Long-Term Evolution of the Geospace Climate

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Take away messages

What is it that heliophysics can learn from stars

and

How did early humans know there was a geospace around the Earth?

anet research can learn from heliophysics

The SAIR protects the lower atmosphere from space weathers FLARES, AURORA, and MAGNETOSPHERIC ELECTRIC FIELDS

When I was a lad, a tiny wee lad
My mother said to me
Come see the Northern Lights my boy
They're bright as they can be
She called them the heavenly dancers
Merry dancers in the sky
I'll never forget, that wonderful sight
They made the heavens bright

Aurora, what is it called in your country?

Post what it is called in your language.

Post an English translation.

Post the name of your country.

Describe the traditional explanation of the aurora in your culture.

Nick will be collecting the data..

History

- 30,000 BC Cro-Magnon “Macaronis”
- 567 BC Babylonians Clay Tablet
- 467 BC Greek sighting of red aurora/sunspots
- 28 BC Chinese records of Aurora/sunspots

- Scientific Counting of Sunspots, 1600 ish
- Then, they went away, 1645-1715
- William Herschel, really bad harvests!
- Magnetometers detected variability!

- Geospace – Solar impact, 1859
- Carrington white light flare and Kew Observatory magnetometer

A working definition of Geospace.

Outer boundary of geospace is the magnetopause/bow-shock and the inner boundary is the lower ionosphere, the SAIR.

The outer boundary interfaces to the solar wind, while the inner boundary interfaces to the atmosphere (at the SAIR).

Solar EUV Photon Radiation

Solar Irradiance at 1 AU is 1340 W/m^2

Solar Minimum EUV irradiance is 2 to 3 mW/m^2

Solar Maximum EUV irradiance is 7 to 8 mW/m^2

Special global averaged 1-D ionosphere – upper atmosphere models to study I-T response to sun's EUV, and extremes of EUV.

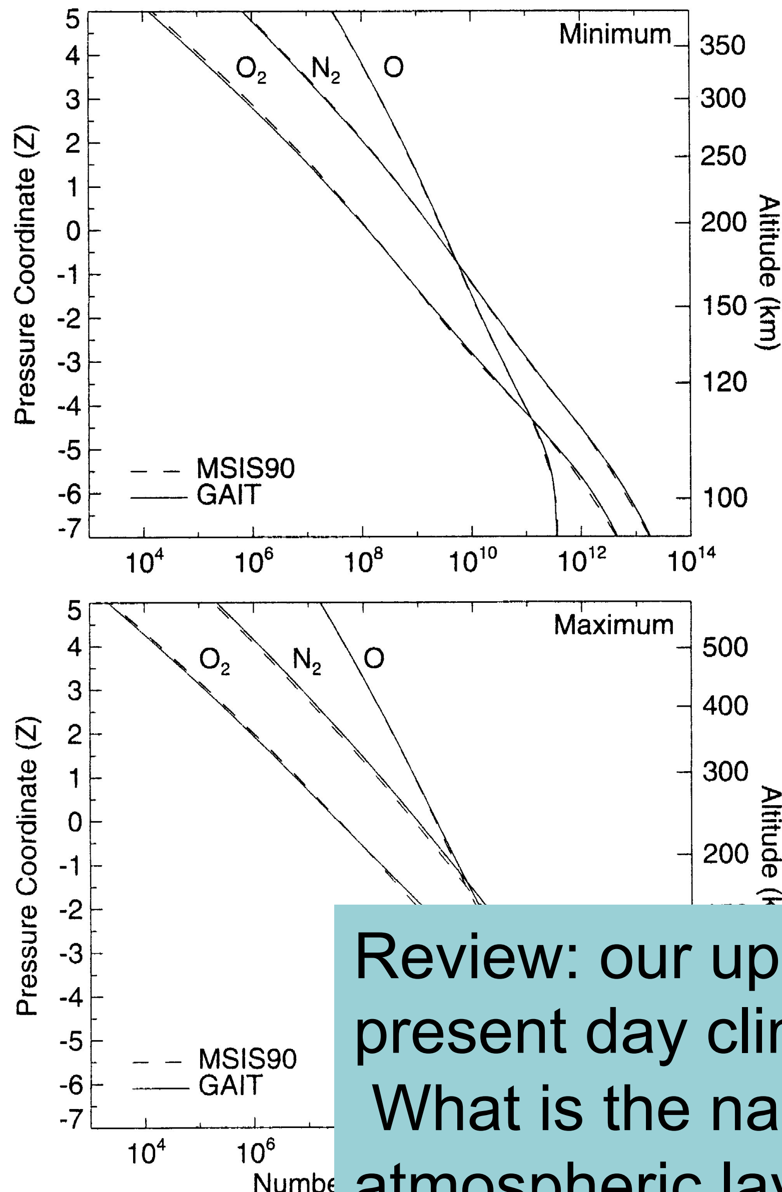
Roble, 1987

Smithtro and Sojka, 2005

Tian et al., 2008

One could argue that solar cycle EUV determines geospace climate

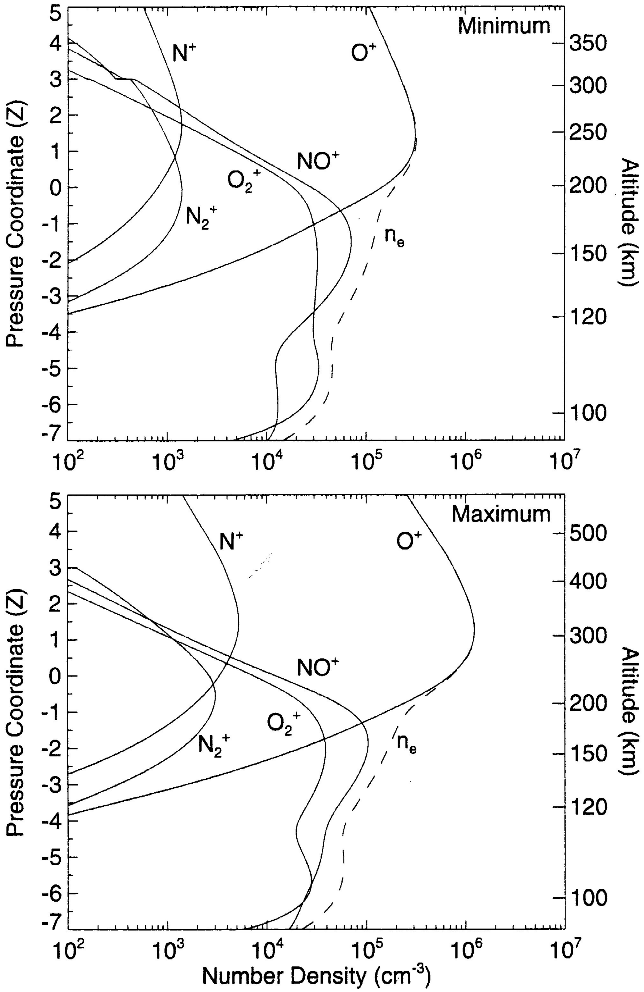
$Z=\ln(p_0/p)$



Dashed line is from the MSIS empirical neutral atmosphere model, hence ground truth!

Review: our upper atmosphere present day climatology. What is the name of this atmospheric layer?

F-region peak is located at about Z=1
But at variable altitudes, WHY?



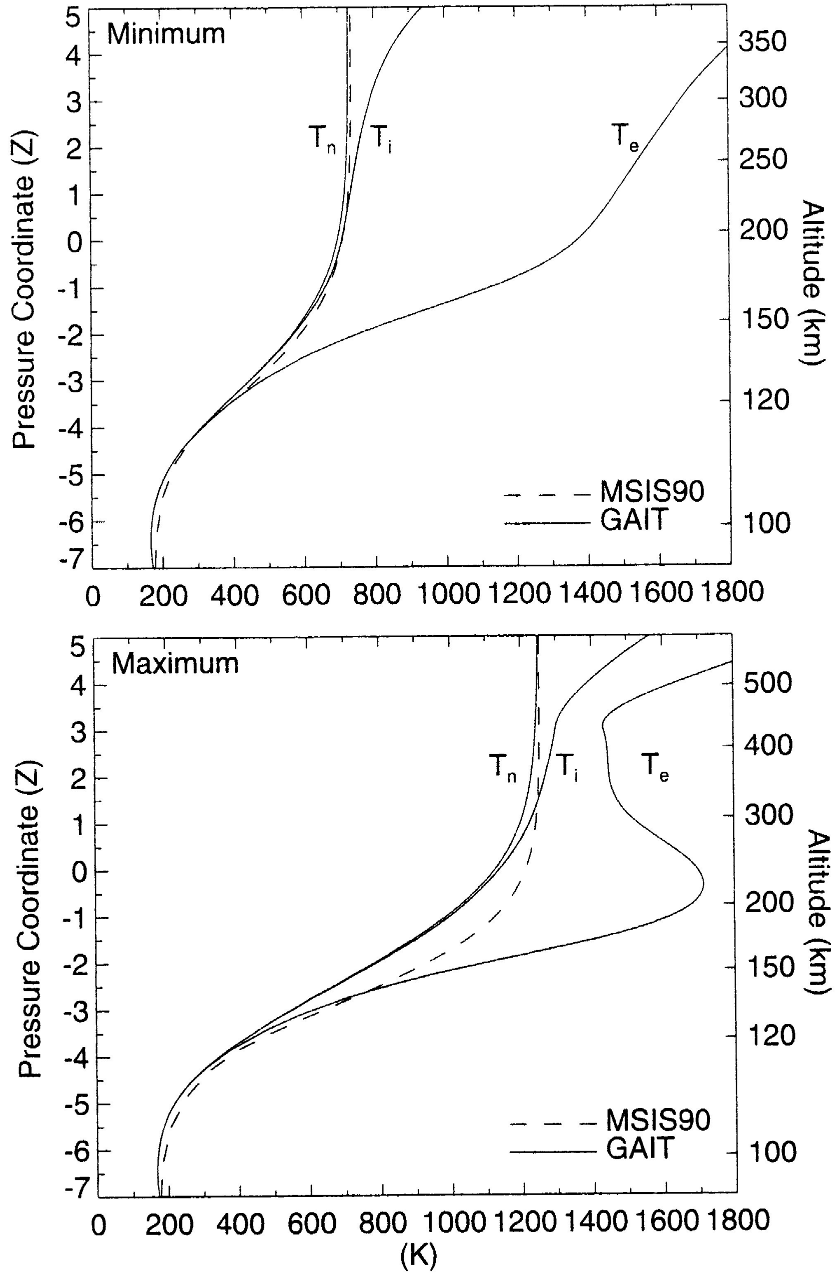
Solar Minimum:
hmF2 = 250km
NmF2 = 3 x 10^5 cm^{-3}

Solar Maximum:
hmF2 = 305 km
NmF2 = 1.3 x 10^6 cm^{-3}

The mesosphere at Altitudes below 100 km has almost no solar cycle dependence!

Why are the dayside electron temperatures elevated?

The electrons also couple to a hot magnetospheric reservoir in the top-side that has a weak solar cycle dependence.

