

Lecture 12: The Magnetosphere & Maxwell's Equations

Last time we reviewed some observations about the earth's magnetic field and then turned to the sun (and stars in general) for further insight. We had just gotten to the observation of the variability of the solar wind - not only the 11-year sunspot cycle but also the variability in the number of sunspots in each cycle.

Sunspot ^{reflect and are} related to burning of nuclear fuel - whether

sun is "on" or "off". If on, we have sunspots,

and a strong solar wind (bulky // of charged

particles from coronosphere that stream toward ^{the} earth at

~400 km/sec + get here in 2 to 3 days (light takes 8 min)

I. Solar Wind

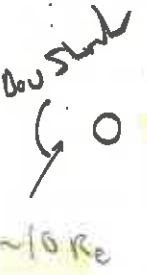
Charged solar wind particles interact with the diurnal, poloidal magnetic field of the earth

Why coronosphere is hot but sun system is cooler

I Solar Wind

charged solar wind particles interact with the dipole (polar) magnetic field of the earth, and are deflected around the earth, distorting the earth's magnetic field into a cavity called the magnetosphere

charge in 2's etc. of the current of the MAGNETOSPHERE (solar wind)



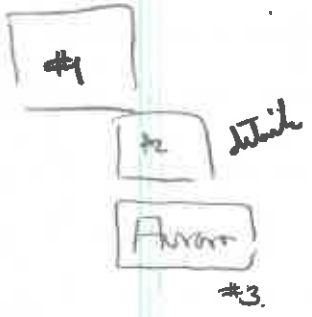
Cavity at times is like a shield which

deflects incoming solar wind particles; at times like an accelerator - accelerating ions + producing beams that produce aurora (stays back at tail).

- solar wind compresses E's magnetic field. High conductivity plasma excludes field lines from its interior. - creates wave dipole that cancels E's field.

Supersonic

400 km/sec vel of solar wind exceeds velocity of pressure waves in plasma - ∴ front of magnetosphere is a bow shock. It is an electromagnetic shock!



- small fraction of solar wind of charged particles enters the magnetosphere via the polar cusps. Goes into boundary layer (plasma mantle) and to region of neutral point (plasma sheet)

- small fraction of ions are reflected back toward sun and bow shock region is area rich in plasma physical phenomenon, RELEVANT TO STELLARATION, TOKAMAK etc.

Solar

Magnetosphere Dynamics

Cyclic transfer of magnetos plasma to tail

and then back to magnetosphere is linked to

aurora. Explosive reconnection of magnetotail can push ionospheric plasma toward dayside at auroral latitudes.

Viscous drag of solar wind on magnetopause

creates Kelvin-Helmholtz (wind-over-water) instability.

Stresses are transmitted to E (to avoid magnetospheric

plasma being blown away) via ^{closed} current systems which

flow across ^{magnet} field lines, producing a force on the plasma.

This system allows stress to be transmitted to viscous shear

in the neutral atmosphere. Cause flow of ionospheric plasma

over polar cap from noon to midnight.

Potential drops along field lines occur + accelerate

electron to few keV in energy — produce Aurora. Magnetic storms are related to instabilities in the high voltage system.

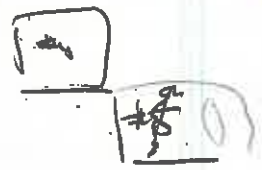
#1 + #2 go

aurora magnetotail wind drag

surface

do not know cause.

A. Van Allen Radiation belts



Trapped ionized particles. Charged particles

milli-sec to sec

- gyrate around magnetic lines / force

sec to minutes

- bounce back + forth vertically by mirror effect of increasing magnetic field near earth.

months to hrs

- Circulate about dipole axis - eg drift around the magnetic core

Adiabatic invariants are conserved in this motion.

(not disturbed by ^{EM} waves from lightning etc).

When conserved, particles remain trapped. They are

trapped in van Allen belts. Particles in belts

are produced by decay of neutrons created by cosmic rays ^{expanding magnetic}

hitting upon atom. Particles can remain trapped for

hundreds of years

- at low energy - Electric field input and charged particle population changing variable

- "Roll" (low energy) ions, but can be same / particles

- EM noise generated by lightning (called whistlers) propagate through the magnetosphere cause particles to stick closer to magnetic field lines + increase probability of loss. (drag of radiation belt ion population).

Whistlers
100 volts/m near
surface sustained by
lightning. Max drag
afternoon & radiation
in aurora.

Other EM waves also contribute to loss of charged particles in radiation belts. One is "down chorus" generated by particle beams (like chirping of birds). → Can buy low freq radio to listen to these sounds

Ionosphere

Ionosphere created by UV radiation. Low E

TEMPERATURE
(UV radiat)

(~2000 K). Speed & plasma density. ∴ measure

radiation belts. Whistlers showed abrupt drop in plasma

density (ionosphere) at about 4 R_e. ^{POP} Separated

region where plasma related with the earth from region

where they can not be case. Plasmasphere comes from

Plasmasphere
(Oiled
10000 km)

ionosphere. Particles accelerated (electrically) in some

places. ∴ Magnetosphere chemically more like ionosphere

than or ground through

II. Magnetic fields on other planets.

Earth is not the only planet with a magnetic field.

'Planetary' fields are diverse in nature + causes.

- Jupiter magnetosphere led by volumetric eruption on Io; energetic particles accelerated to eating by energies. Extrem hazard to spacecraft. Land on moon - fried quickly!

magnetic moment
20,000 times that
of E.

- Saturn mag fld aligned along rotational axis. Daily change in strength of magnetosphere small. Rings absorb particles.

magnetic moment 600
times E

- Uranus - rotation axis in ecclyptic plane. but mag fld 60° from rotational axis.

- Venus - no magnetic field. Ours looks to solar wind $\sim R_{Venus}$ not $10 R_{Venus}$ like E. Mag fld in the ionosphere & becomes twisted into ropes

- Mars - probably no magnetic field.

