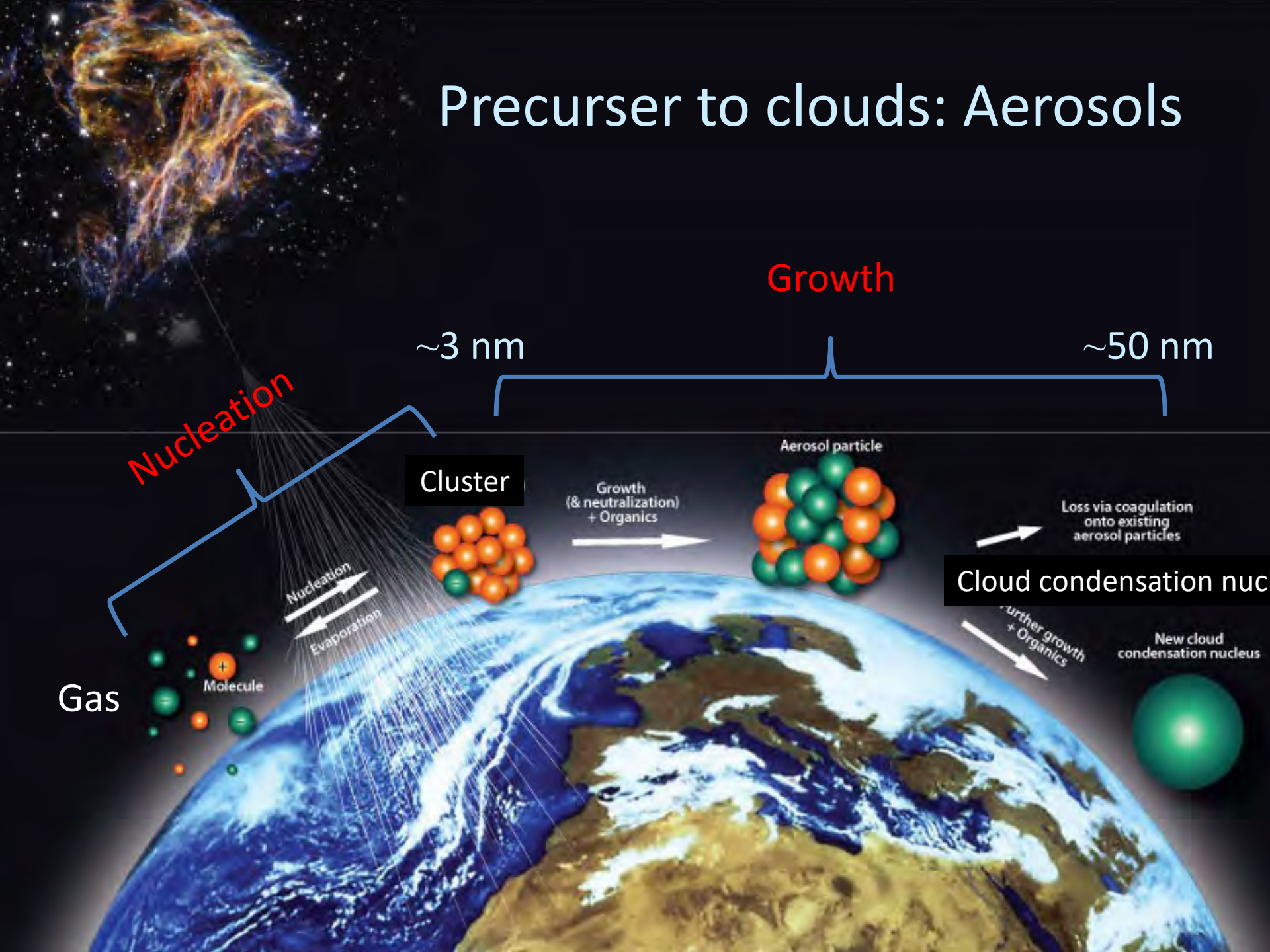
Require an amplification mechanism

CLOUDS

Total Solar Irradiance

Shaviv, 2008

Precurser to clouds: Aerosols



Aerosols and microphysics of clouds

Satellite observations of ship tracks

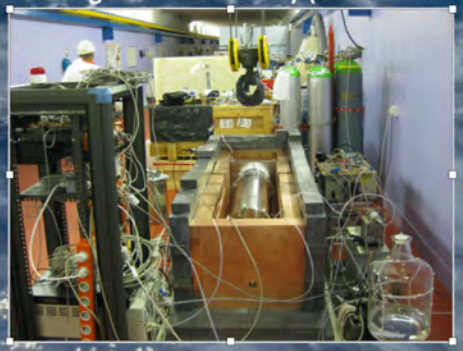
More than ten years of experimental work in order to understand the microphysical mechanism

DTU, National Space Institute

ASTRID accelerator, Aarhus Universitet

CERN

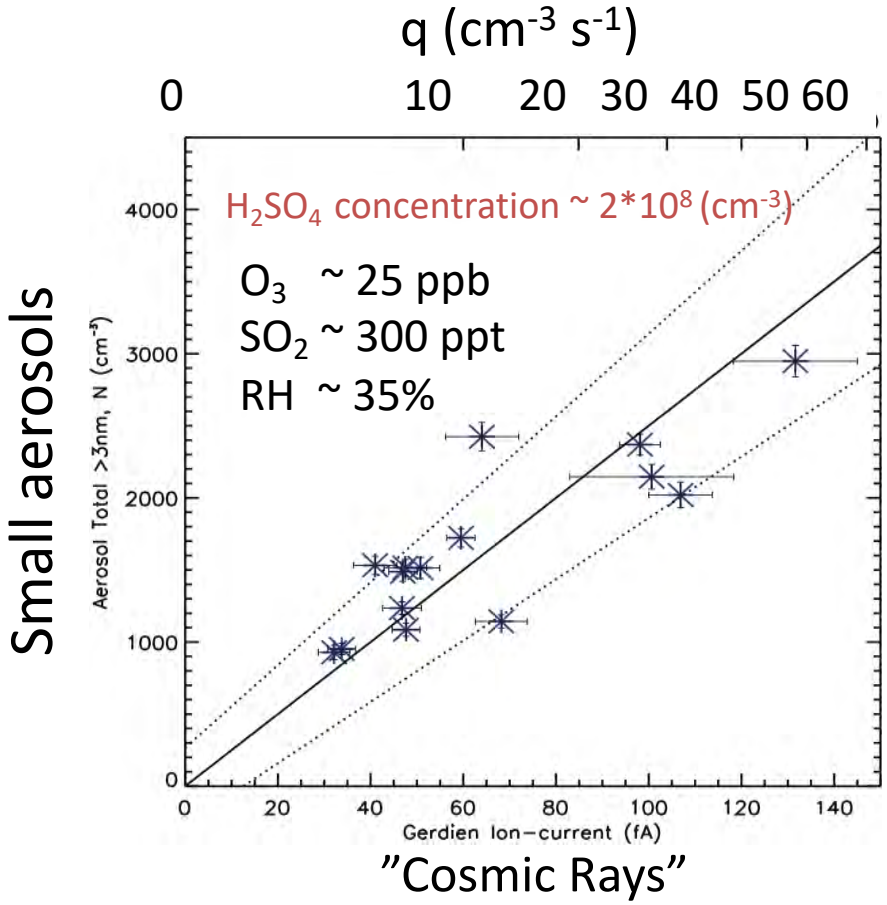
BOULBY Underground Laboratory (1.1 km underground)