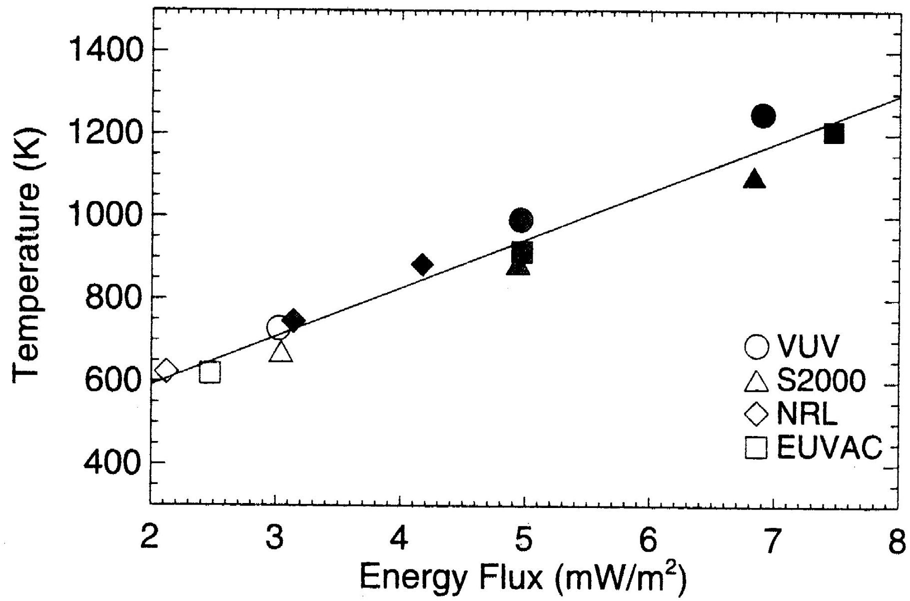


S introduced as a Solar EUV index

Maunder Minimum

Grand Maximum

S negative S=0 S=1 S=2 and 3



4 standard EUV models

Maunder Minimum

Run the global average I-T models for S values of -0.5 and -1.0

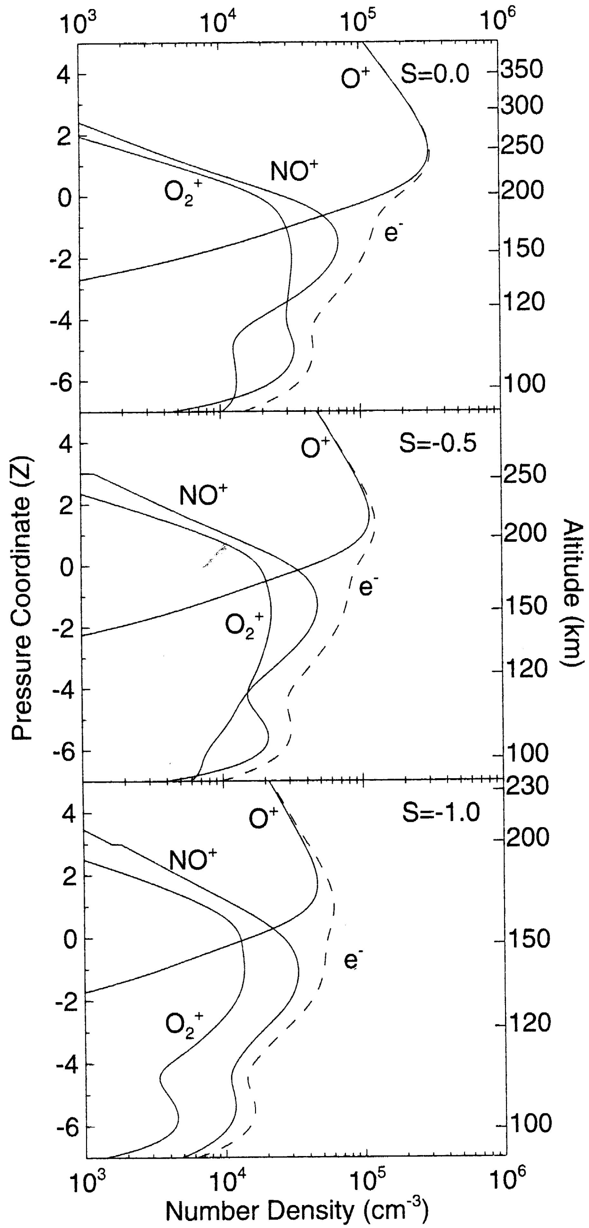
What could happen?

Would we even know geospace was affected?

Hint: for about 100years humans have developed technologies that depend on GEOSPACE!

The F-layer peak stays at a constant pressure level surface.

Almost a G-condition



hmF2 = 250km
NmF2 = 3 x 10^5 cm^{-3}

hmF2 = 220km
NmF2 = 1.1 x 10^5 cm^{-3}

hmF2 = 180km
NmF2 = 5 x 10^4 cm^{-3}

Maunder Minimum

Radio waves used today to carry over the horizon radar work will not go over the horizon!

But satellite drag would be insignificant in todays “LEO” orbits.

GPS geo-location would be almost independent of the ionosphere.

Marconi’s trans-Atlantic first radio communication might not have worked!

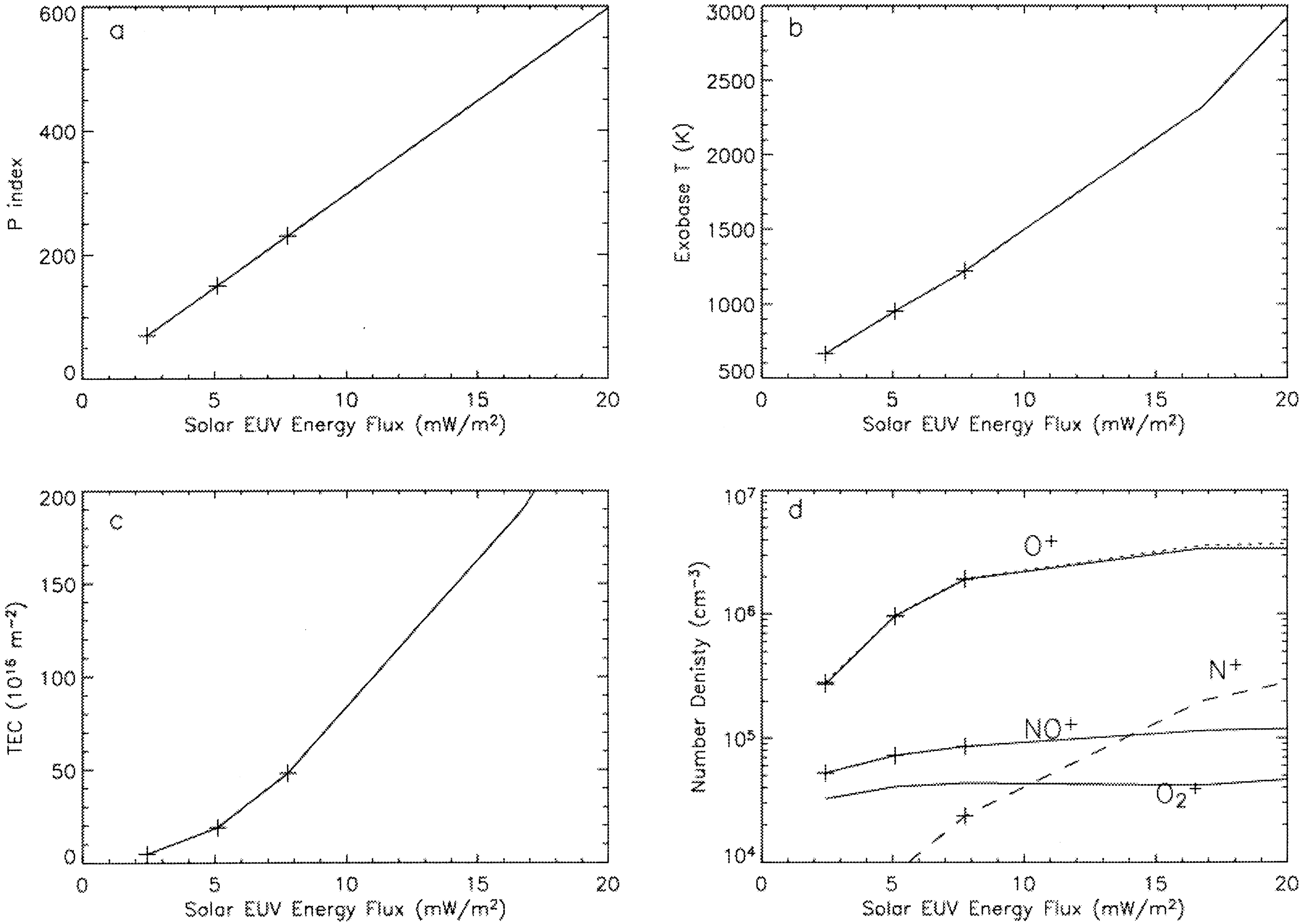
Extreme Maxima

The Grand maximum occurred around 1250 AD !

The S index could well be between 2 and 3 for these conditions.

Which would correspond to EUV fluxes from 14 to 21 mW/m^2

Tian et al model studied this condition and even more extreme conditions.


a
P index
600
400
200
0
0
5
10
15
20
Solar EUV Energy Flux (mW/m²)
b
Exobase T (K)
3000
2500
2000
1500
1000
500
c
TEC (10¹⁶ m⁻²)
200
150
100
50
d
Number Denisty (cm⁻³)
10⁷
10⁶
10⁵
10⁴
O+
N+
NO+
O2+

Extreme Maxima

The hmF2 height for S=2 and S=3 are 360km and 500km

BUT the O+ peak density, NmF2, saturates at about 2 x 10^6 cm-3

However, total electron content (TEC) continues to increase linearly!

The exospheric temperature also increases linearly with EUV irradiance.

The exospheric temperature at S = 3, reaches almost 3000K, is this important?

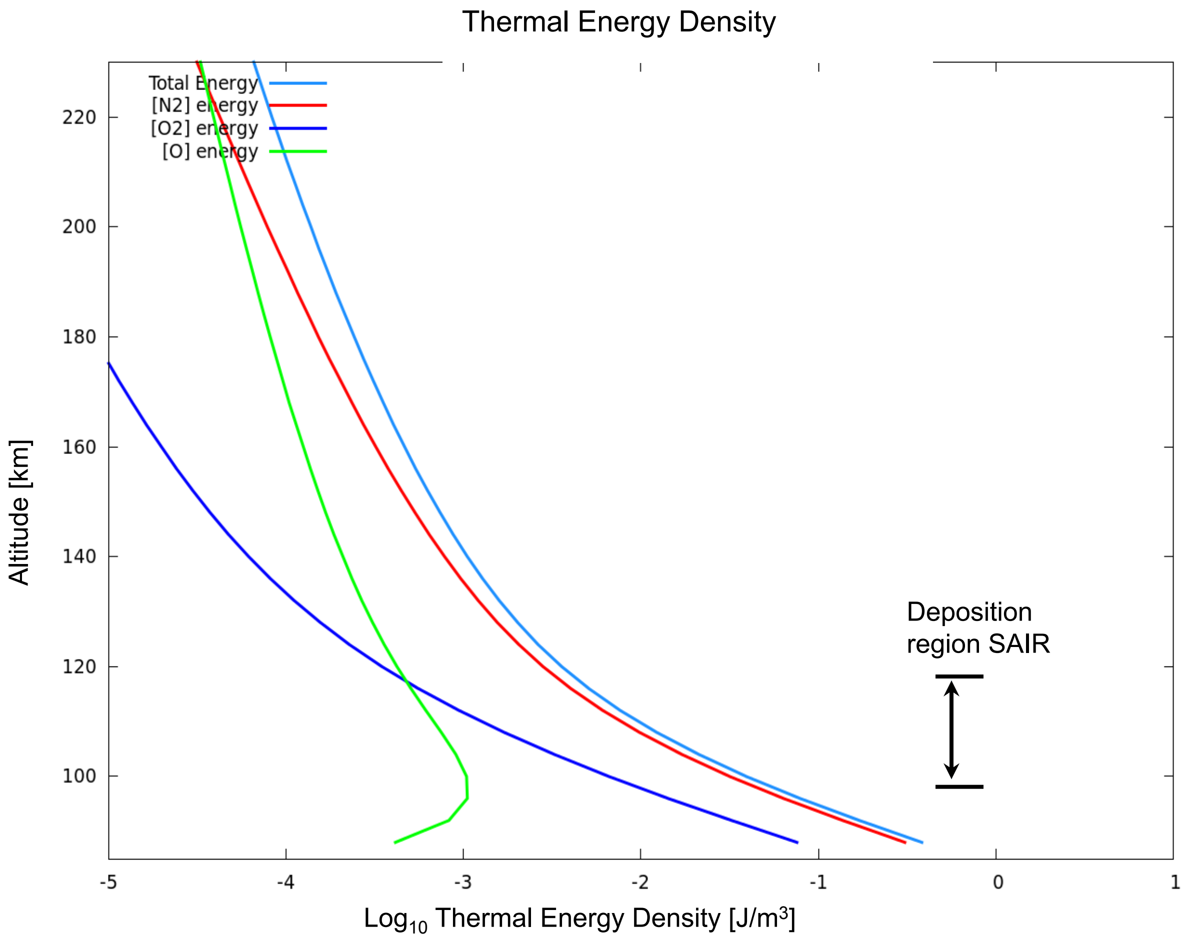
Does Space Weather impact Geospace Climate?