- comets - cometary solar wind shock front

Future —

Do not know mechanism of field
Do not understand aurora

See: <http://www-ssc.igpp.ucdavis.edu/SSC/Electrodynamics/magnetospheres.html>

www-ssc.igpp.ucdavis.edu/SSC/Electrodynamics/magnetospheres.html

II: Connection between Sunspot, solar wind + climate change

No answer
do Corona

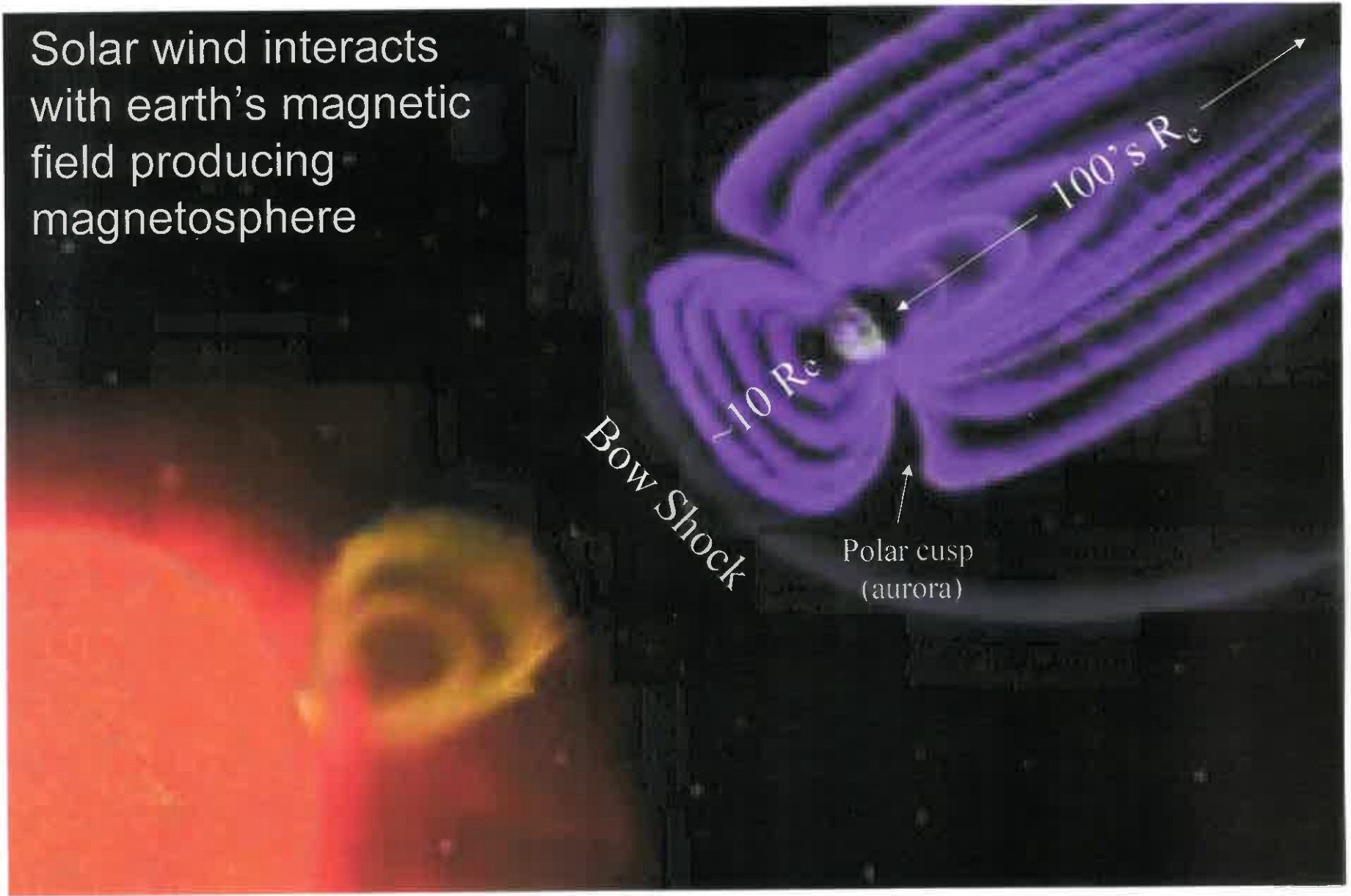
- Number of sunspot changes relatively
- + There have been periods when there were no sunspots (head Royal Astronomical Society in 17th century just before died).
- Hansen is on solar wind is strong
- strong solar wind = strong magnetosphere shield to cosmic rays
- ∴ cosmic rays like C^{14} , O^{18} when sun "on" or "off"
- cosmic rays also nucleate clouds (Hansen cloud chamber).

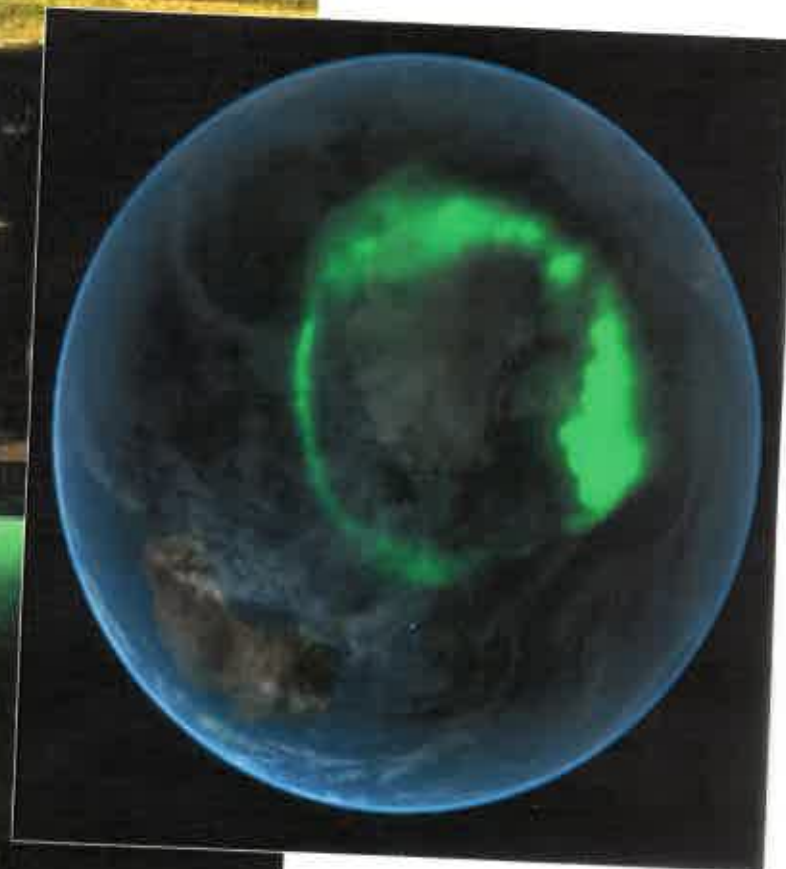
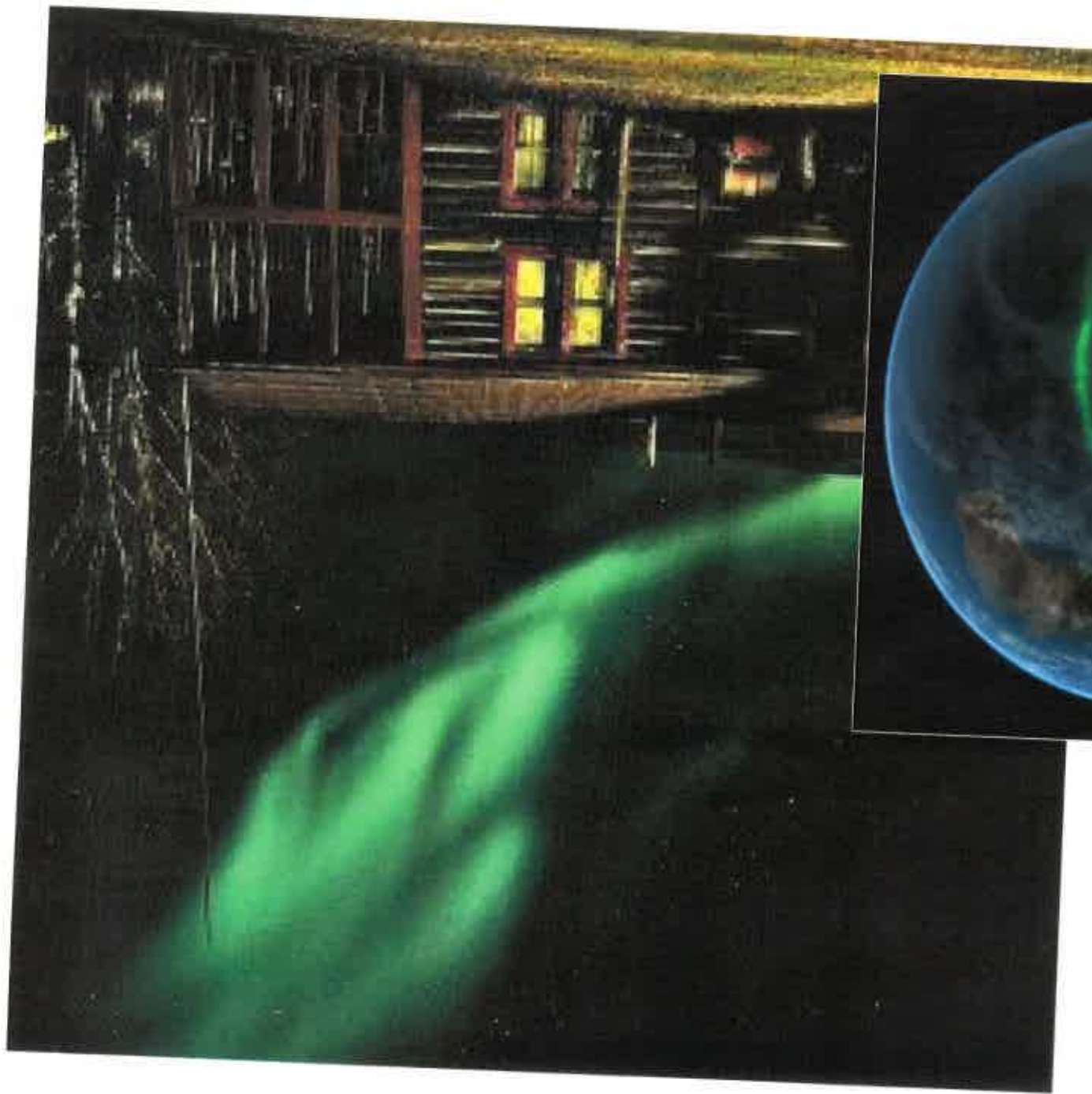
So "earth system" is really a system. The