Experimental challenges

1-2 nm stable aerosols

2004 - 2007



Svensmark et al. Proc. R. Soc. A (2007) 463, 385–396

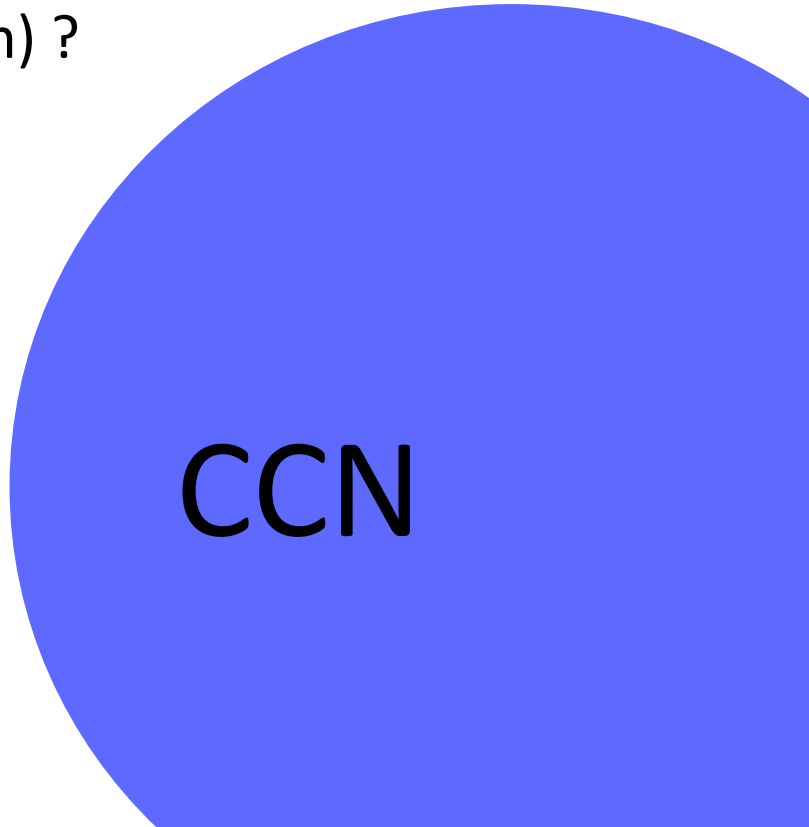
So experimentally there is good evidence for the generation of ultrafine aerosols by ions ~ 1-3 nm

- An important remaining question:

Will the small aerosols grow to Cloud Condensation Nuclei (~ 50 nm) ?

Nucleation

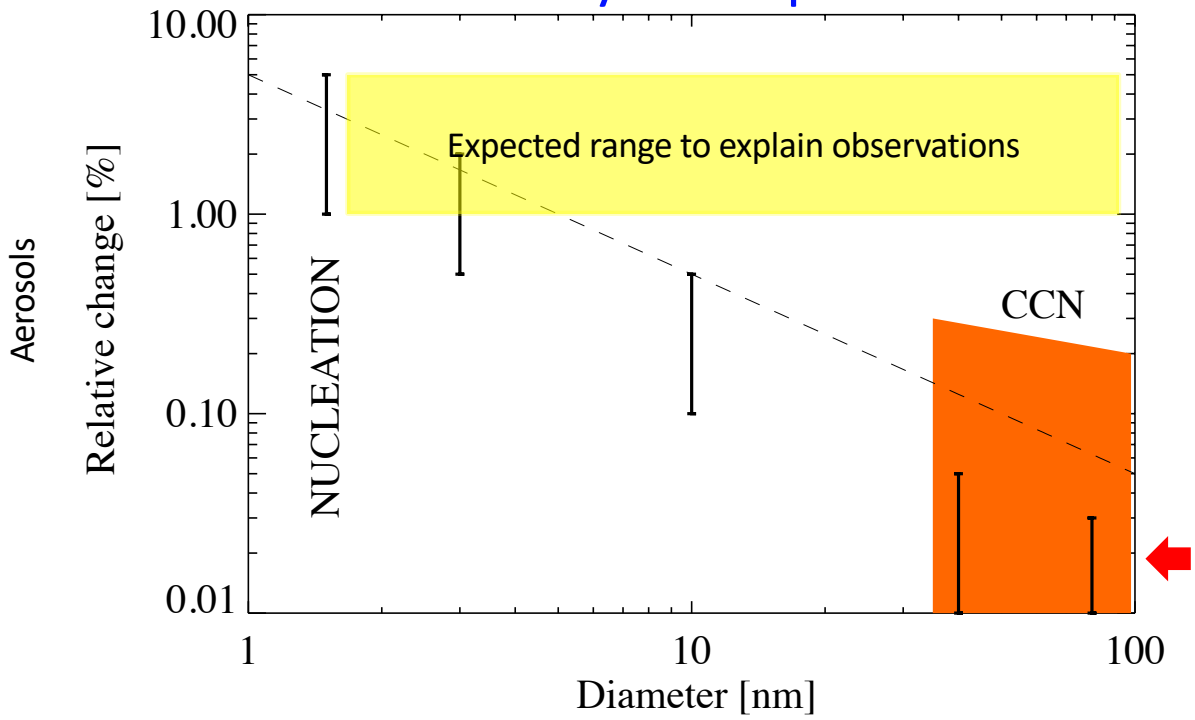
If not no impact on clouds.