Today there are three main aspects of space weather that can supply enough energy in a space weather event to disrupt geospace climatology:

1) Aurora associated with major geomagnetic storms,

2) X-Class solar flares,

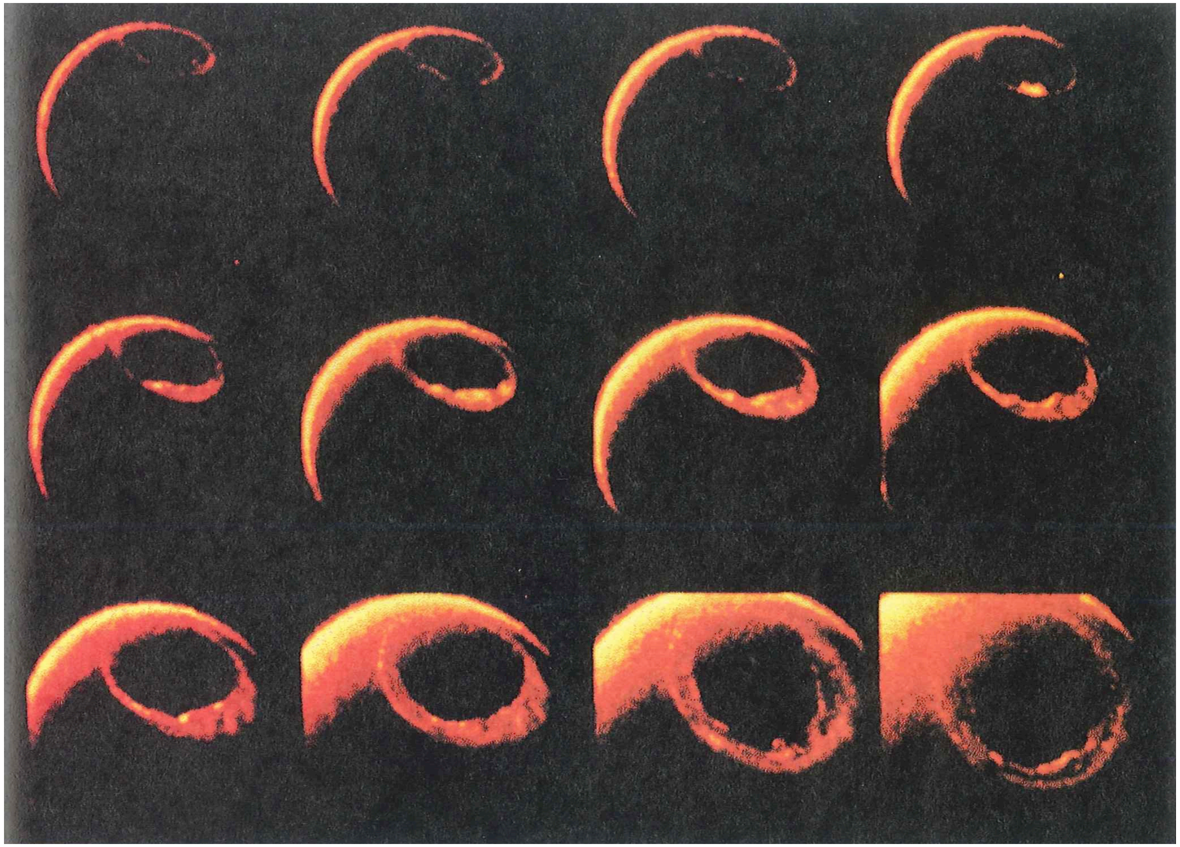
3) Joule heating associated with very large magnetospheric cross tail potentials.



Combining neutral density and temperature produces the altitude distributions of only the thermal energy density.

During a space weather event is there sufficient energy deposited to cause a hydrostatic "climate" scenario to become a hydrodynamic problem?

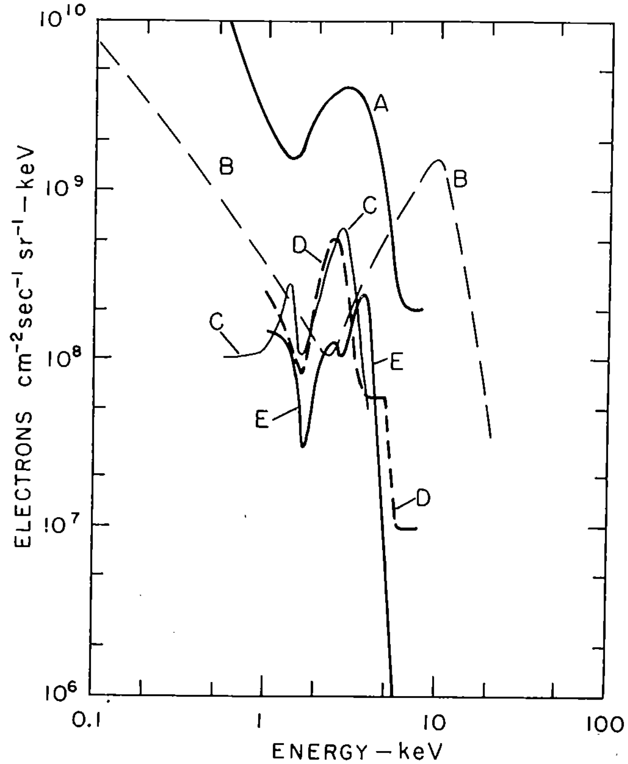
Dynamics Explorer Auroral Images: 12 Minute cadence



Sunlight

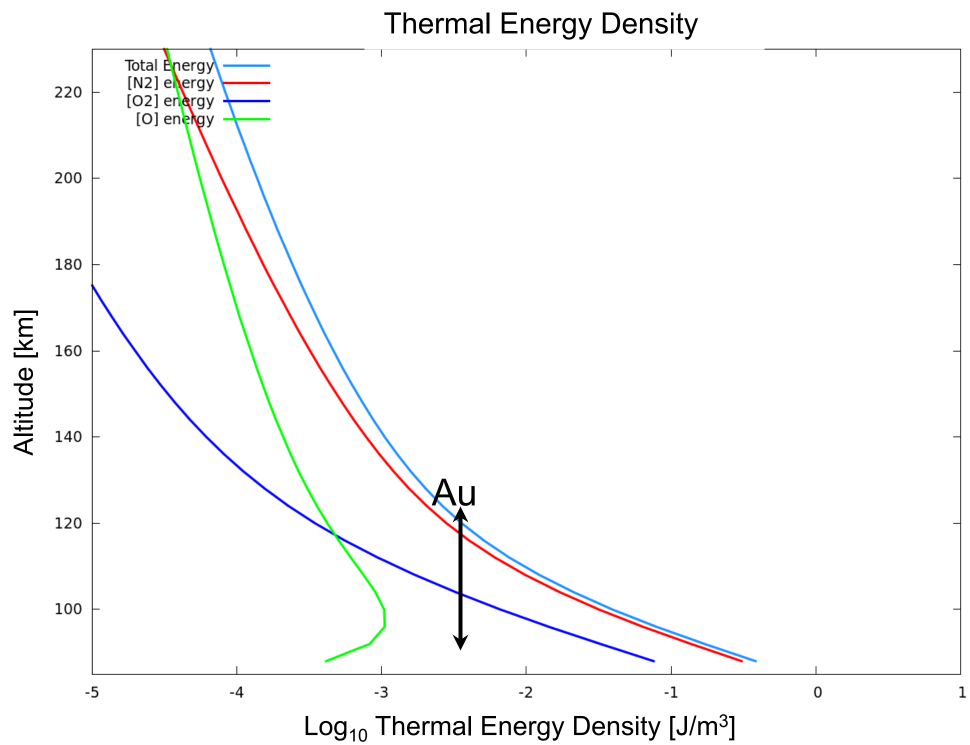
Knipp, D. J. (2011), *Understanding Space Weather and the Physics Behind it*, M. McQuade and D. Kirkpatrick (Eds.) McGraw-Hill

Auroral Electron Spectra



Choose A as "typical" of strong auroral precipitation.

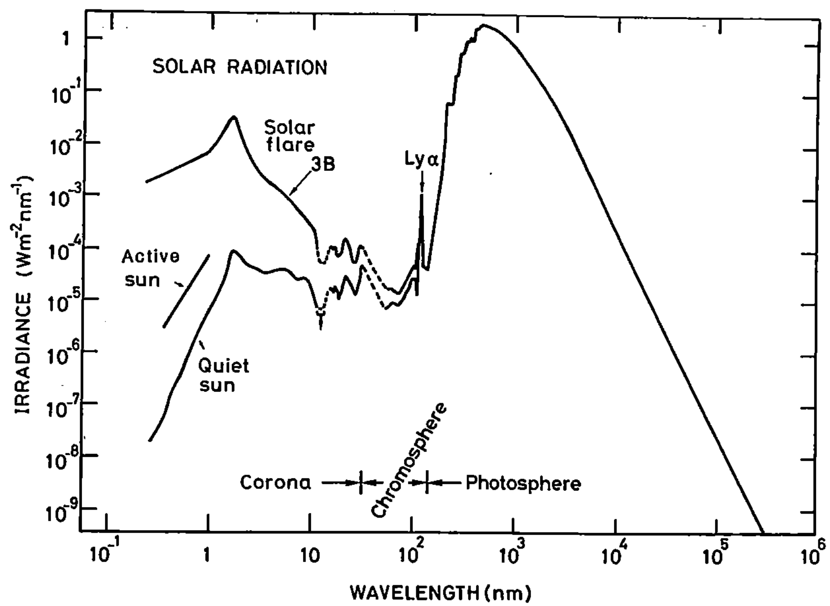
Jones, A. V. (1974), *Aurora*, B. M. McCormac (Ed.), D. Reidel Publishing



In auroral zone the strong precipitation can result in up to 3 mJ/m^3 between 95 and 120 km altitude.

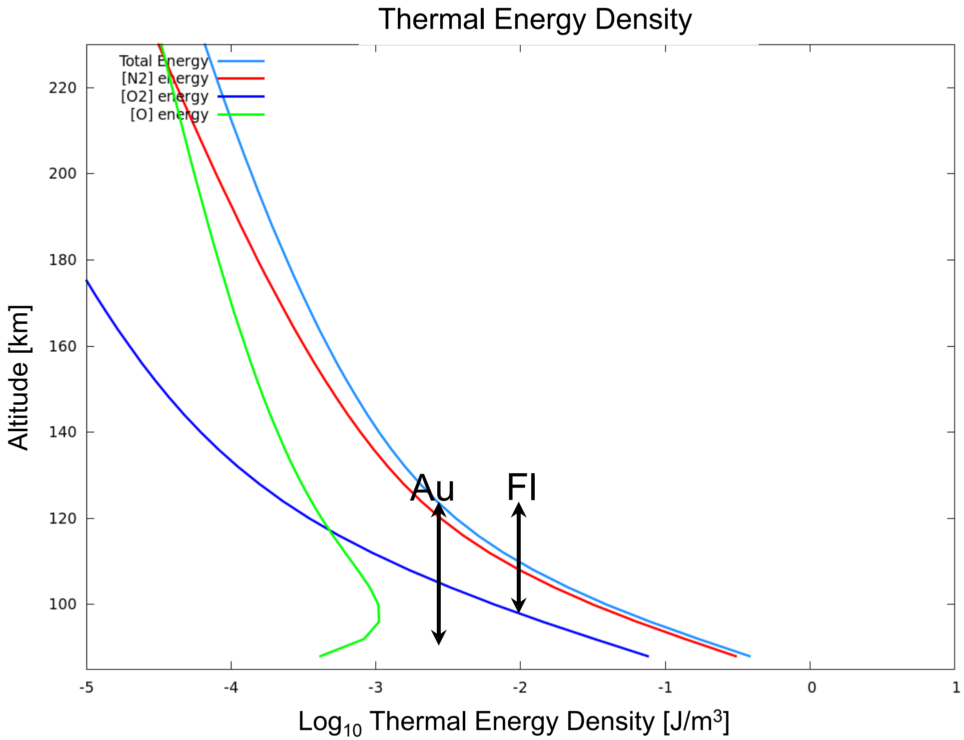
Assume 10 minute integration!