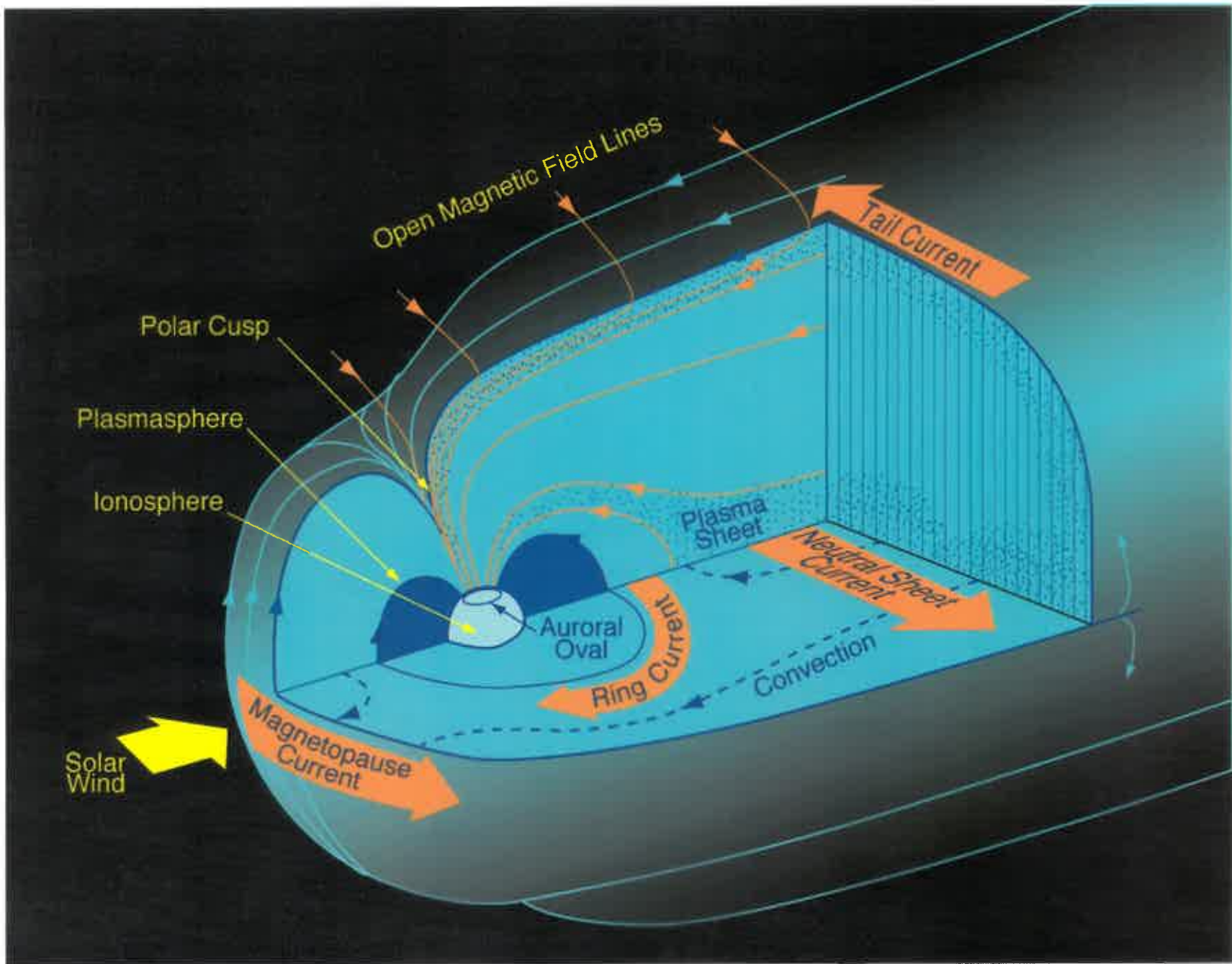
inner core ties to sun-derived phenomena, and to the atmosphere + climate!