RESULTS FROM A GLOBAL CIRCULATION MODEL

GEO-CHEM-TOMAS

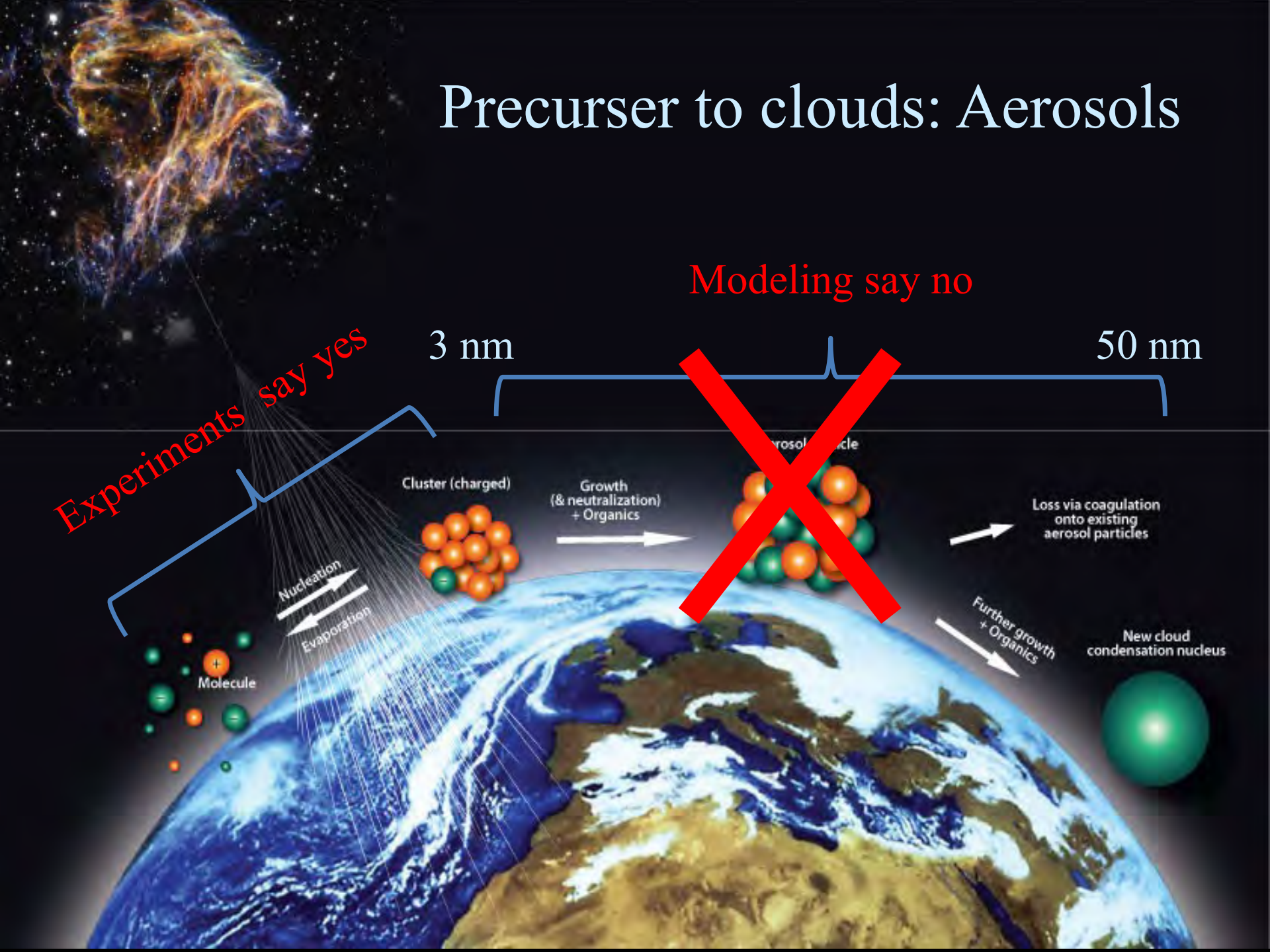
Solar cycle response



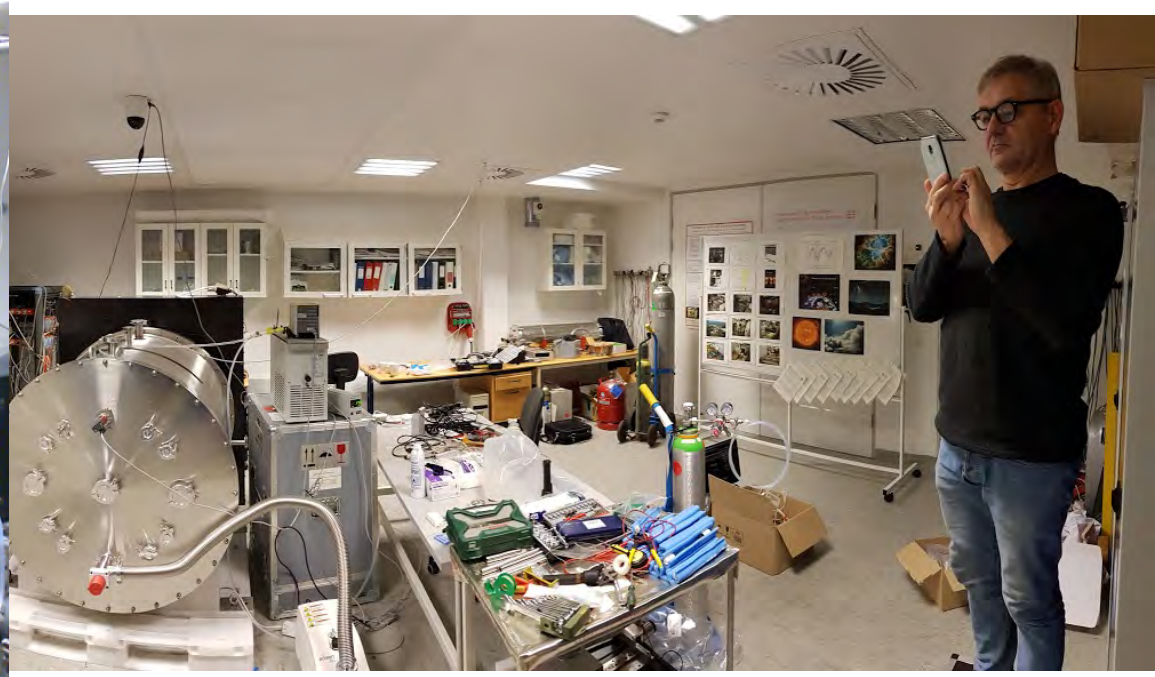
To small to affect clouds

Data from: Snow-Kropla et al. 2011

Precurser to clouds: Aerosols



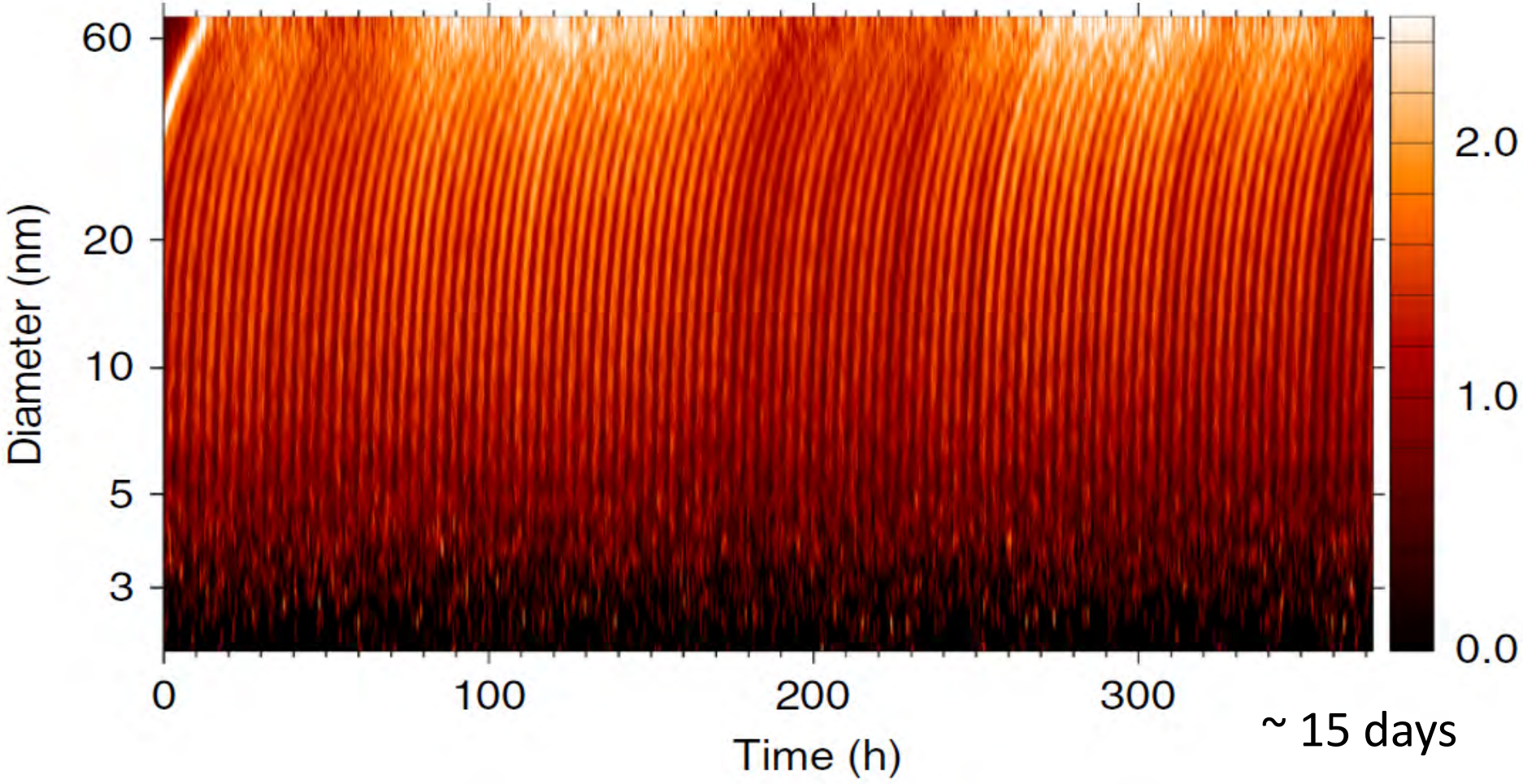
TESTING THE GROWTH OF AEROSOLS EXPERIMENTALY



Changing **γ**-rays every four hours on experimental settings lasting several weeks