X-ray flares lead to significant Space Weather energy deposition in atmosphere



Photons in the 1 to 10 nm range are most geo-effective

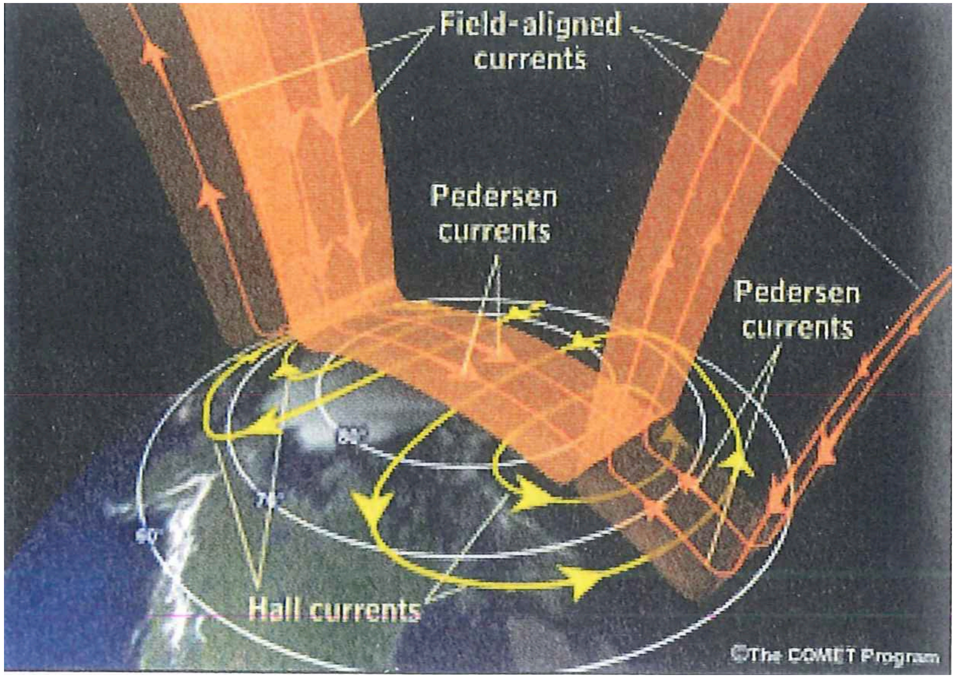
From Aeronomy of the Middle Atmosphere: Brasseur and Solomon (1984)



On the dayside a strong X-ray flare can result in up to 10 mJ/m^3 between 100 and 120 km altitude.

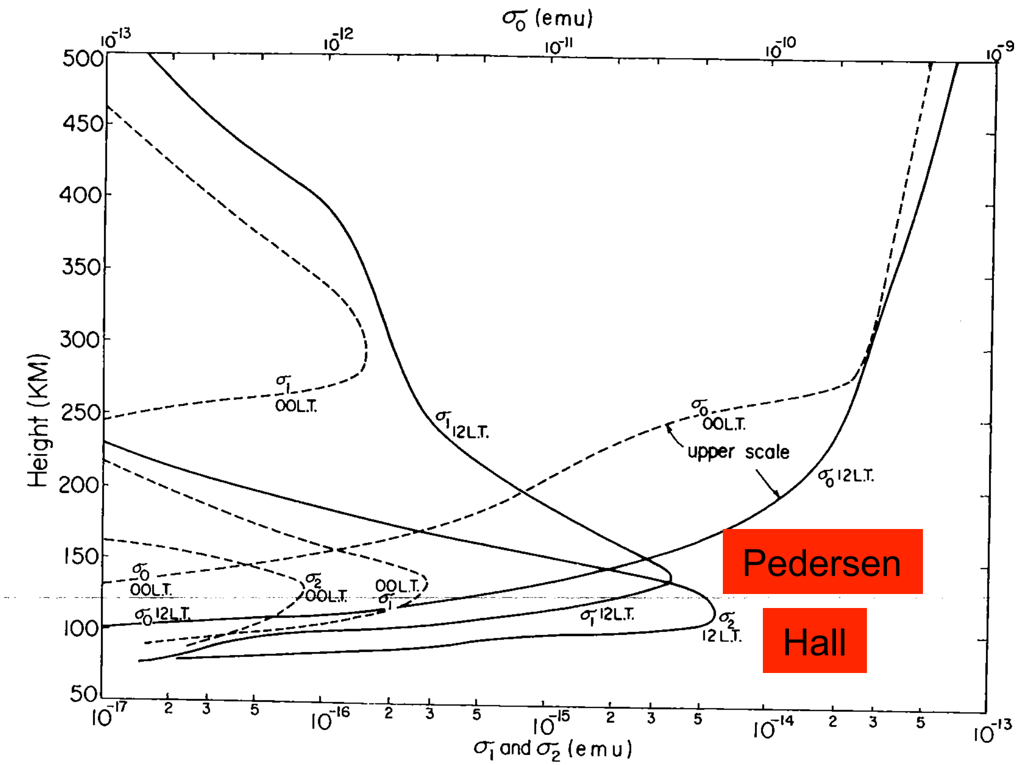
Assume 20 minute integration!

Schematic of M-I coupling electrodynamic closure in the ionosphere

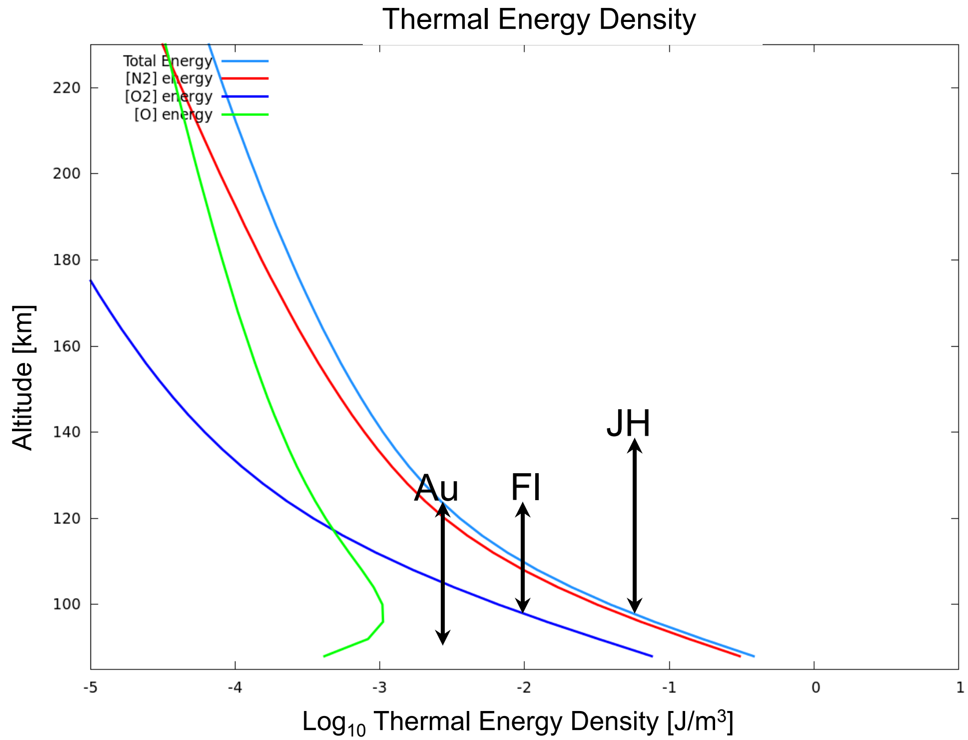


Knipp, D. J. (2011), *Understanding Space Weather and the Physics Behind it*, M. McQuade and D. Kirkpatrick (Eds.) McGraw-Hill

Closure altitude determined by altitude of conductivity layers.



Matsushita, S. (1967),Solar Quiet and Lunar Daily Variation Fields, in *Physics of Geomagnetic Phenomena, International Geophysics Series,* vol. 1, edited by S. Matsushita and W. H. Campbell, pp. 301-424, Academic Press, New York.



In the auroral zone Joule heating can result in up to 60 mJ/m^3 between 100 and 140 km altitude.

Assume 3 hour storm integration!

Present day space weather does disrupt geospace climatology on short time scales of hours to days associated with a specific space weather event!

Tracking of LEO satellite and space debris is disrupted!

GPS geolocation tools are disrupted during such periods!

But humans get the pleasure of seeing geospace's beauty at mid-latitudes!

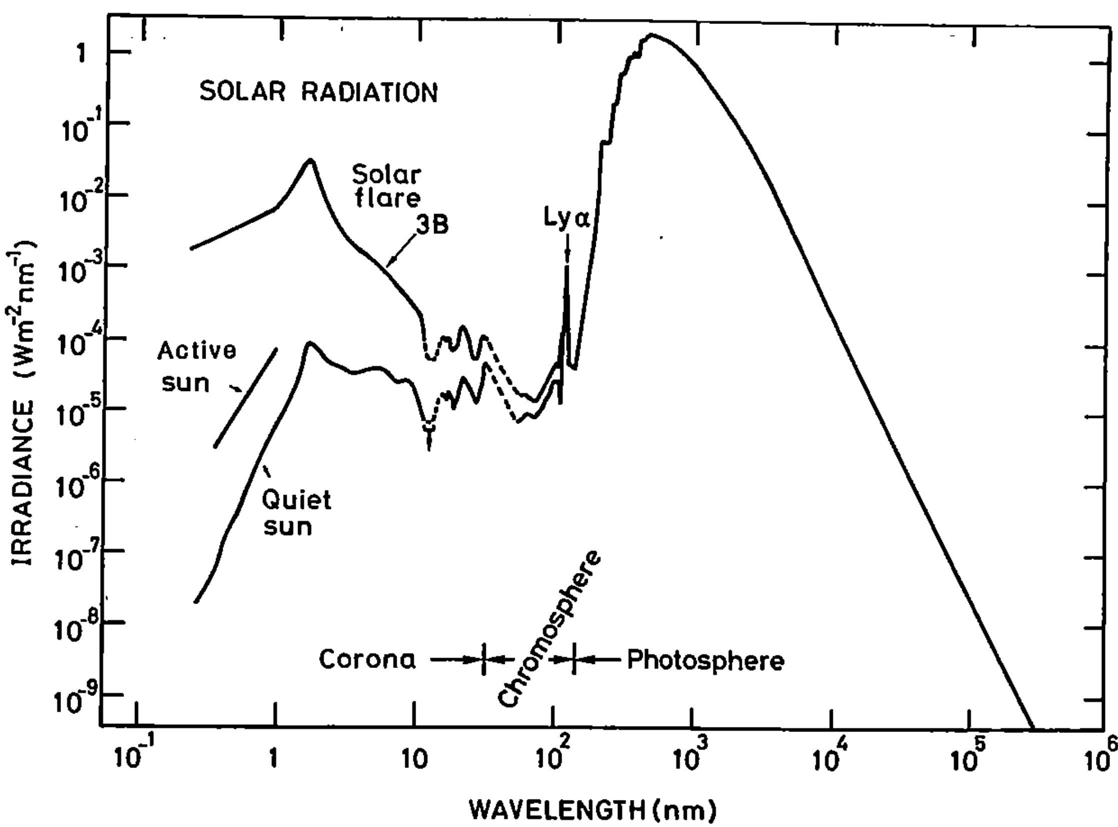
PART-II Billions of years ago!
Or
EXO-planets and their stars

Main Sequence star temperatures:

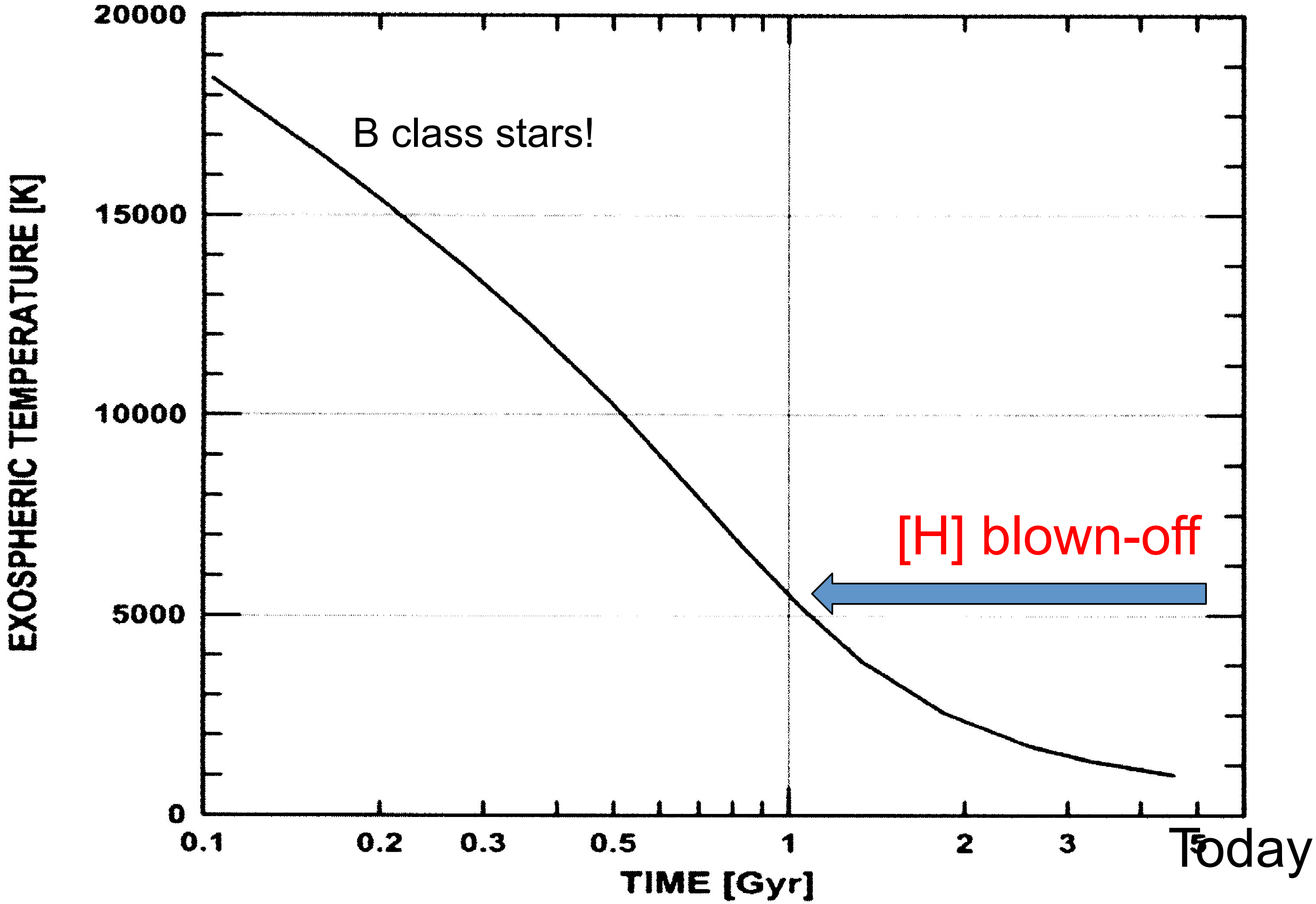
B: 20,000K, no dynamo, no EUV or "Space Weather"

Sun: 6,000K, we have it

M: 2,000K, cold with huge dynamo system, abundant EUV and "space Weather"



Estimated of Thermospheric temperatures in the past

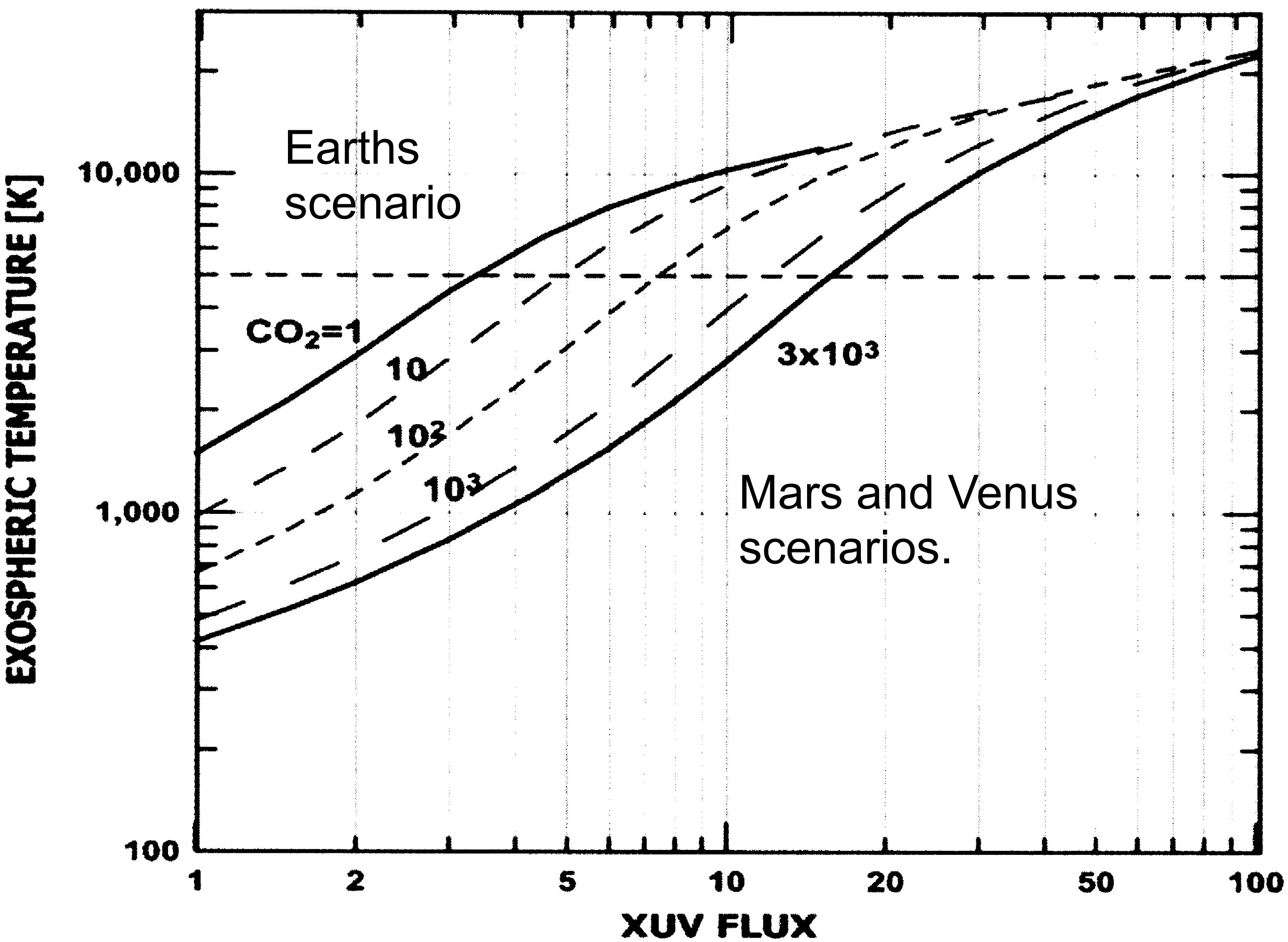


Billions of years ago!

- However there is another significant problem to consider.

- At these earlier times the thermosphere contained CO_2!
- CO_2 is an excellent green house gas in the lower atmosphere but in the thermosphere is acts as an Infra Red (IR) radiator!
- Hence the the CO_2 is competing against the enhanced EUV fluxes to cool the thermosphere.
- Venus and Mars are rich in CO_2 and have very cold thermospheres.

Today



[H] blow-off temperature

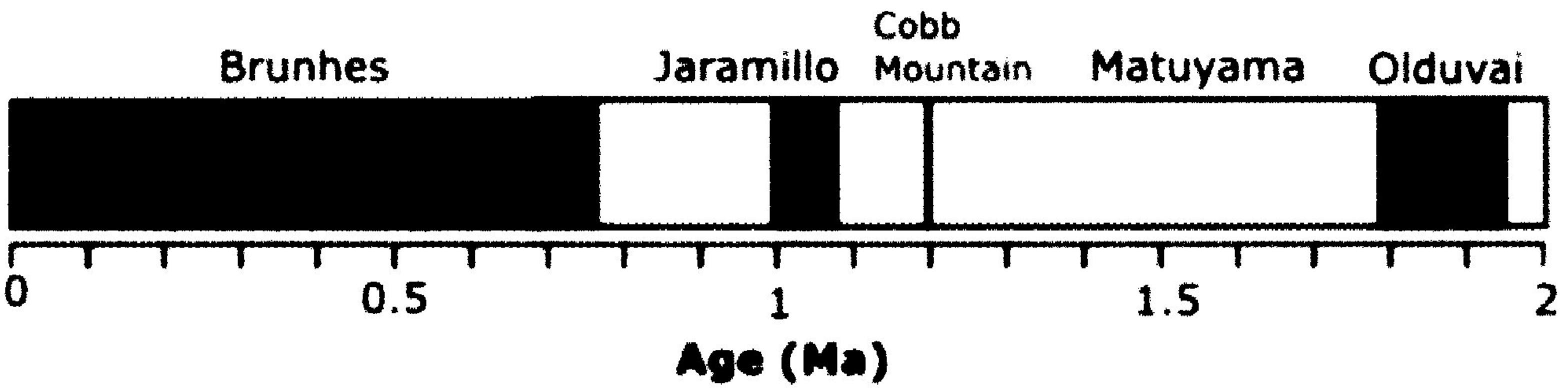
Dipole Field----flips

- The Earth magnetosphere is dependent on the Earth’s intrinsic magnetic field.

- Geologists have collected evidence to quantify the geological history of the “Virtual Axial Dipole Moment” (VADM)
- Higher moments are still difficult to extract.

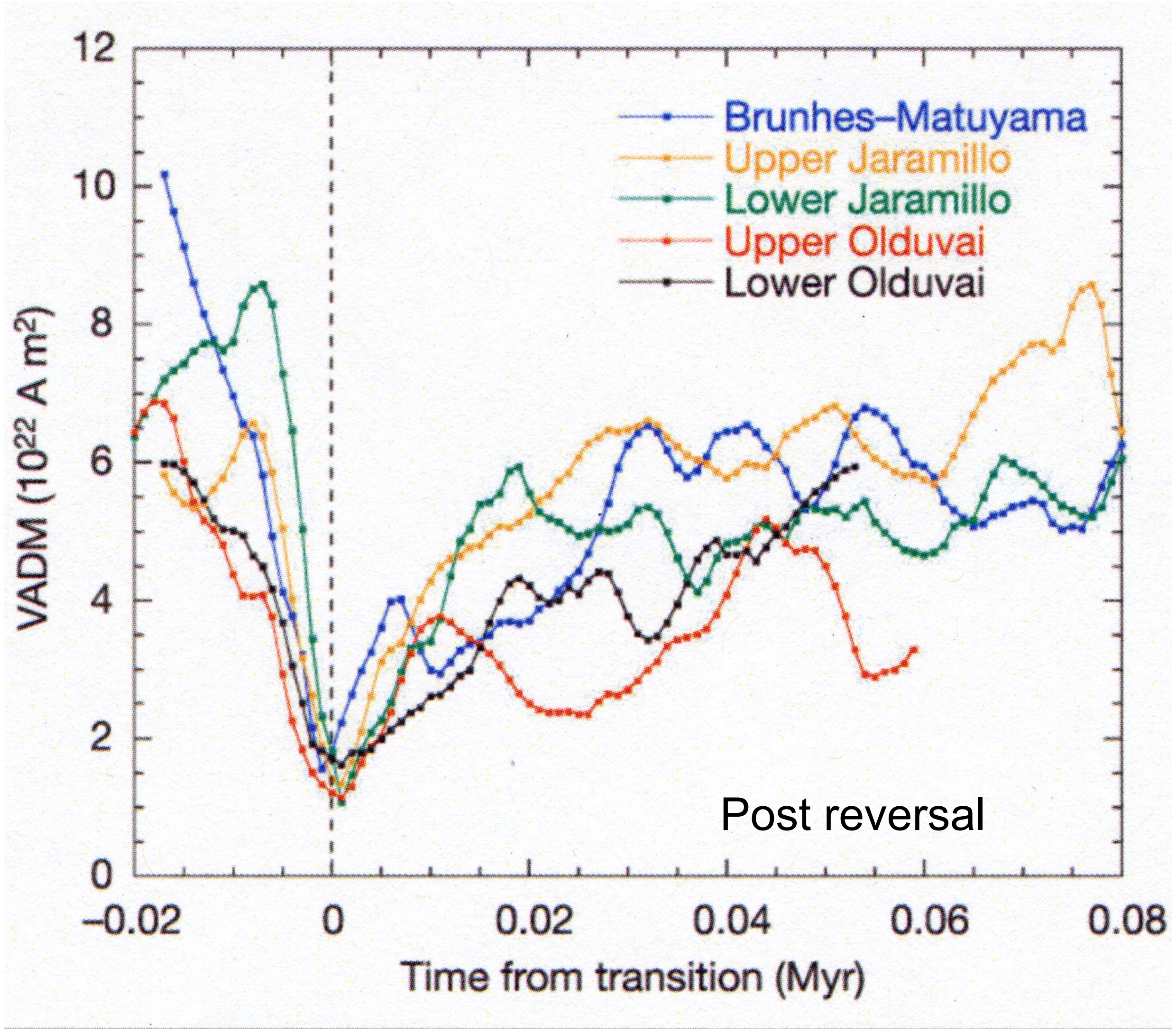
- The VADM technique has provided a historic record of the magnitude and “up-down” orientation of the dipole field.