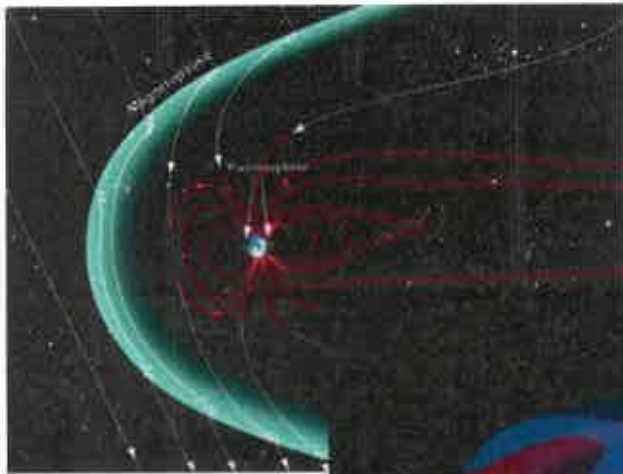
→ p 8-15 moved to L12

Solar wind interacts
with earth's magnetic
field producing
magnetosphere

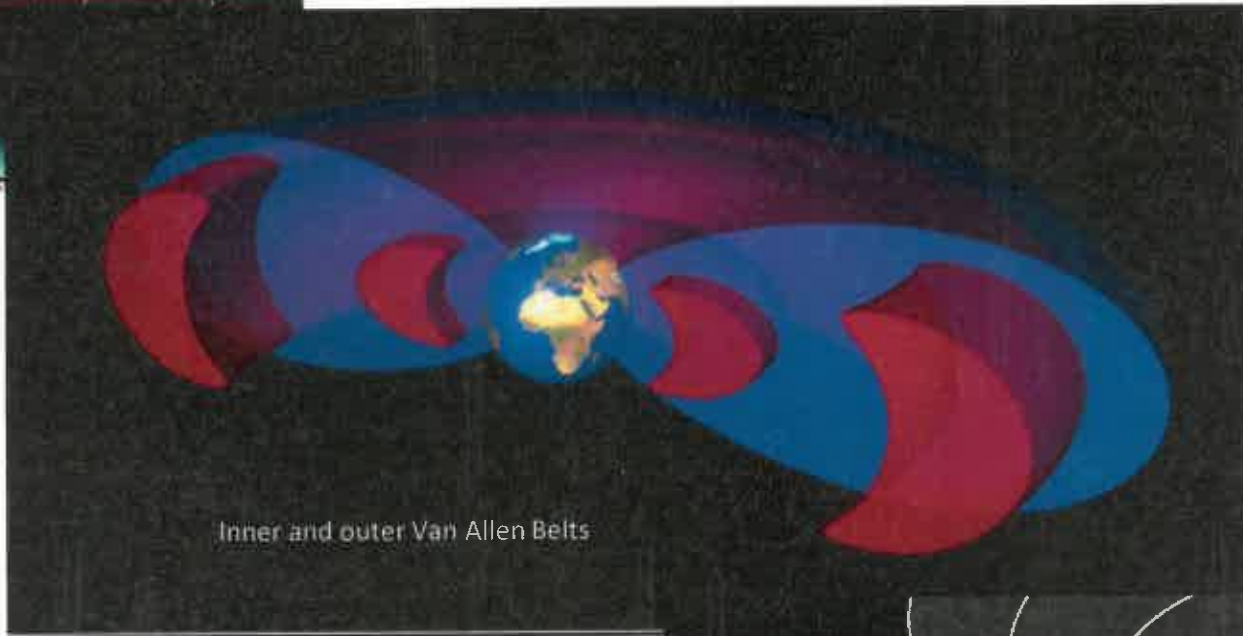








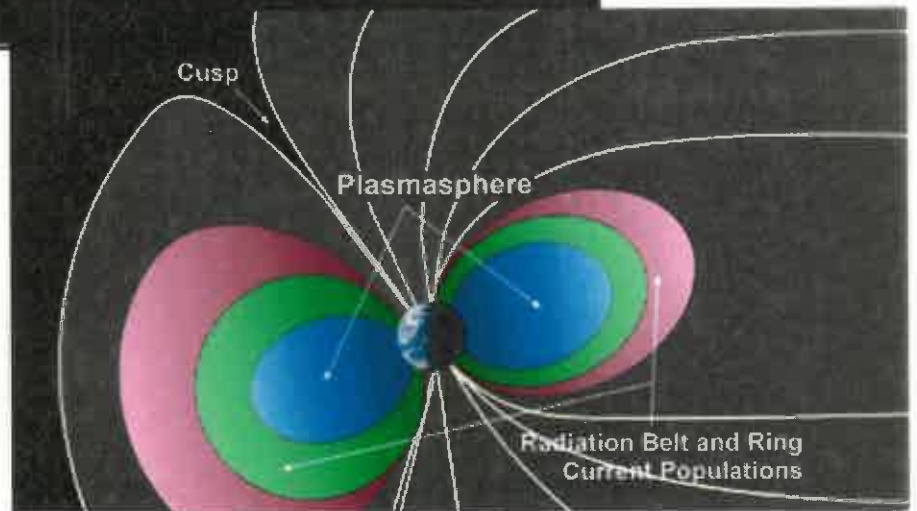
Van Allen Belts
Plasmasphere
Ionosphere

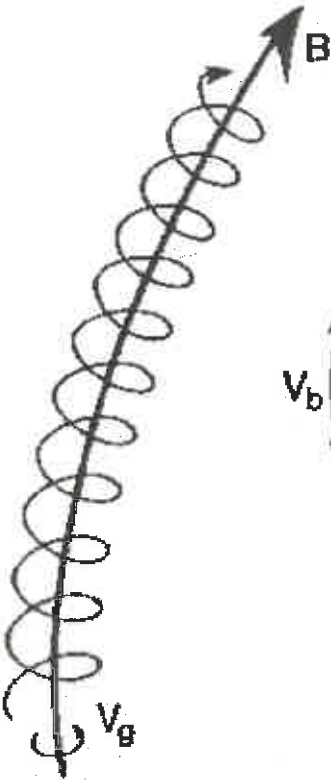


Inner and outer Van Allen Belts



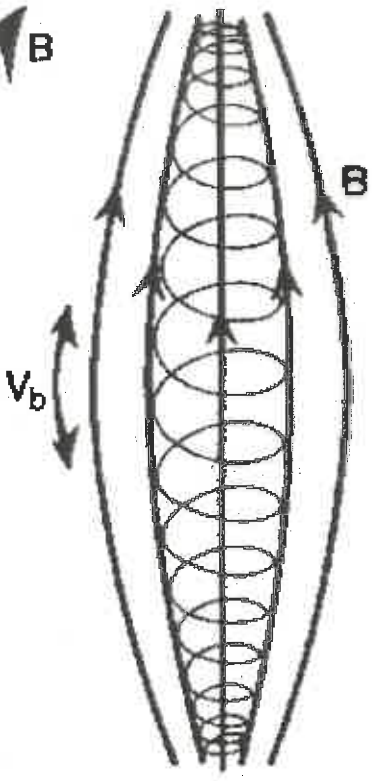
Plasmasphere boils off ionosphere





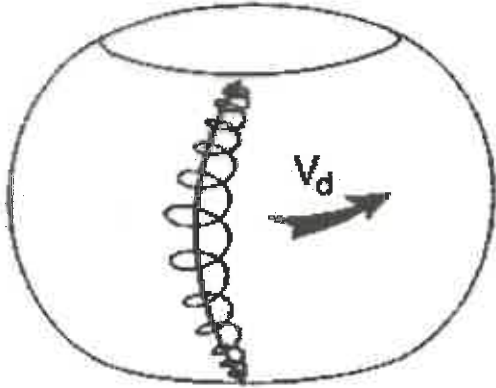
Gyro Motion

$10^{-3} - 1$ sec



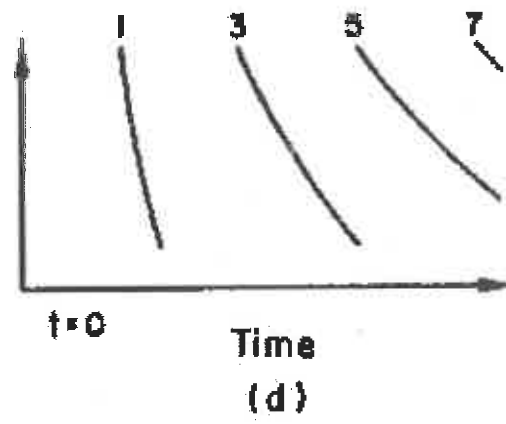
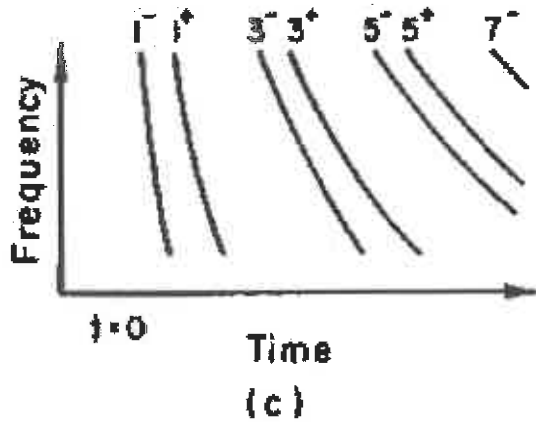
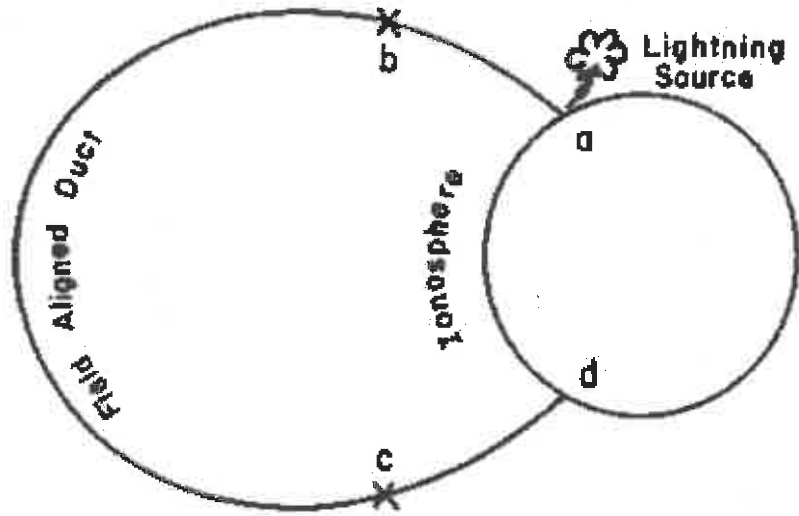
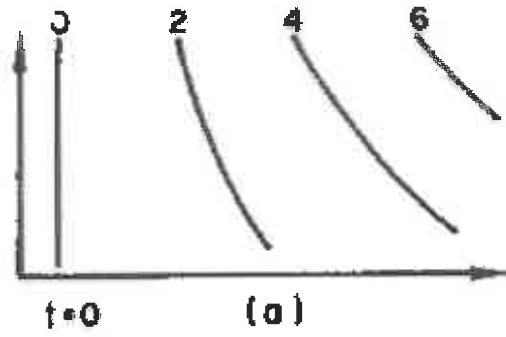
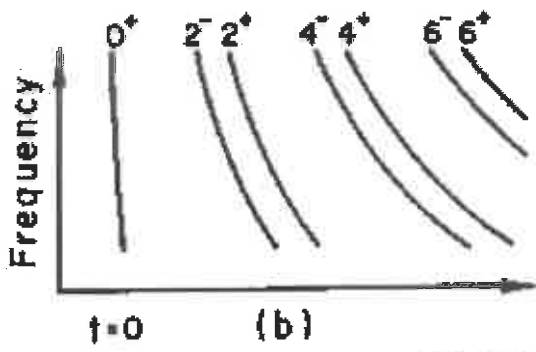
Bounce Motion