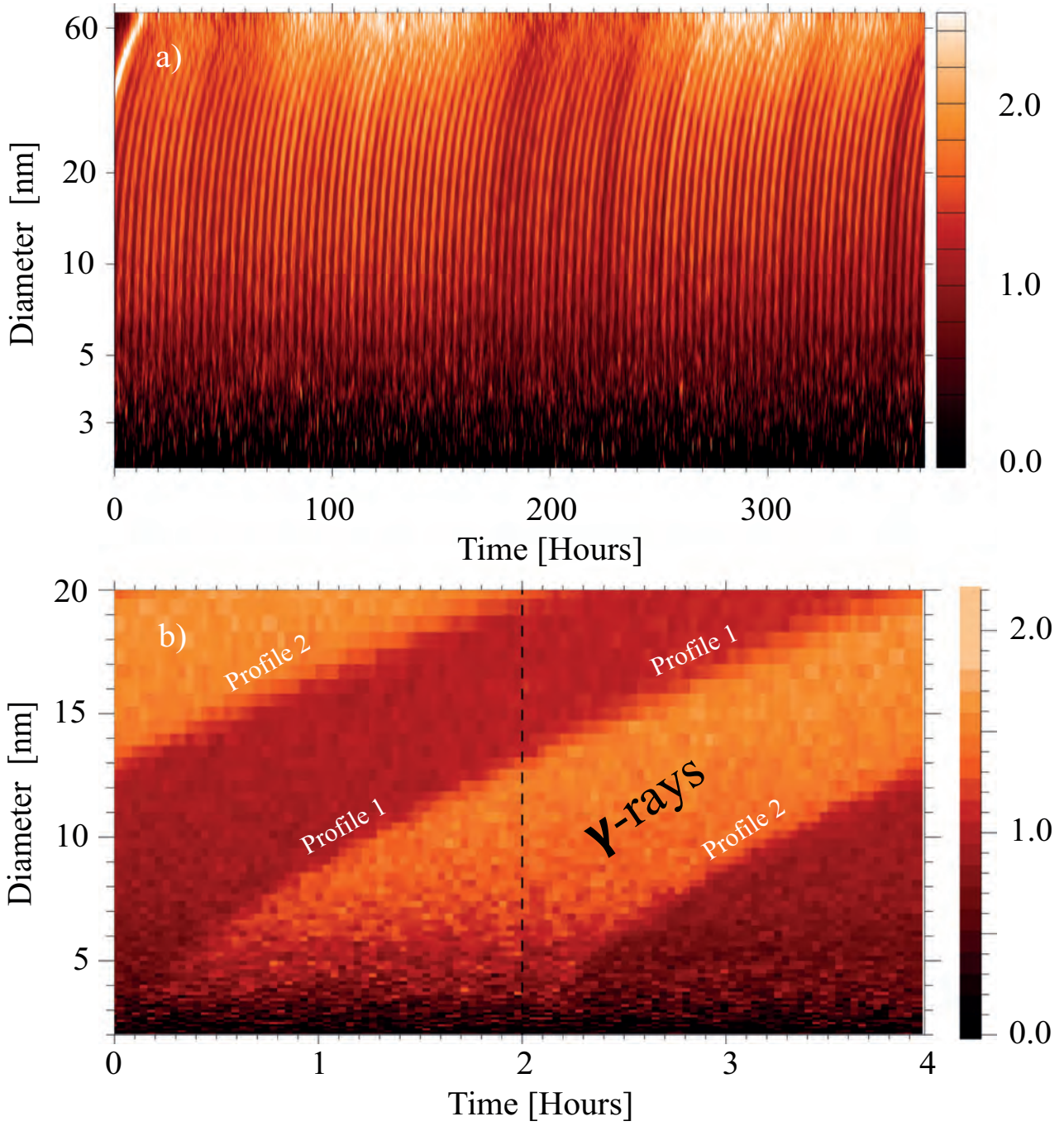
Experimental challenge

To measure changes in aerosol growth rate of < 1%

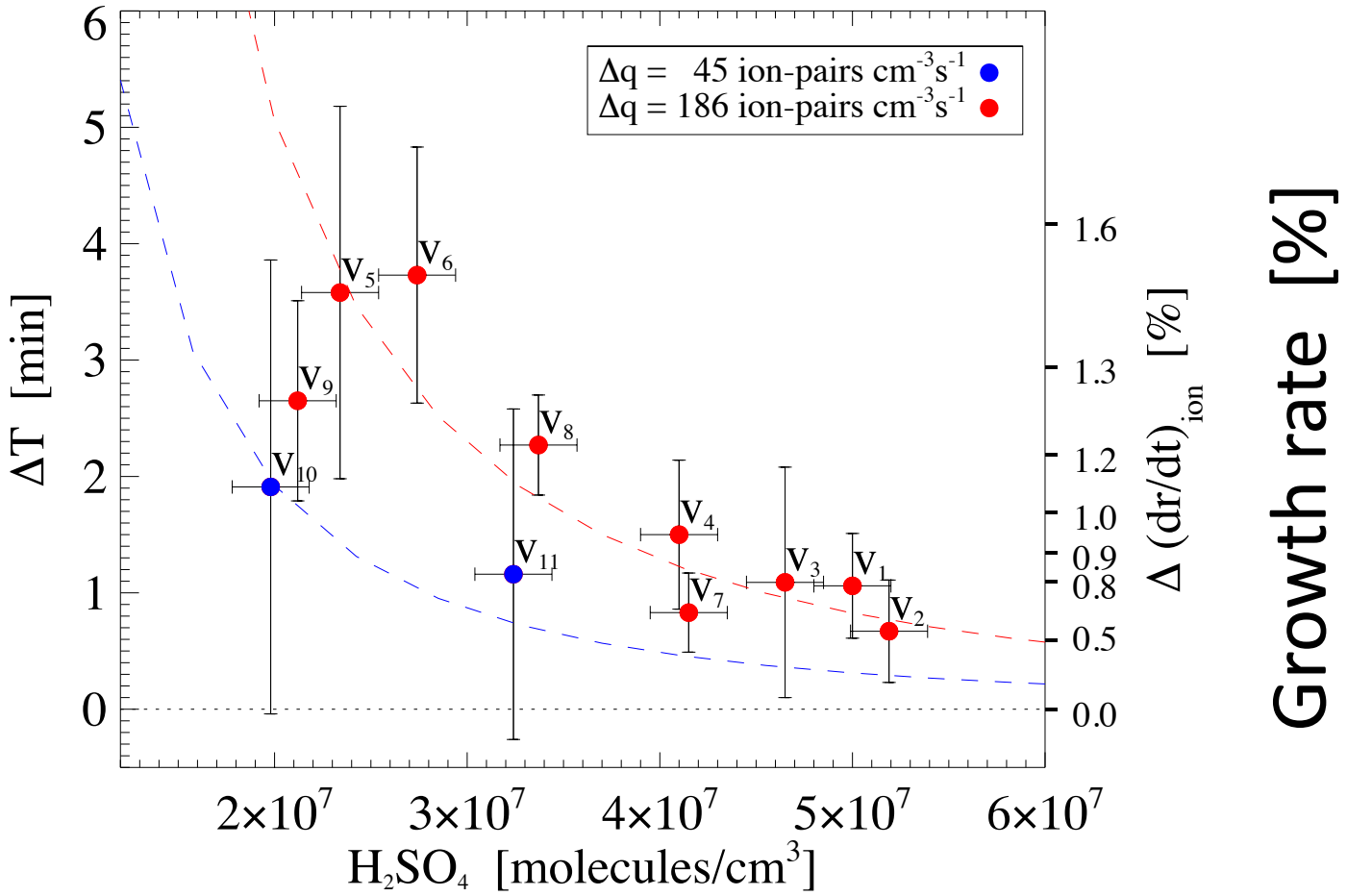


Svensmark, Enghoff, Shaviv, and Svensmark, *Nature Comm.* 8:2199, 2017

Svensmark, Enghoff, Shaviv, and Svensmark, *Nature Comm.* 8:2199, 2017



After 3100 Hours of measurements we get:



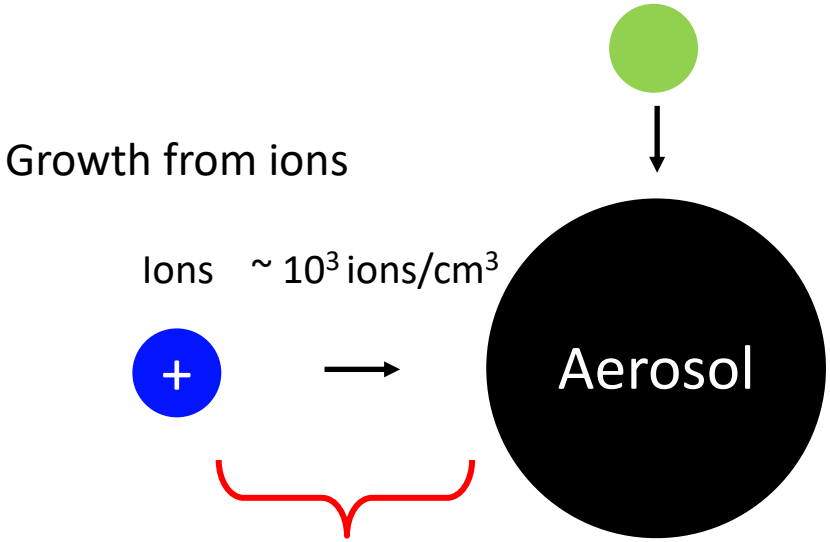
Theory and experiments are consistent !