Names of the periods with alternate dipole orientations.



Today

Cobb Mountain double reversal occurred within a 10,000 year period!


Brunhes–Matuyama
Upper Jaramillo
Lower Jaramillo
Upper Olduvai
Lower Olduvai
Post reversal
VADM (10^{22} A m^2)
Time from transition (Myr)
0
2
4
6
8
10
12
–0.02
0
0.02
0.04
0.06
0.08

Conditions at time of reversal

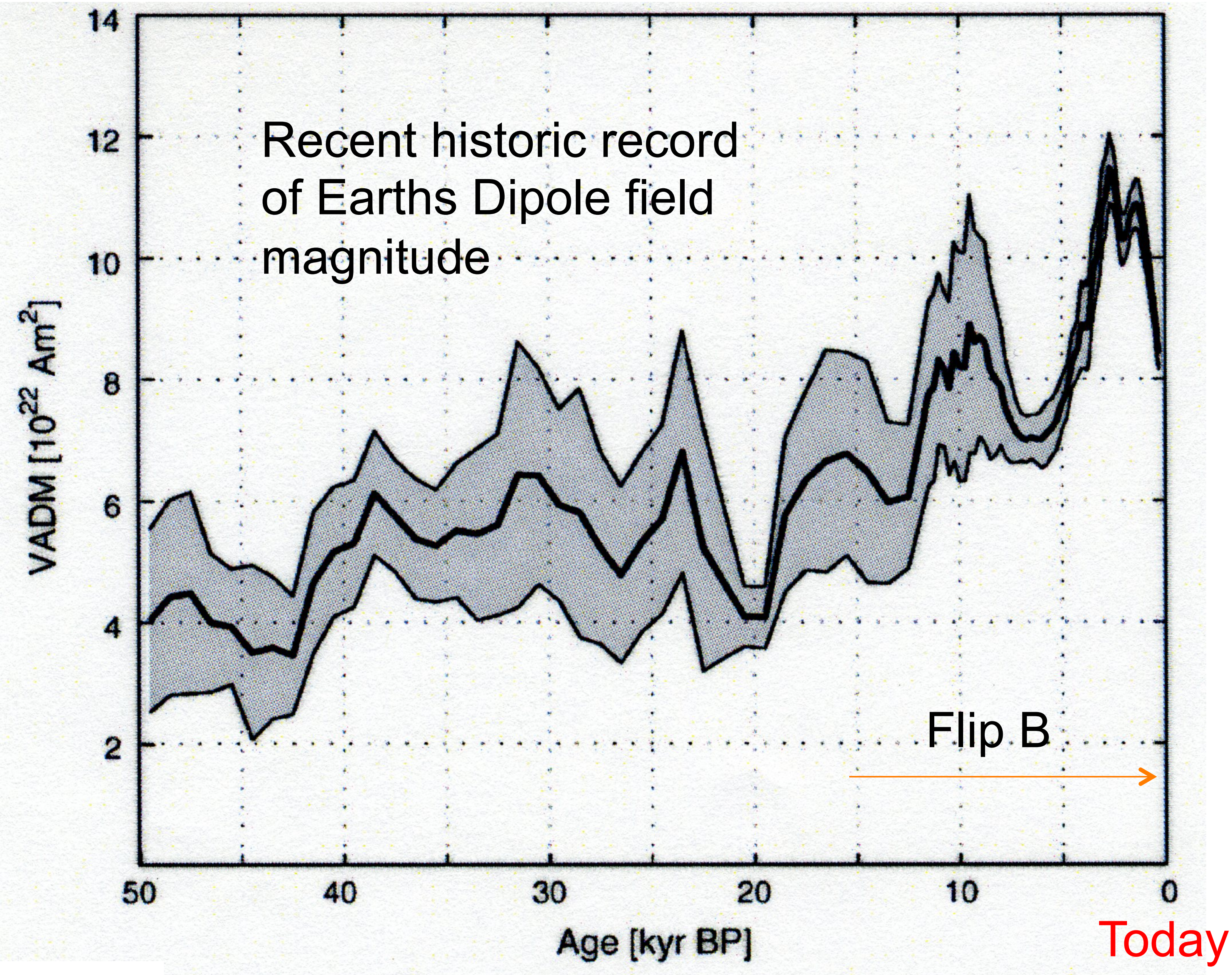
- A key question is: how is the Earths magnetic field to be described at the time of a reversal?

- The Dipole Moment (VADM) has decrease by a factor of 10 from its largest values.
- Largest values 10 x 10^{22} Am^2
- Flip value 1 X 10^{22} Am^2
- Todays value about 8 x 10^{22} Am^2

Friday's magnetosphere Lab reduced dipole to 1/10

- Many examples show that it takes 60 to 80 Kyr for the VADM to decrease to the flip value.

- Is the Earth due for a B flip?

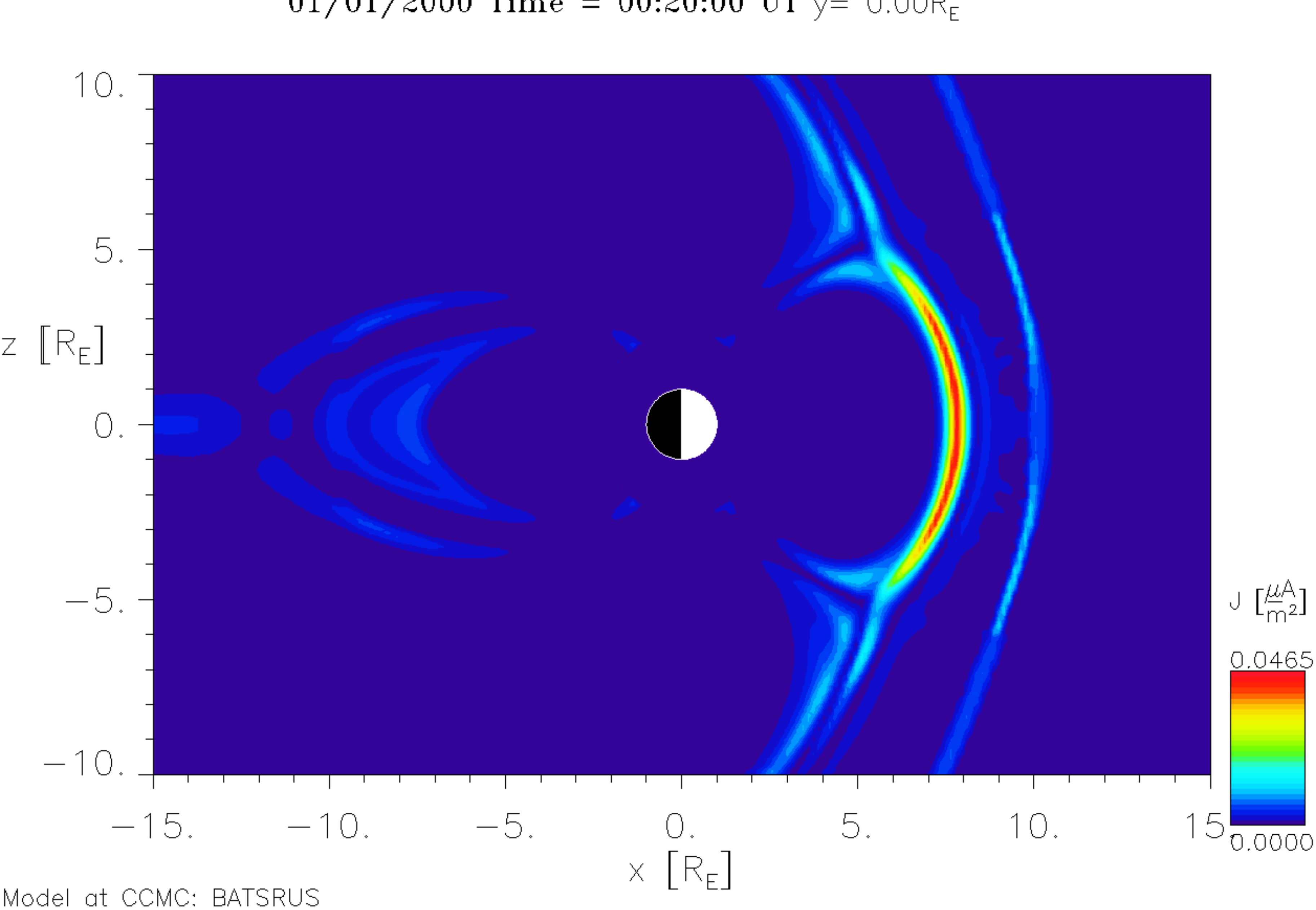

Recent historic record of Earths Dipole field magnitude
VADM [10^{22} Am^2]
14
12
10
8
6
4
2
50
40
30
20
10
0
Age [kyr BP]
Flip B
Today

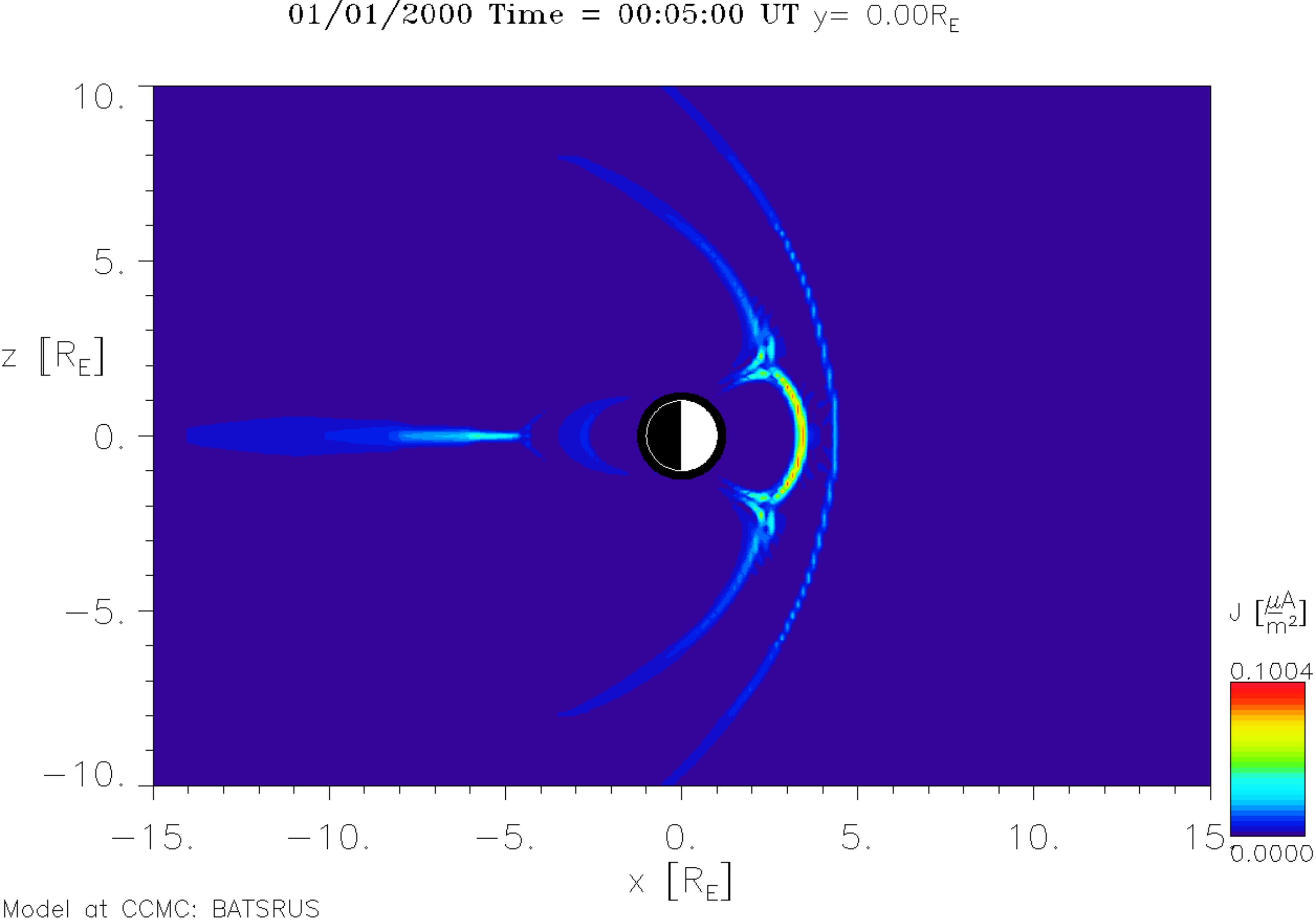
Geospace Response

Friday's Magnetospheric Labs provided opportunity to contrast effects of the reduced Earths Dipole moment.