Sec - min



Drift Motion

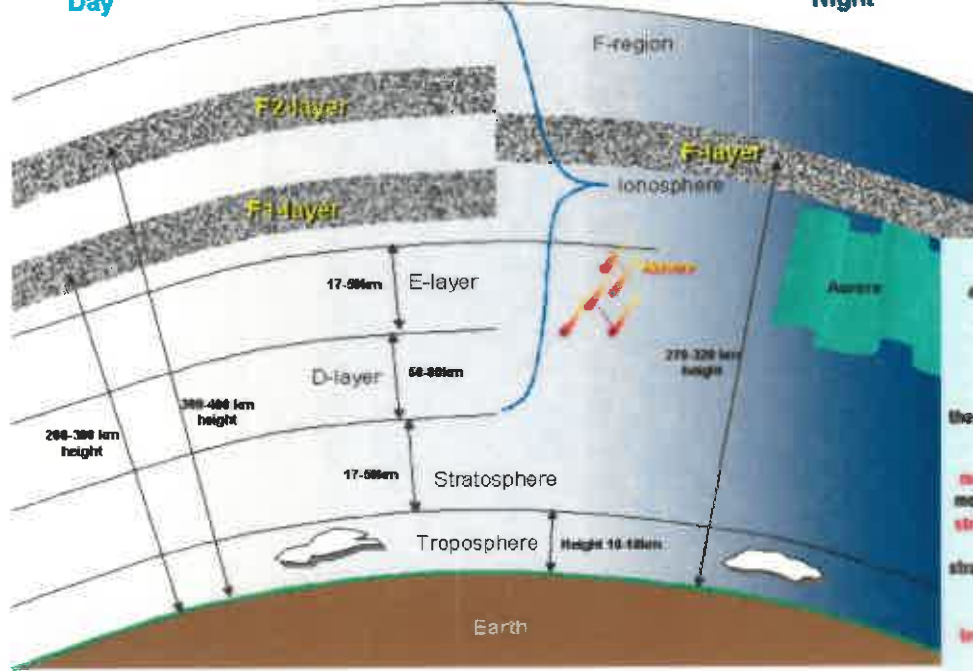
min - hr



Day

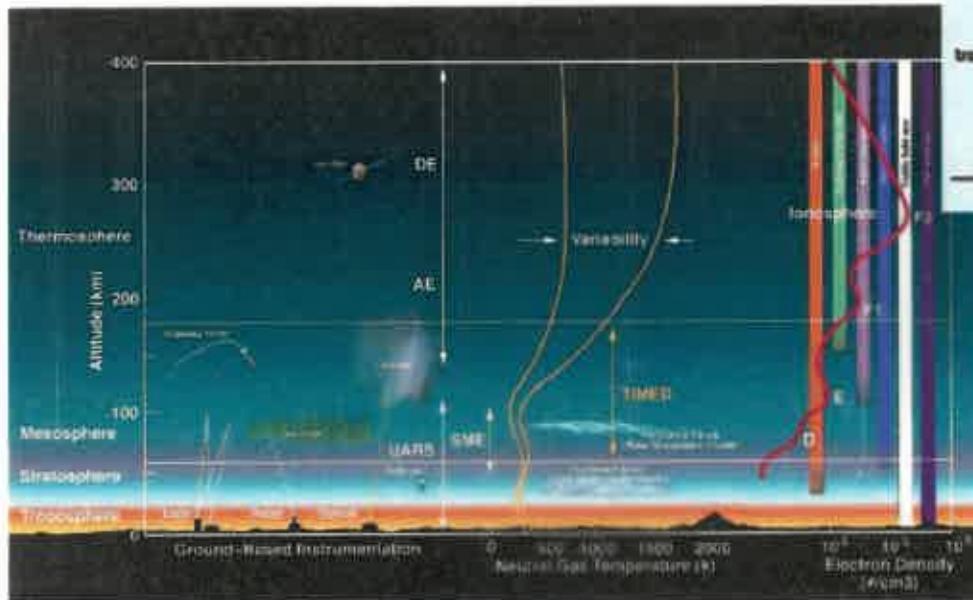
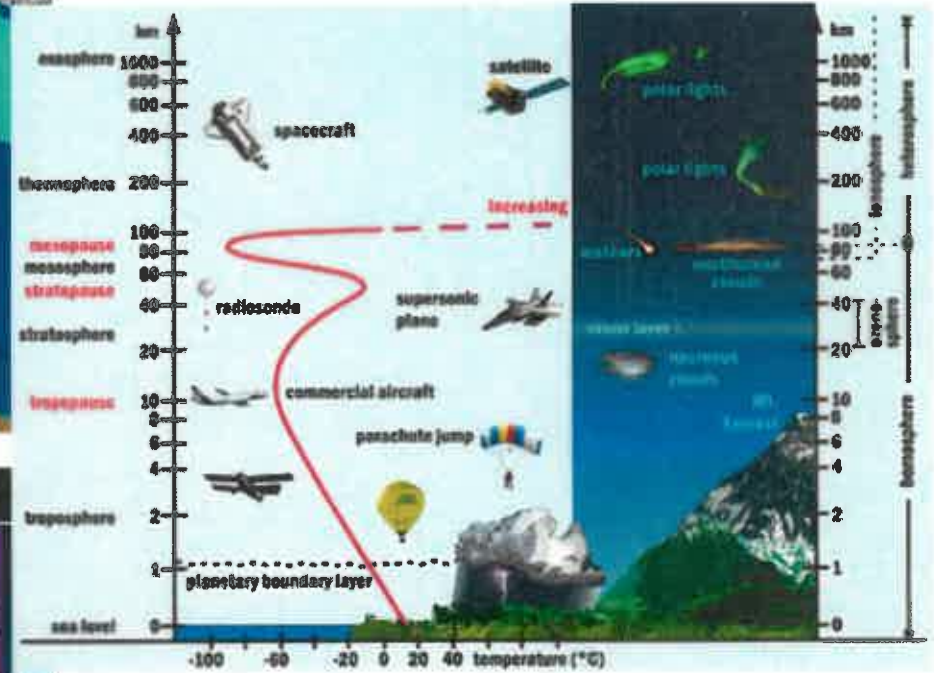
The Sky Above