Svensmark, Enghoff, Shaviv, and Svensmark, *Nature Comm.* 8:2199, 2017

A few numbers

Growth from neutral molecules

H_2SO_4-H_2O ~ n_0 ~ 10^6 molecules/cm^3



Naively:

$GR_{ion}/GR_0 \sim n_{ion}/n_0 \sim 10^{-3} \sim 0.1\%$

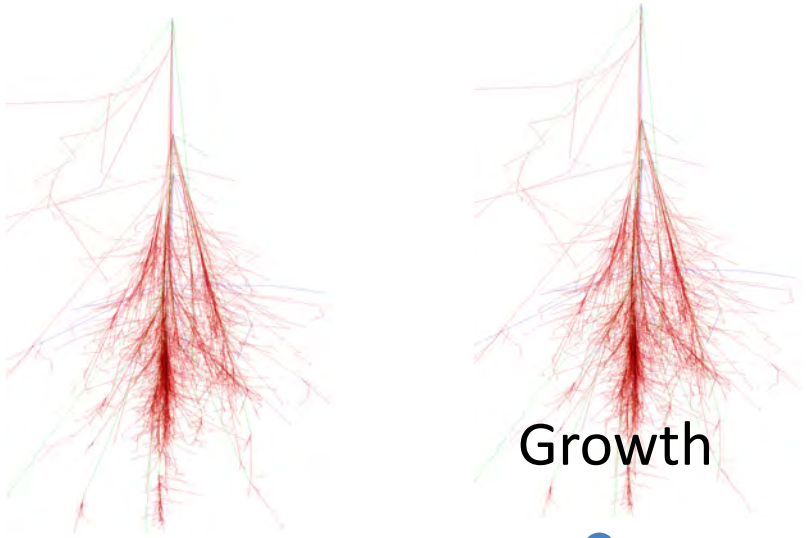
1. Coulomb forces
2. Mirror forces
3. Van der Waals forces
4. Viscous forces

Enhanced interactions

Svensmark, H., Enghoff, M. B., Shaviv, N. J., & Svensmark, J. Nature Communications, 8(1), 2199, 2017