Friday's Labs also enabled the effect of changing the angle between the dipole axis and the Earths rotational axis.

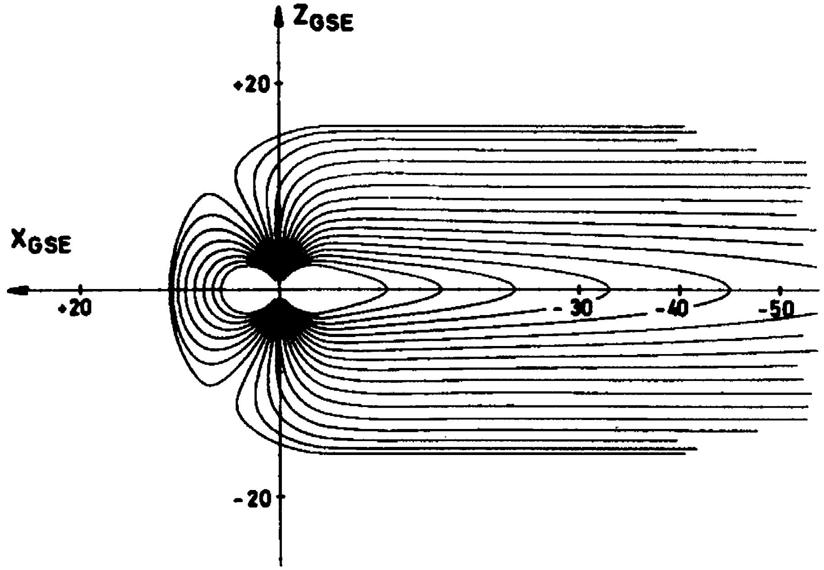
Under these conditions the SAIR still exists but locations for the Auroral or Joule Heating will change.


01/01/2000 Time = 00:20:00 UT y= 0.00R_E
z [R_E]
x [R_E]
10.
5.
0.
−5.
−10.
−15.
−10.
−5.
0.
5.
10.
15
J [μA/m²]
0.0465
0.0000
Model at CCMC: BATSRUS

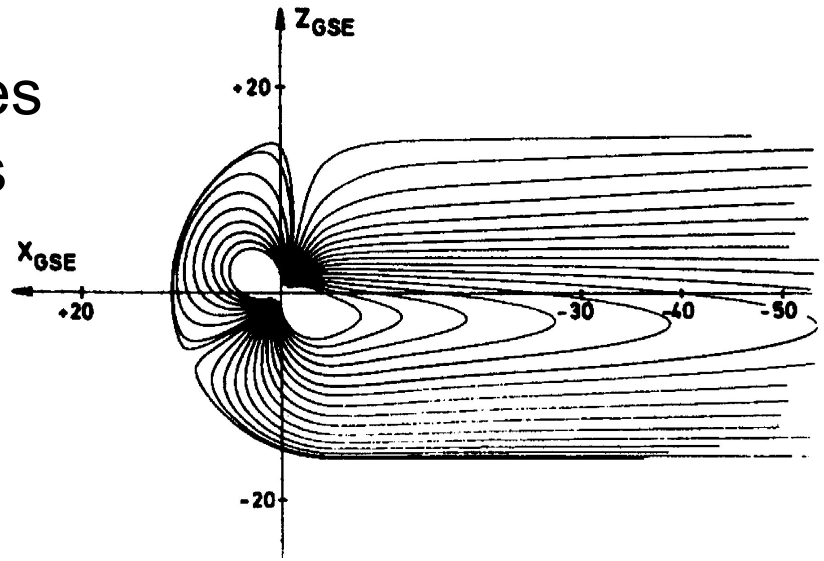


01/01/2000 Time = 00:05:00 UT y= 0.00R$_E$
10.
5.
0.
−5.
−10.
z [R$_E$]
−15.
−10.
−5.
0.
5.
10.
15
x [R$_E$]
J [$\frac{\mu A}{m^2}$]
0.1004
0.0000
Model at CCMC: BATSRUS

Todays magnetosphere for equinox type conditions!



Tilt of 35^o. This geometry changes during the day as dipole sweeps round in Local Time.



UtahState University

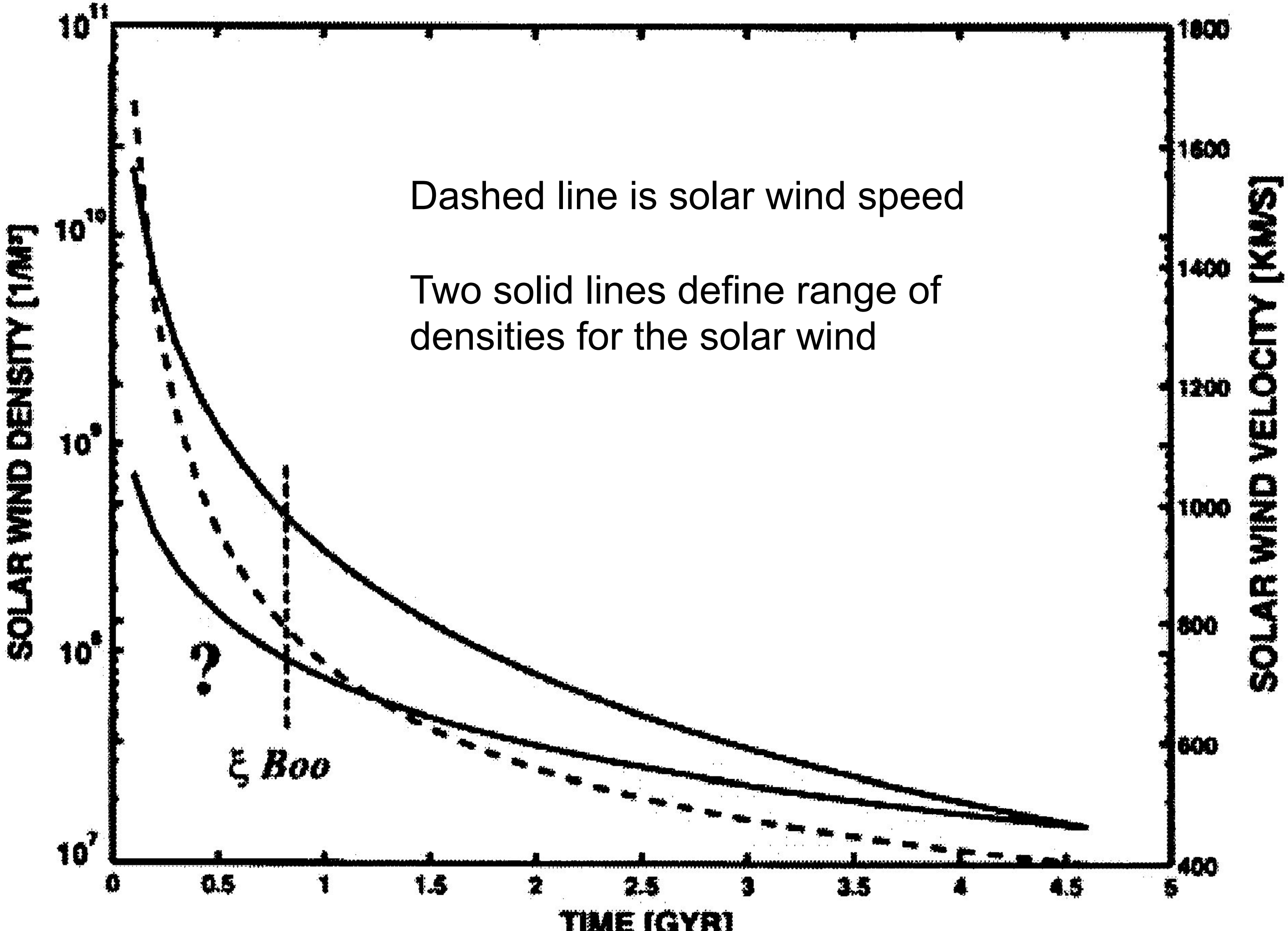
Solar Wind in the distant past

The solar wind speed and density will modify the magnetosphere.

What did it look like in the distant past, billions of years ago?

How do we estimate this?

These two parameters are determined from studying Sun like stars.
These stars are of different ages, and hence need to be rescaled in time to our Sun.
This is done using an idea of “zero-age main sequence” (ZAMS)
How about the solar wind magnetic field?



Dashed line is solar wind speed

Two solid lines define range of densities for the solar wind

Today

Take away messages

What is it that heliophysics can learn from stars?

What is it that exo-planet research can learn from heliophysics?

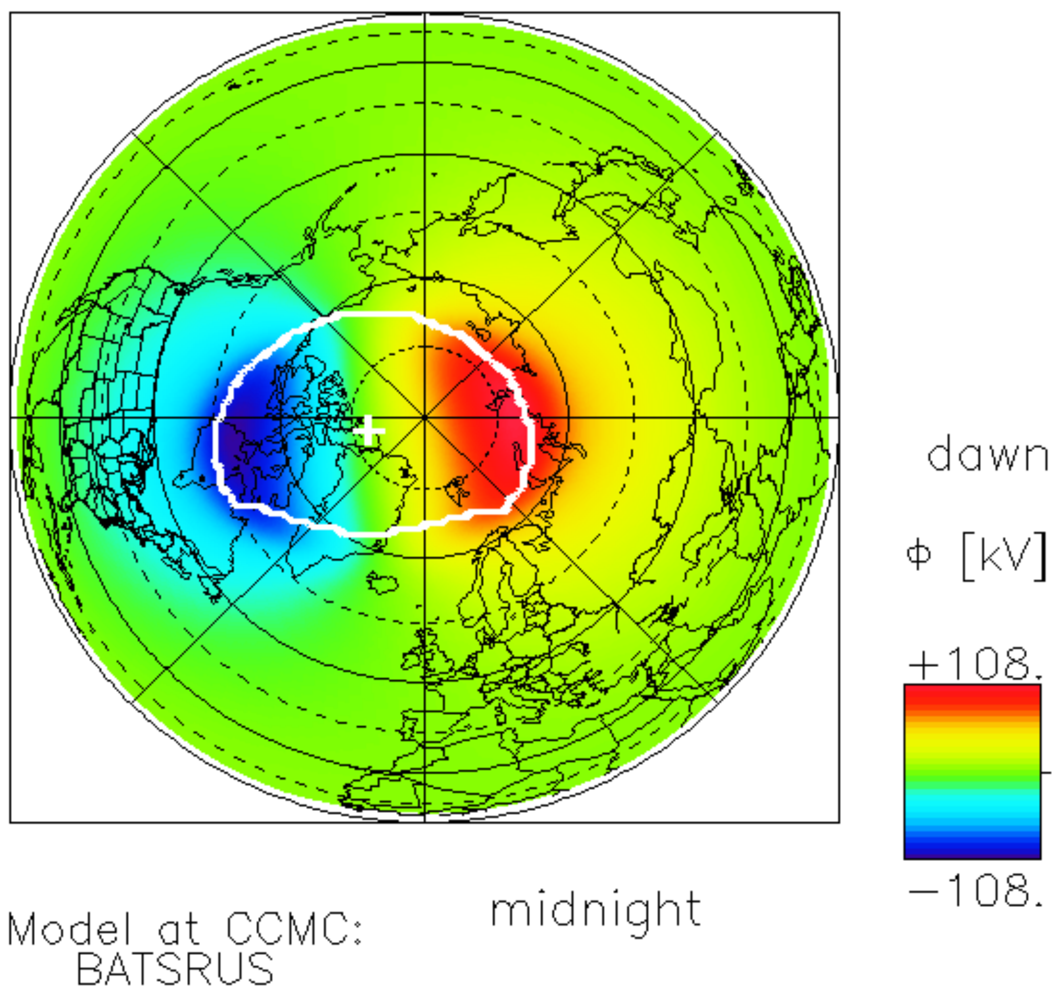
The SAIR protects the lower atmosphere from space weathers FLARES, AURORA, and MAGNETOSPHERIC ELECTRIC FIELDS

Laboratory-6

- During the recitation find out what happened when the dipole decreases by 10!