Night



Thermosphere
 Mesosphere
 Stratosphere
 troposphere

Plasmasphere
 Ionosphere



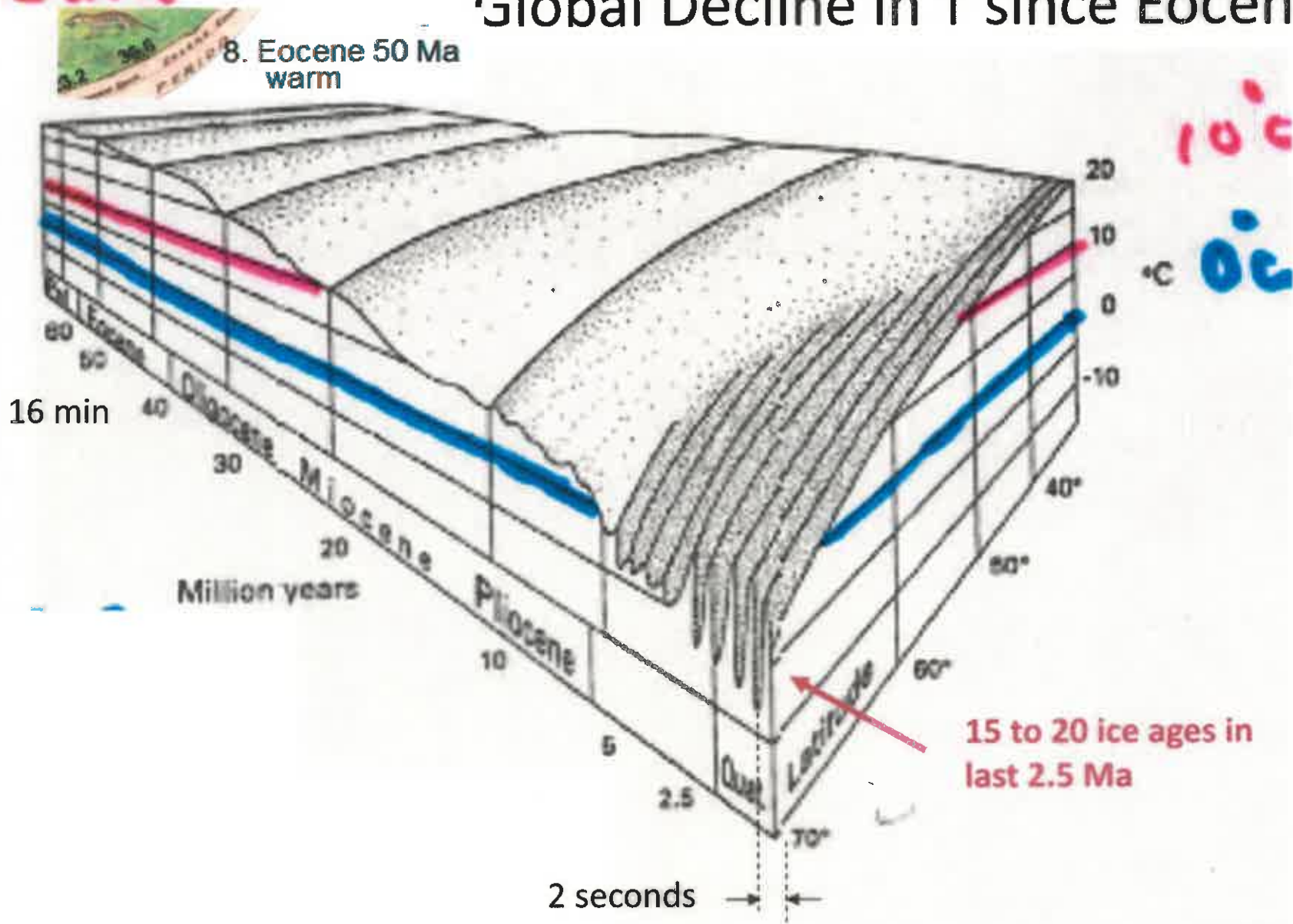
Climate requires time Perspective

- Geologic history (4.56 billion years) is to all of recorded human history (6 thousand years) as 1 day is to the last 0.1 seconds of that day: We must use geological evidence to gain perspective.

4.56 Ga	Solar System	24 hrs
3.8	Amitsog Gneiss	20 hrs
0.57	Skeletal Creatures	3 hrs
0.066	Dinosaurs Extinct	21 min
0.050	Tropical England	16 min
0.003	Humanoids	1 minute
0.000006	Recorded History	0.1 sec

Eden

Global Decline in T since Eocene



From Bloom, 1998

20 Ma, Lucern Area

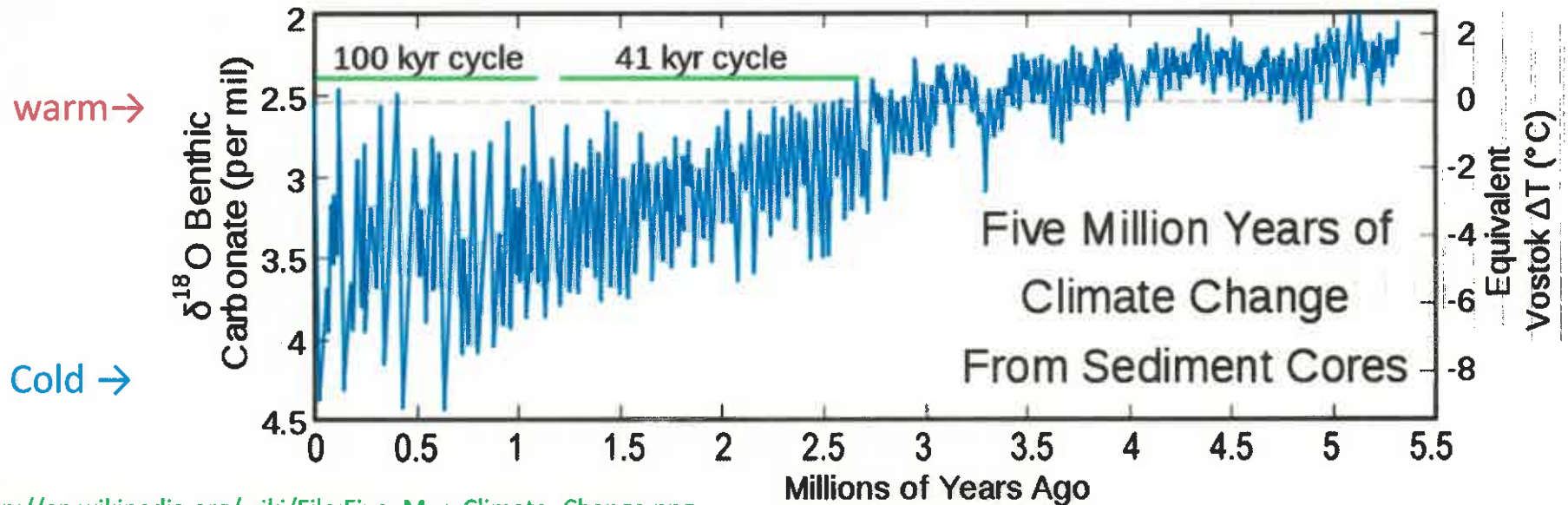
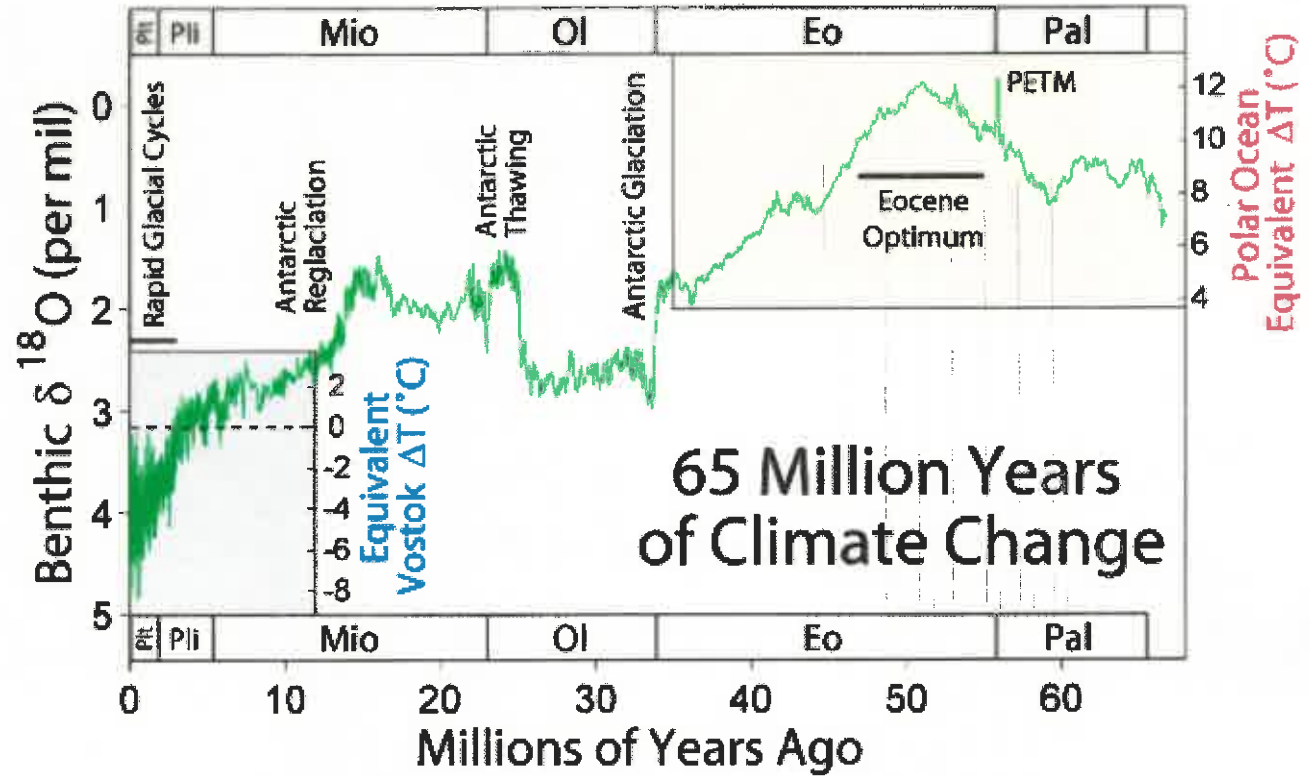