Precurser to clouds: Aerosols
The last 4 years

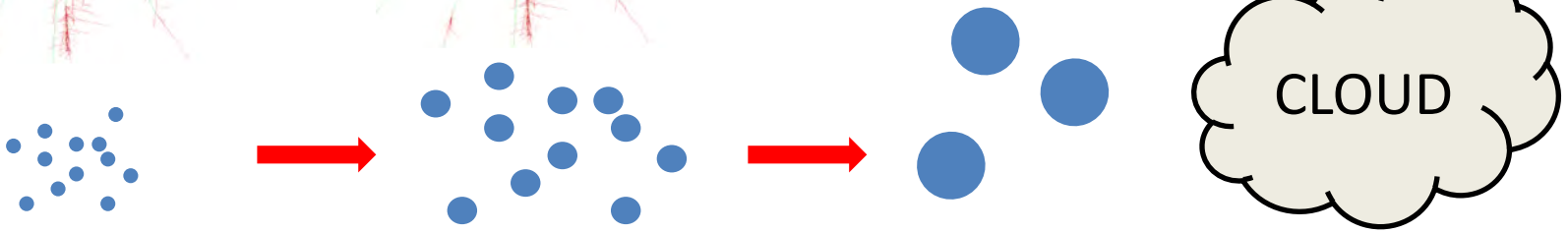
Cosmic Ray Ionization



$$\frac{\mathrm{d}r}{\mathrm{d}t} = A_0 n^0 \beta^{00} [1 + \Gamma].$$

$$\Gamma = 4\left(\frac{n_{\mathrm{ion}}}{n_0}\right)\left(\frac{\beta^{\pm 0}}{\beta^{00}}\right)\left(\frac{m_{\mathrm{ion}}}{m_0}\right)\left(\frac{N^0(r,t)}{N^{\mathrm{tot}}(r,t)}\right).$$