01/01/2000 Time = 00:20:00

Northern Hemisphere



Laboratory-6

- During the recitation find out what happened when the dipole decreases by 10!

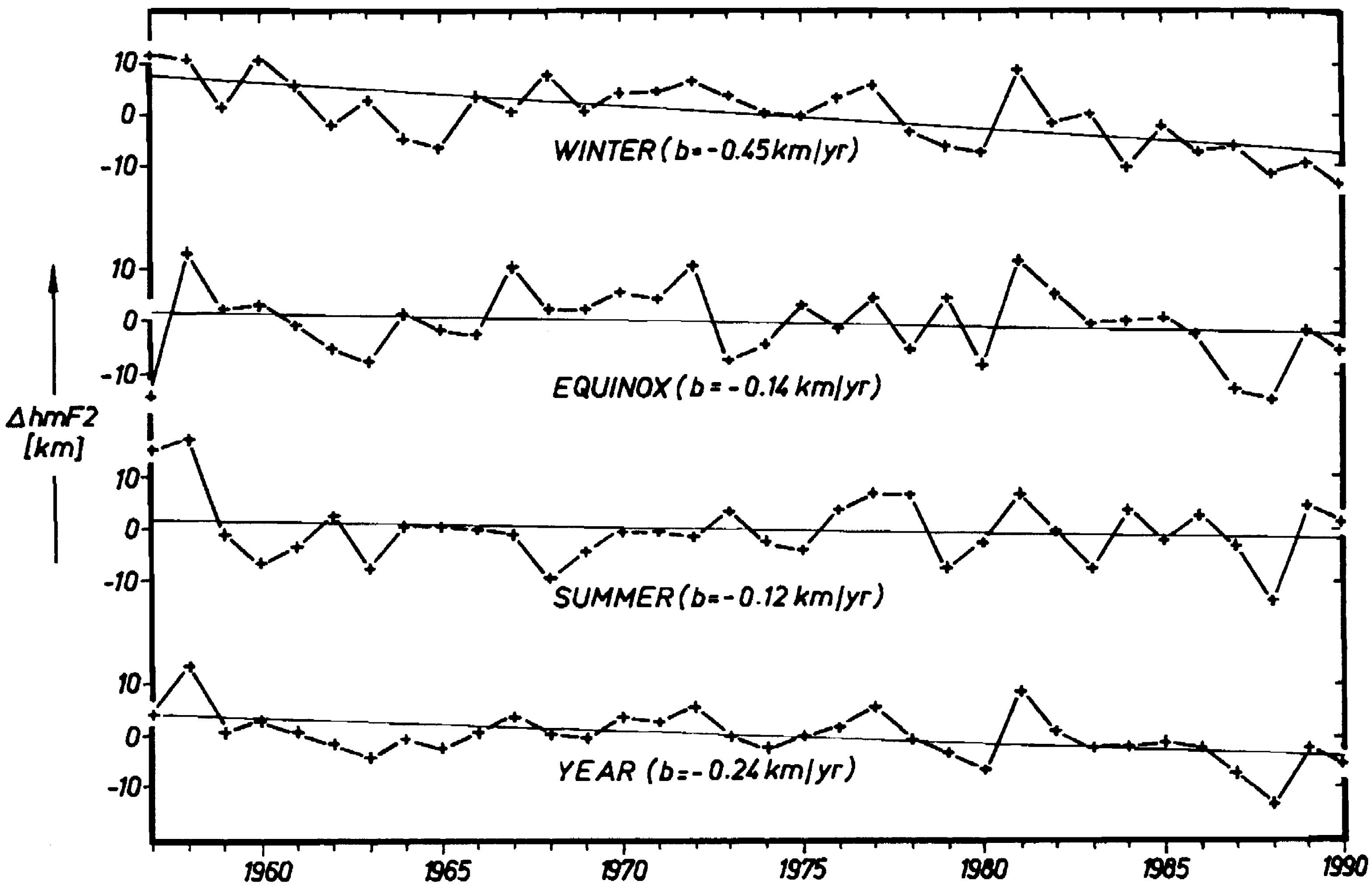
Anthropogenic sources of geospace climate change

- Does Geospace observation provide a record that contibutes to the climate change debate?

- IGY in 1957 saw the deployment of ionosondes.
- Hence a 50 year record of ionospheric variations and climate.

- Roble predicted that in the thermosphere increase of CO_2 would lead to cooling.
- Risbeth and Roble then concluded the F-region would decrease in height, among other things.

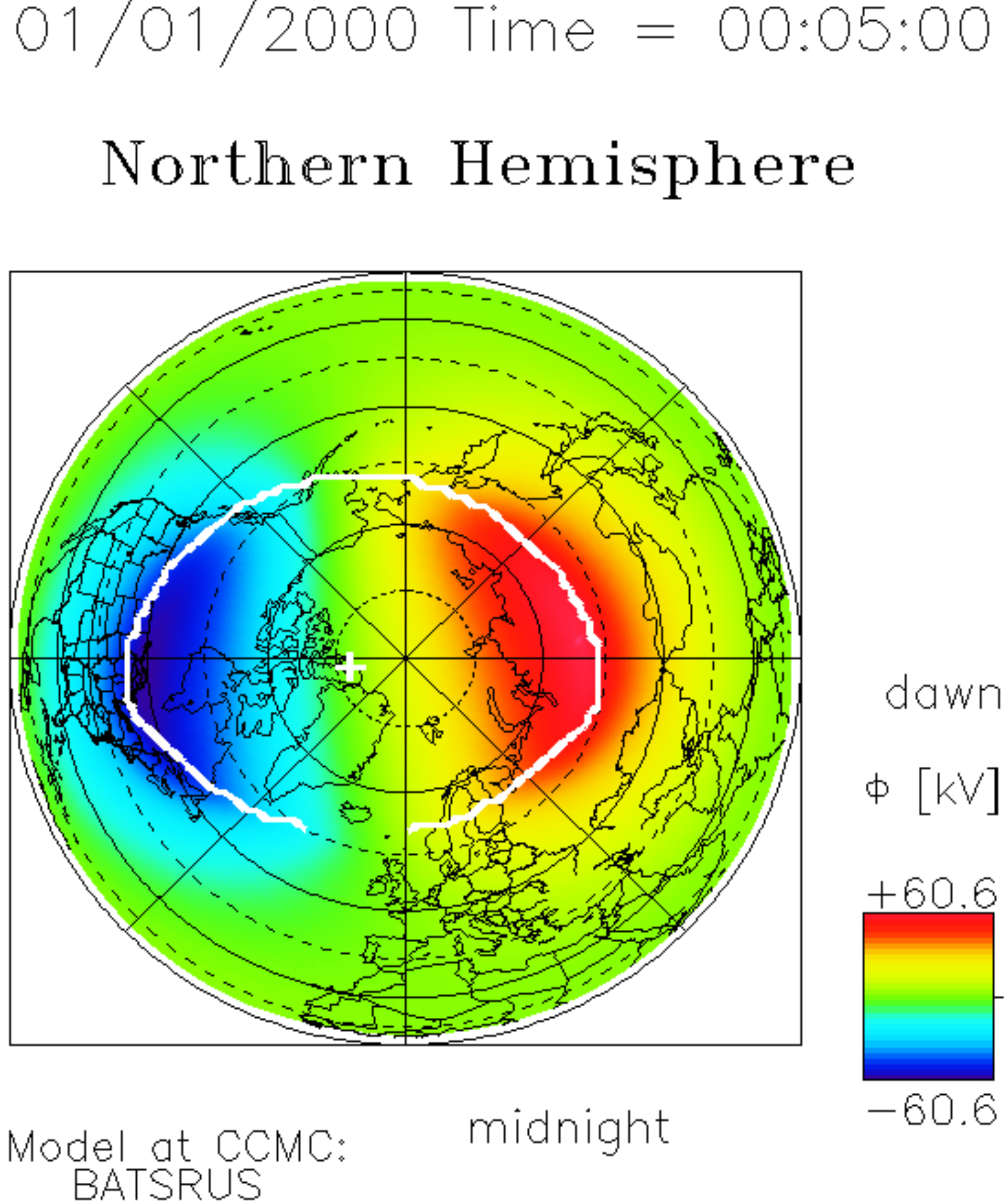
Analysis of change in hmF2 for one ionosondes observations.



years

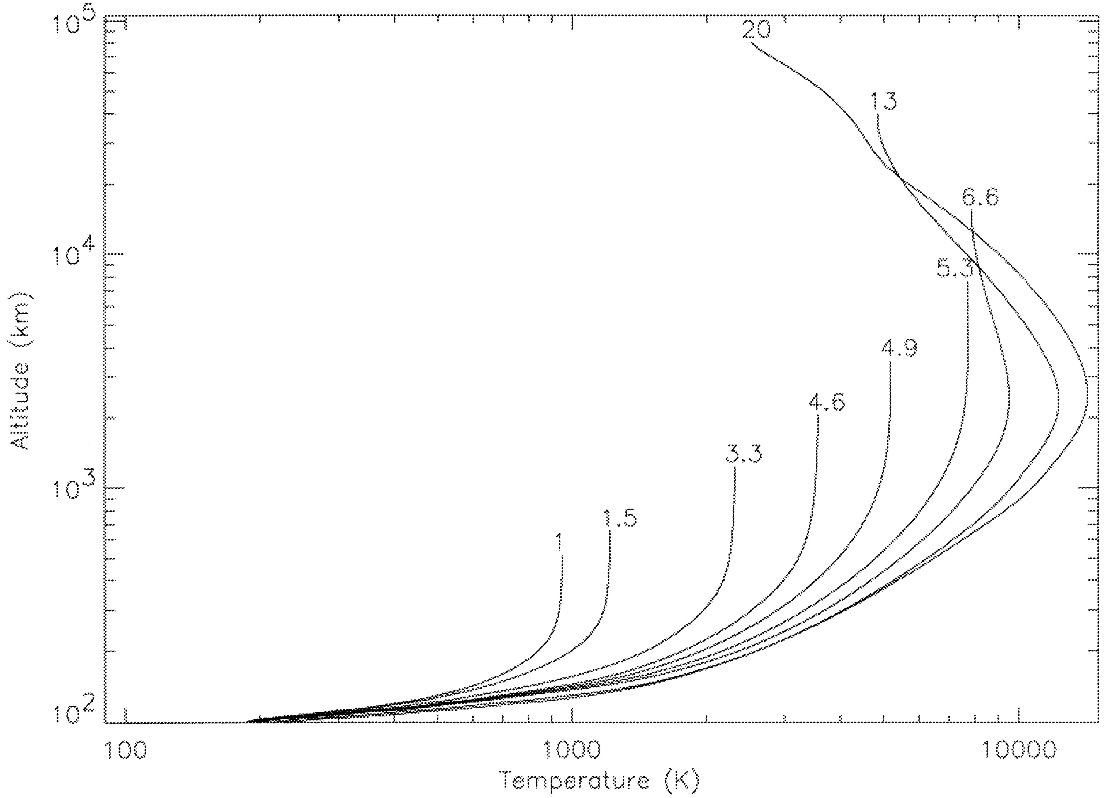
- During the recitation find out what happens when the earths dipole strength decreases by a factor of 10.

- Special thanks to Maria (Masha) Kuznetsova for these CCMC runs


01/01/2000 Time = 00:05:00
Northern Hemisphere
dawn
φ [kV]
+60.6
−60.6
midnight
Model at CCMC:
BATSRUS

PART-II Billions of years ago!
Or
EXO-planets and their stars

- The solar EUV was much more power full!
- Kulikov et al 2007 developed a diffusive-gravitational equilibrium and thermal balance model to study these earlier times.
- [H] is the first atmospheric constituent to suffer from excessive high Jeans escape fluxes.
- Worse yet at about exospheric temperatures of 5000K [H] is blow-off!



Tian et al showed that at S of about 5 the [H] blow-off temperature is reached.

These were conditions found about a billion years ago!

Extreme EUV Irradiances

- Should these occur and CO_2, NO, OH, etc molecules do not cool sufficiently then:
- [H] is blown-off
- The F-layer now extends up over 1000km

- Can such enhanced EUV increases occur without the solar constant of 1340 W/m^2 being also affected?