20 ka

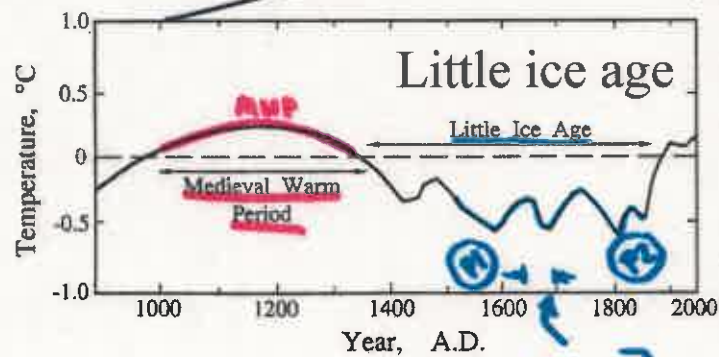
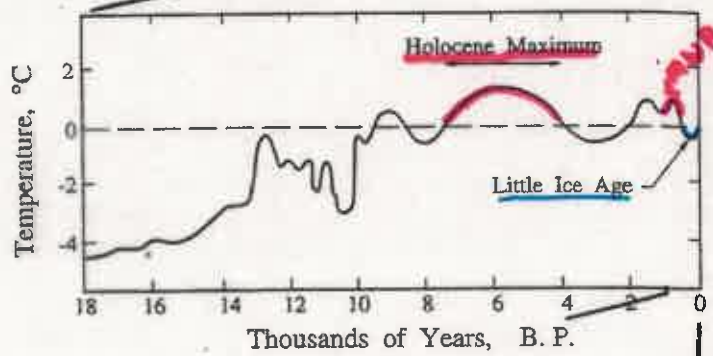
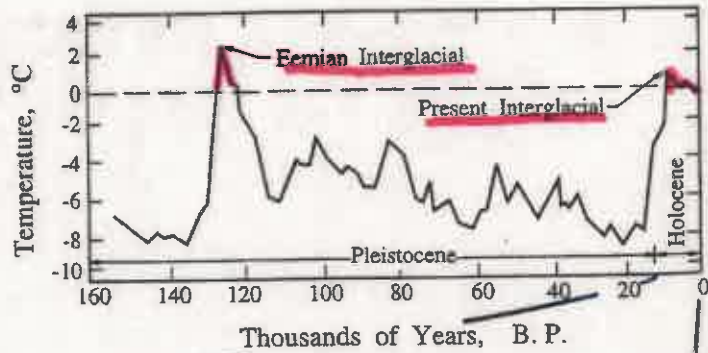


More Details

1. High ^{18}O = cold
Ice takes ^{16}O
2. Present T
warmest ~1% of last
2.5 Ma



Historical Zoom:



Mandarin
Mandarin
(No Satisfy)

1565 (P1)



'Hunters in the Snow' in 1565, when Pieter Bruegel the Elder painted this picture, the Earth's climate was ice-crawling in the Little Ice Age. Contemporary rates of

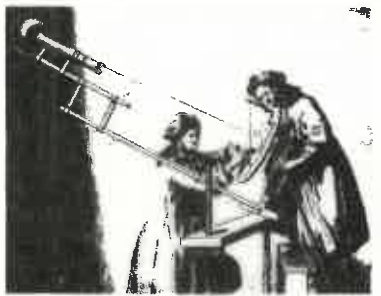
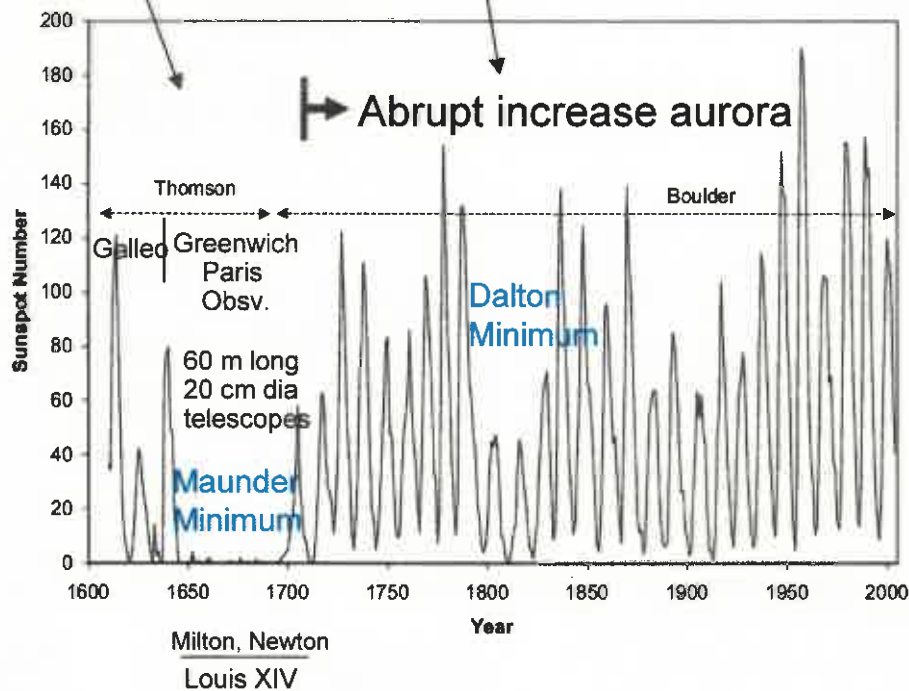
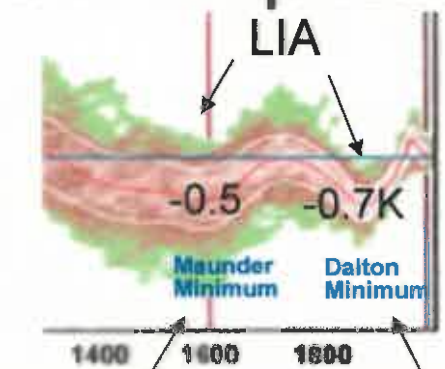


Below the global warming in the 1990s the world was, on average, about 100 degrees cooler than the 1990s. The 1990s is a very warm, or even by the low standard (Chernobyl) April International Energy Agency

Sun implicated in Holocene climate changes...

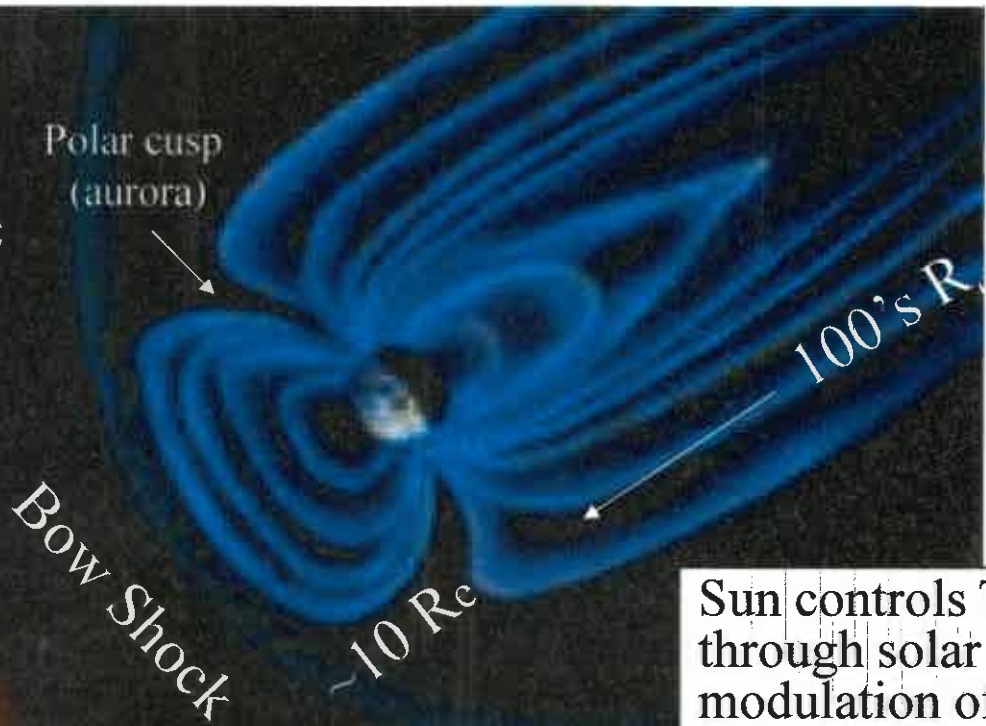
During Maunder Minimum:

There were no sunspots, no solar corona during eclipses, and no aurora displays- sun was "off"