Growth



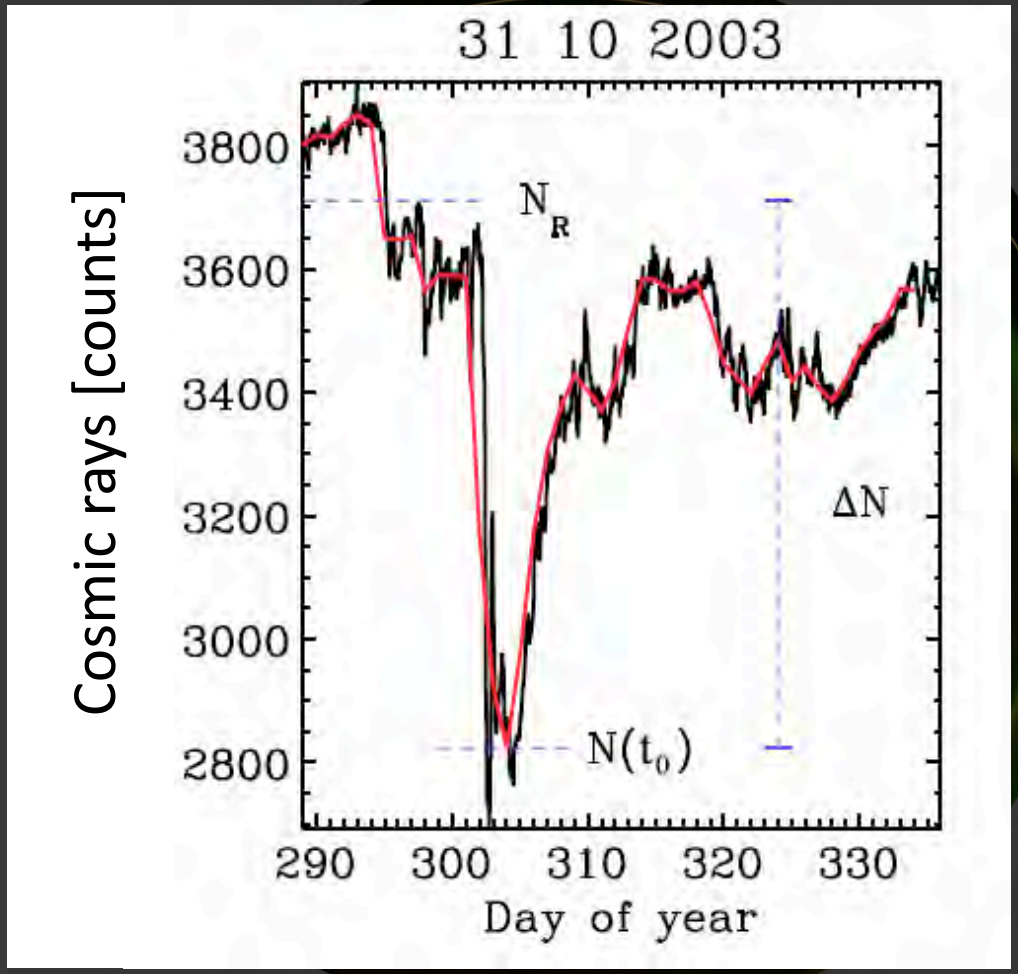
1-2 nm stable aerosols

CCN > 50 nm

H. Svensmark , Enghoff, Shaviv, J. Svensmark
Nature communications 2017

Coronal Mass Ejections

Natural experiments for testing the GCR-atmosphere link

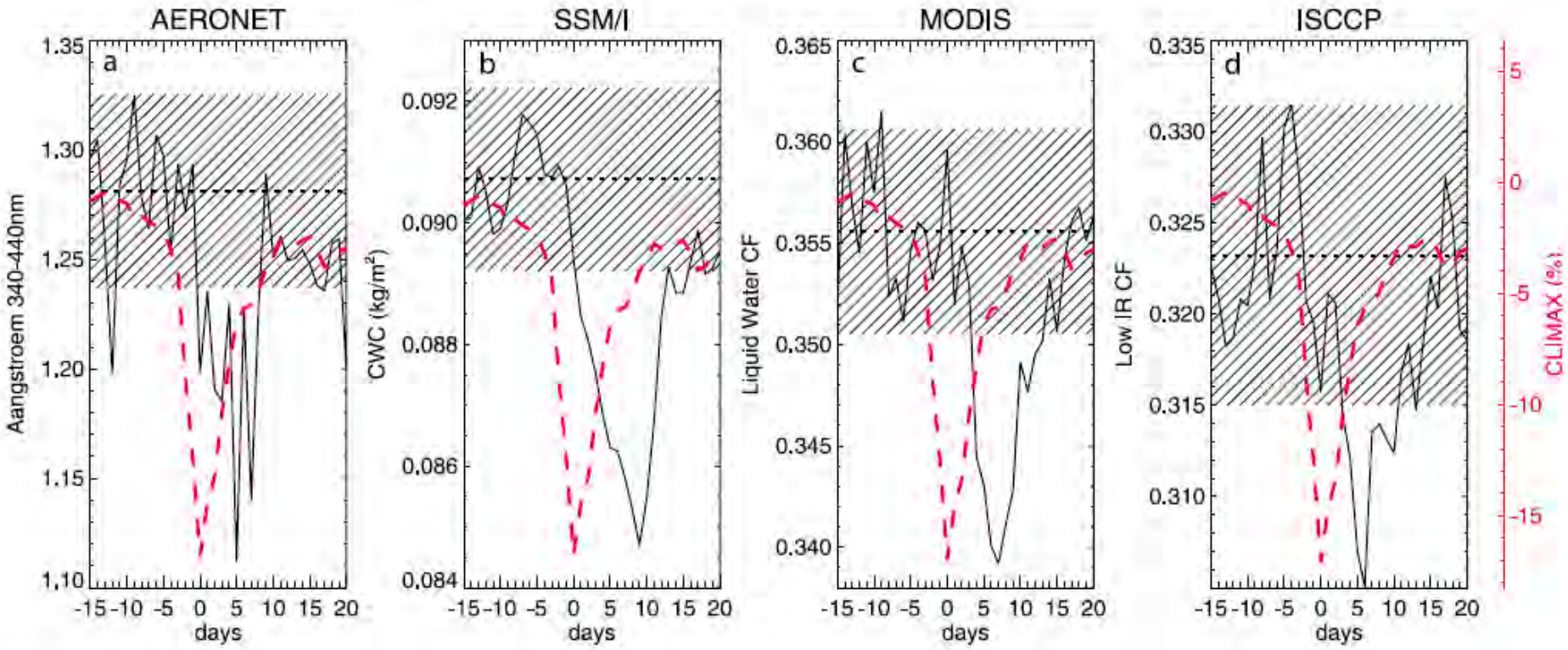


AERONET, SSM/I, MODIS and ISCCP data for 5 strongest Forbush decreases

Aerosols

Clouds

Liquid water | Liquid cloud fraction | Low Clouds

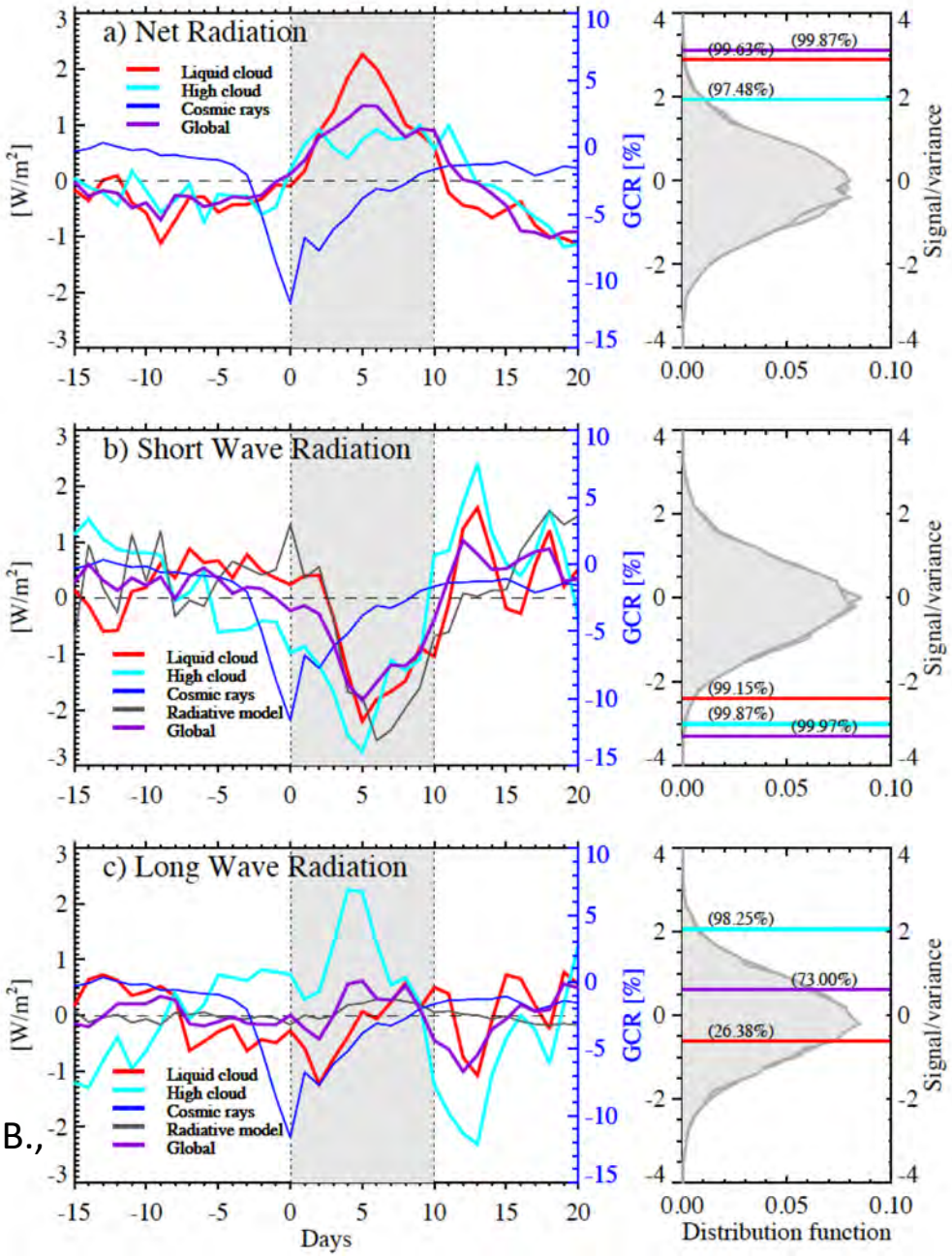


Svensmark, Bondo, Svensmark, Geophysical Research Letters, 2009

Svensmark, Enghoff, Shaviv, Svensmark, J. Geophys Res., 2016

Earth's energy balance during a change in cosmic ray flux

Globally, the Earth is forced by ~ 2 W / m^2 in response to a ~ 15% change in the cosmic ray flux