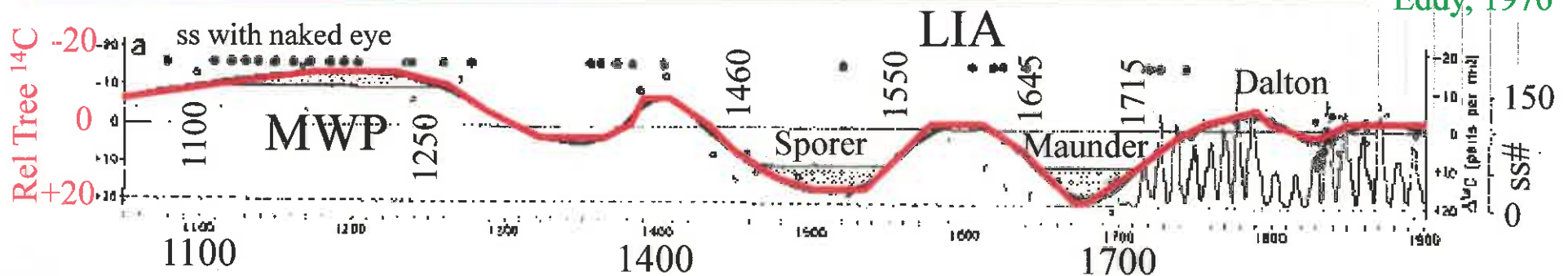
Eddy, The Maunder Minimum, Science, 1976

Solar wind interacts with earth's magnetic field producing magnetosphere



Sun controls T_{earth} through solar wind's modulation of cosmic ray shield; recipe

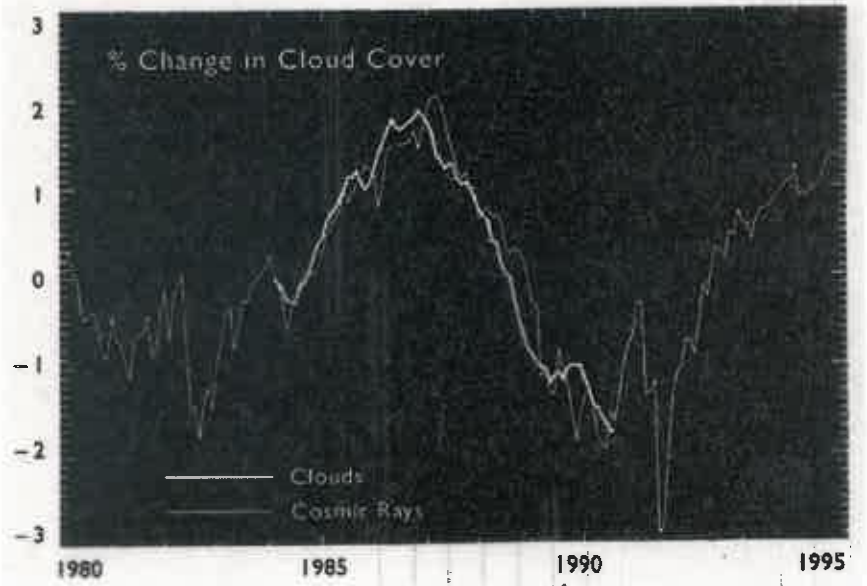
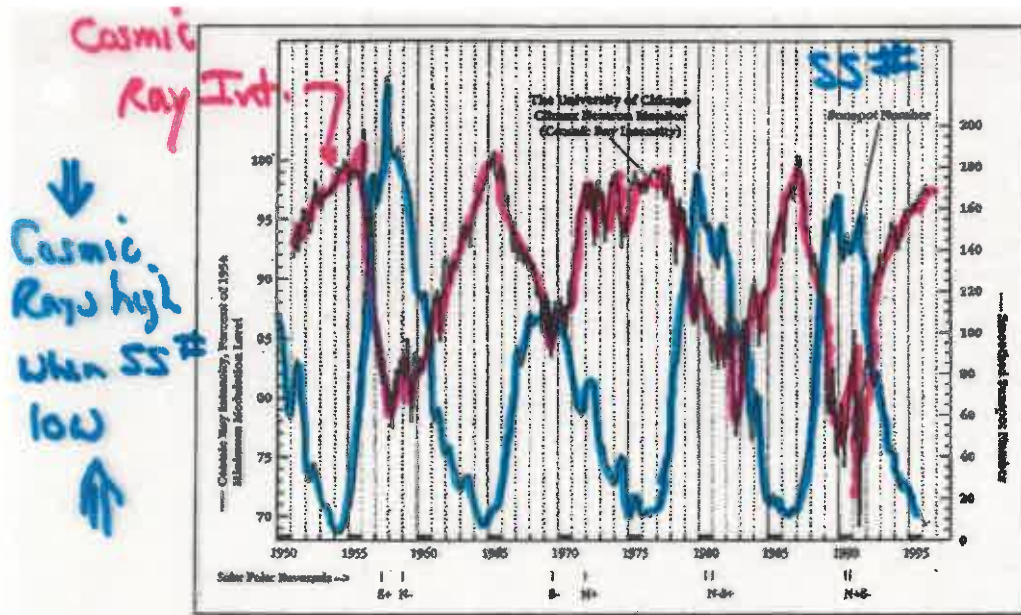
- Recipe:
- Sun Off
 - Magnetic shield down
 - More cosmogenic isotopes ^{14}C , ^{10}Be
 - Colder
- evidence



Eddy, 1976

Cosmic Ray Intensity correlates with Sunspot activity

Clouds correlate with cosmic ray intensity (climate connection?)



Current testing: CLOUD experiment in CERN

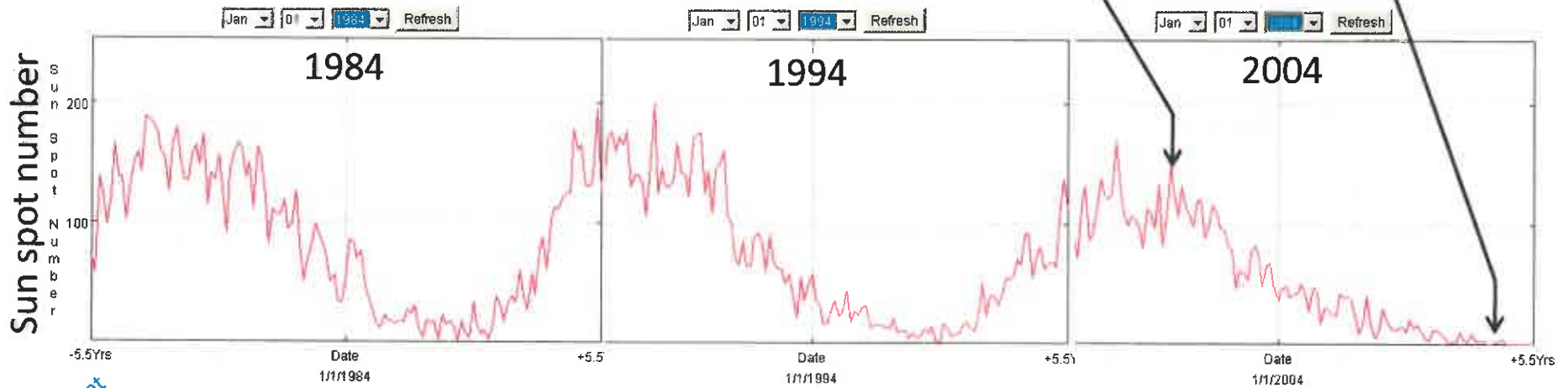
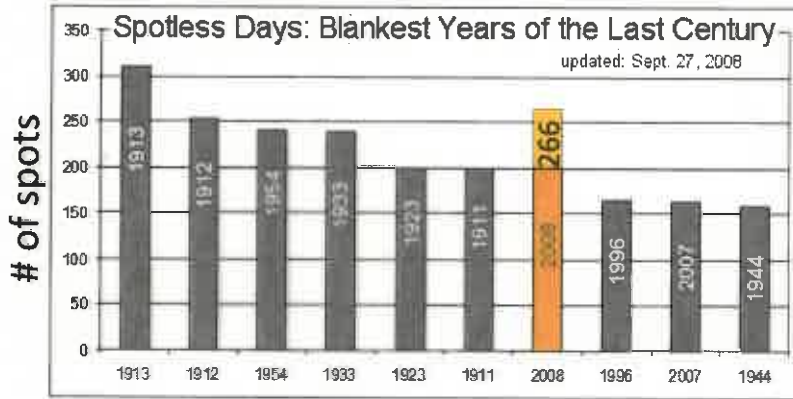
2008: the "blankest year of space age"

Solar wind
20% drop
since 1990s



http://science.nasa.gov/headlines/y2008/23sep_solarwind.htm

2008 had most spotless days since 1913



Easy to get

<http://spaceweather.com/glossary/sunspotplotter.htm>

<http://spaceweather.com>