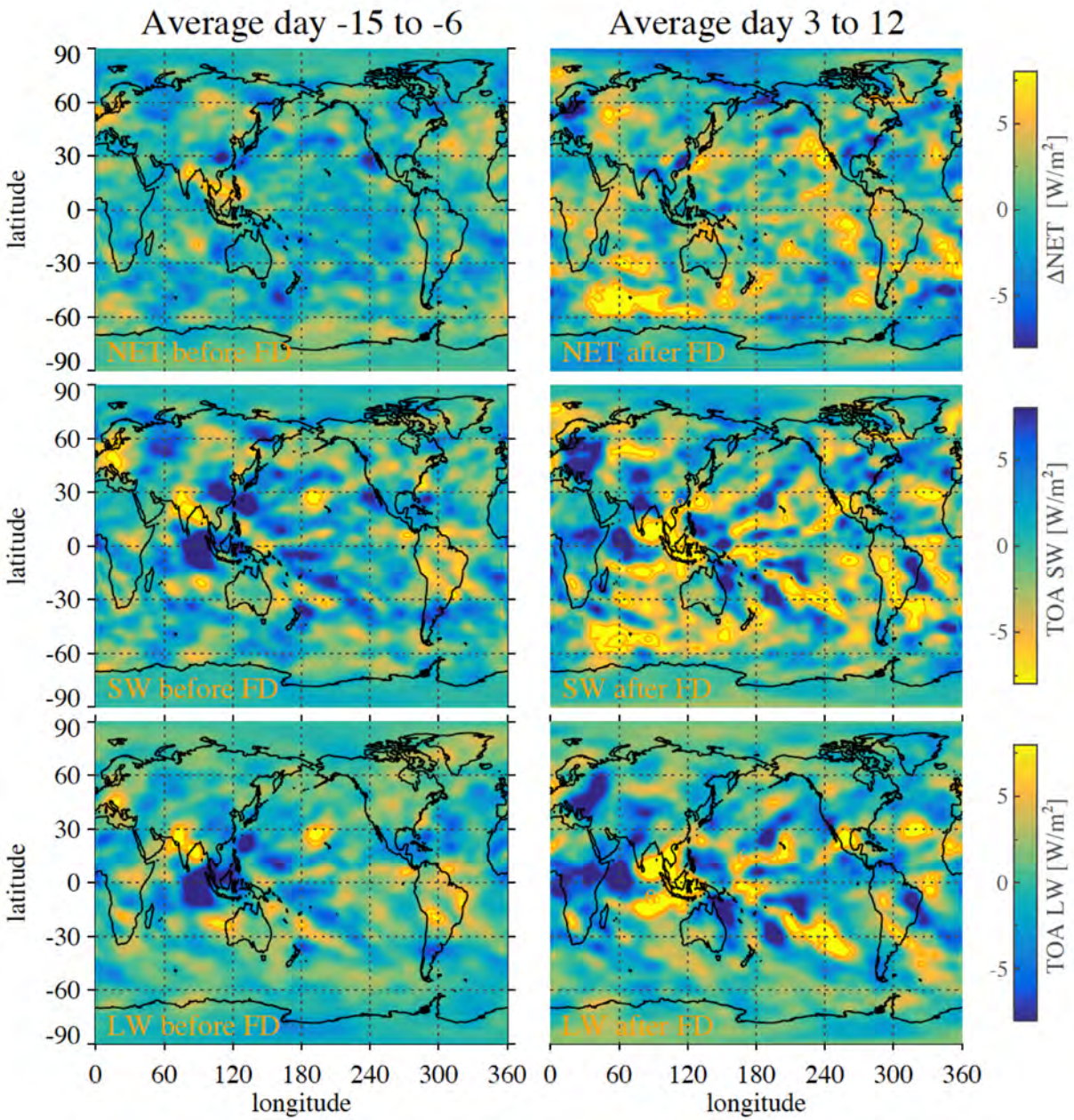


Svensmark, H., Svensmark, J., Enghoff, M.B., Shaviv, J. N., *Sci Rep* **11,** 19668 (2021)

Spatial distribution of the effects

Before cosmic ray change

After cosmic ray change



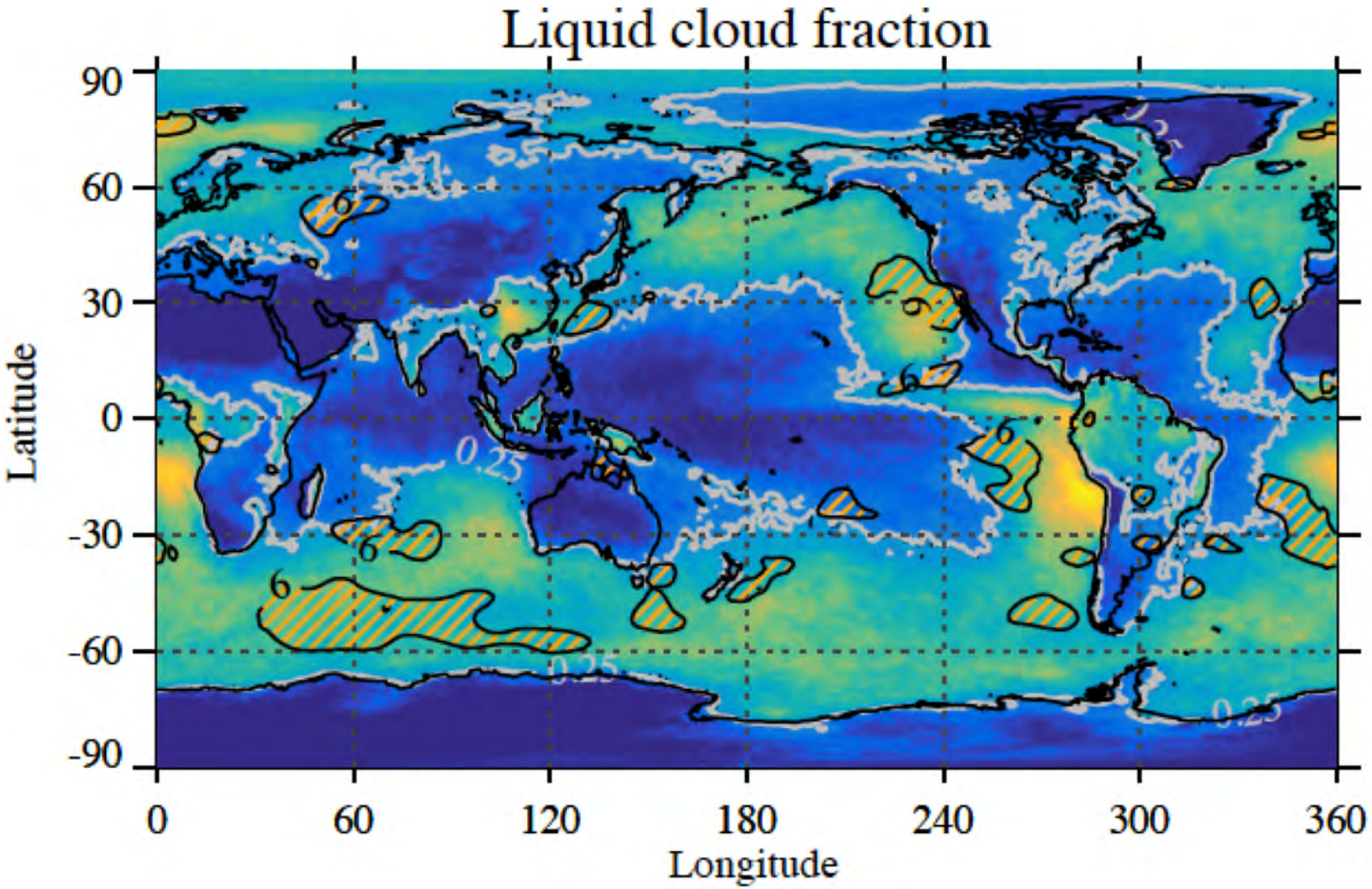
Net radiation

Shortwave

Longwave

Svensmark, H., Svensmark, J., Enghoff, M.B., Shaviv, J. N., *Sci Rep* **11,** 19668 (2021)

Main Effect in low liquid clouds over the Oceans



Svensmark, H., Svensmark, J., Enghoff, M.B., Shaviv, J. N., *Sci Rep* **11,** 19668 (2021)

Summary of observations

The following chain of events are observed

1. Solar activity in the form of coronal mass ejection =>
2. Decrease in cosmic rays at Earth (day zero) **=>**
3. Decrease in ”large” aerosols 4-5 days later **=>**
4. Decrease in clouds 5-7 days later **=>**
5. Energy budget of the Earth changes 5-7 days later with 2-3 W/m2 extra energy entering the Earths system

- Mainly low clouds are responsible for affecting the energy budget
- Clouds over the oceans have the largest responses