The Earth's thermosphere and coupling to the Sun:

Does the stratosphere and troposphere care?

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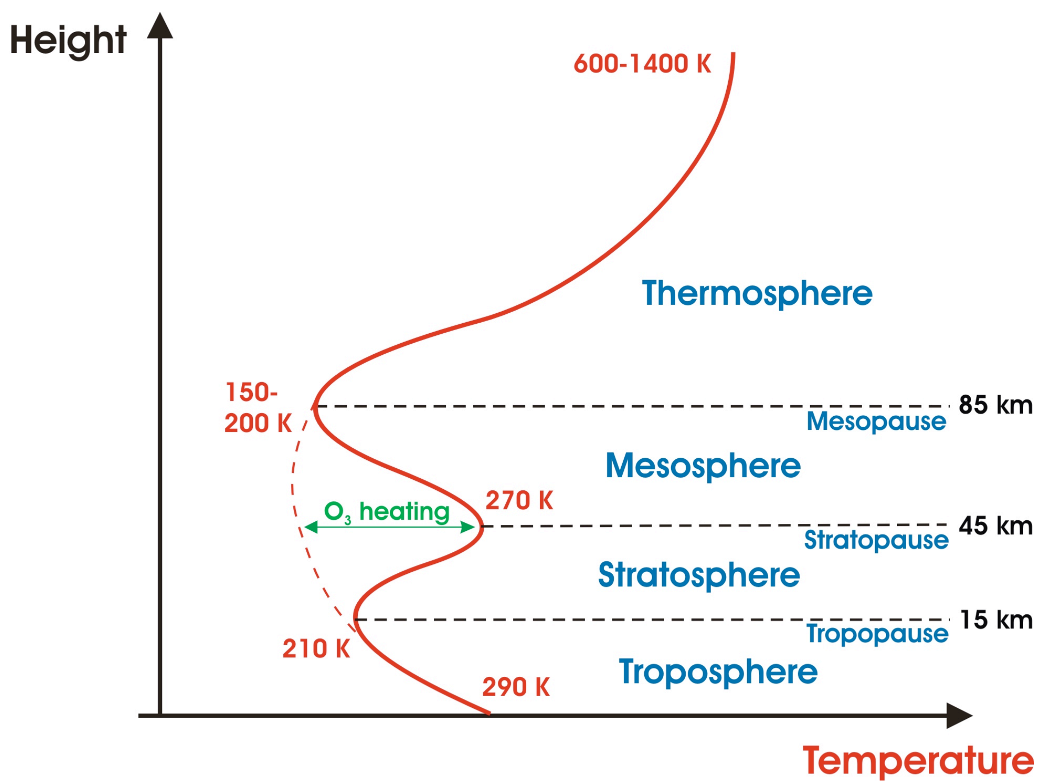
The Chain of energy flow (the terrestrial perspective)

- Energy leaves the Sun …
- ….as e/m radiation it reaches the Earth, and as particles
- ….is carried through the heliosphere
- ….impinges on the magnetic field of the Earth
- …..is linked into the Earth environment via the ionosphere
- …But then what happens to it?
- Dumped in the thermosphere….
- Or does it get further?
- (Not to mention feedback…)

b) Thermal structure

The Earth's atmosphere may be subdivided vertically into different regions:



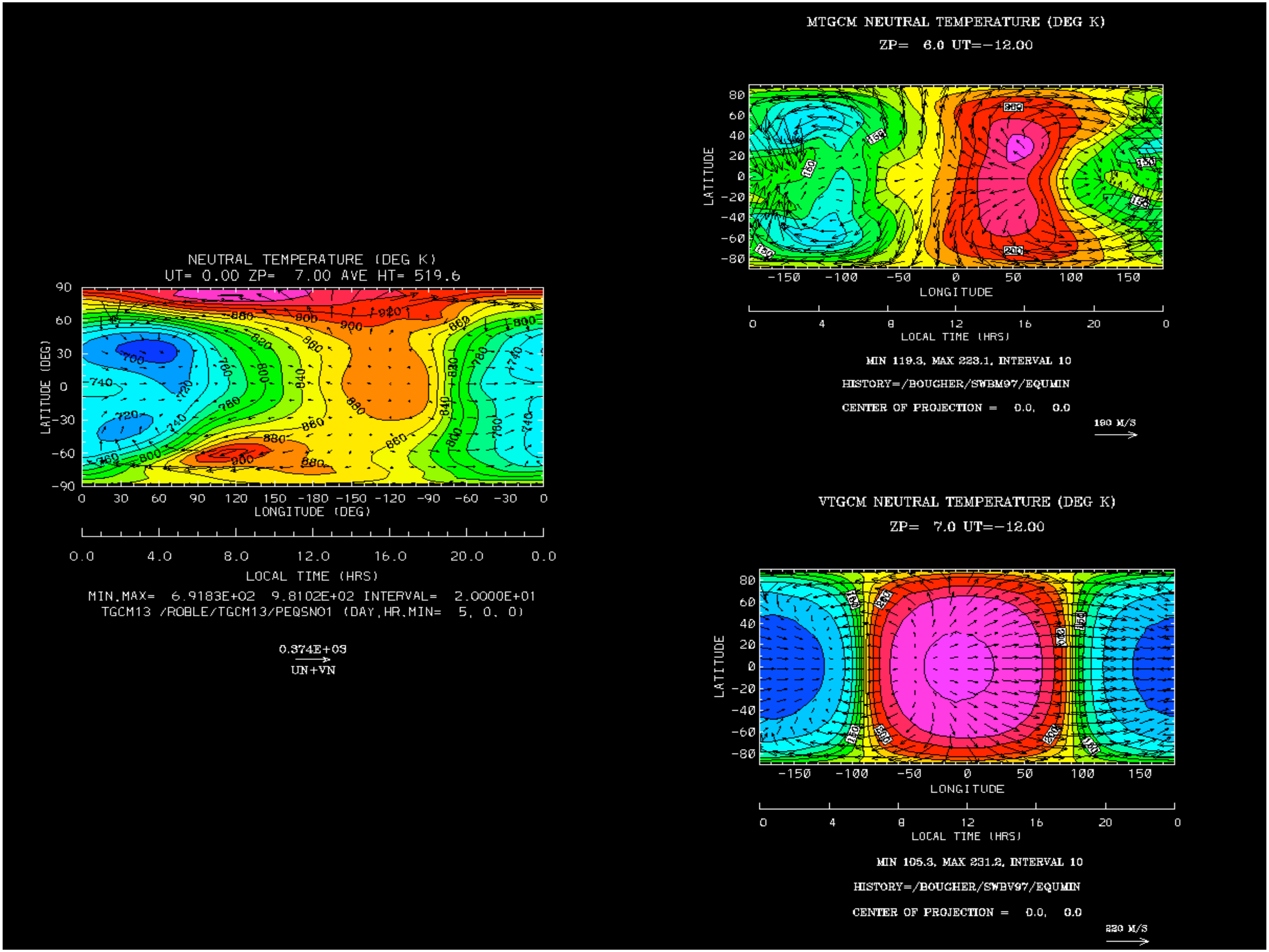
The importance of the thermosphere

It is the ultimate sink for much of the energy in the solar-terrestrial energy and momentum chain

It is an important interface for climate change effects linked to solar variability

There are three levels of complexity at which we can consider solar influence on the Earth's upper atmosphere

- Diurnal and seasonal variations - effects of "average" solar insolation
- Variability of solar output or the transfer function on "short" time scales - minutes to 22 years - seen in solar cycle effects and geomagnetic storms /substorms
- Long term and climactic effects apparently amplified beyond expectation



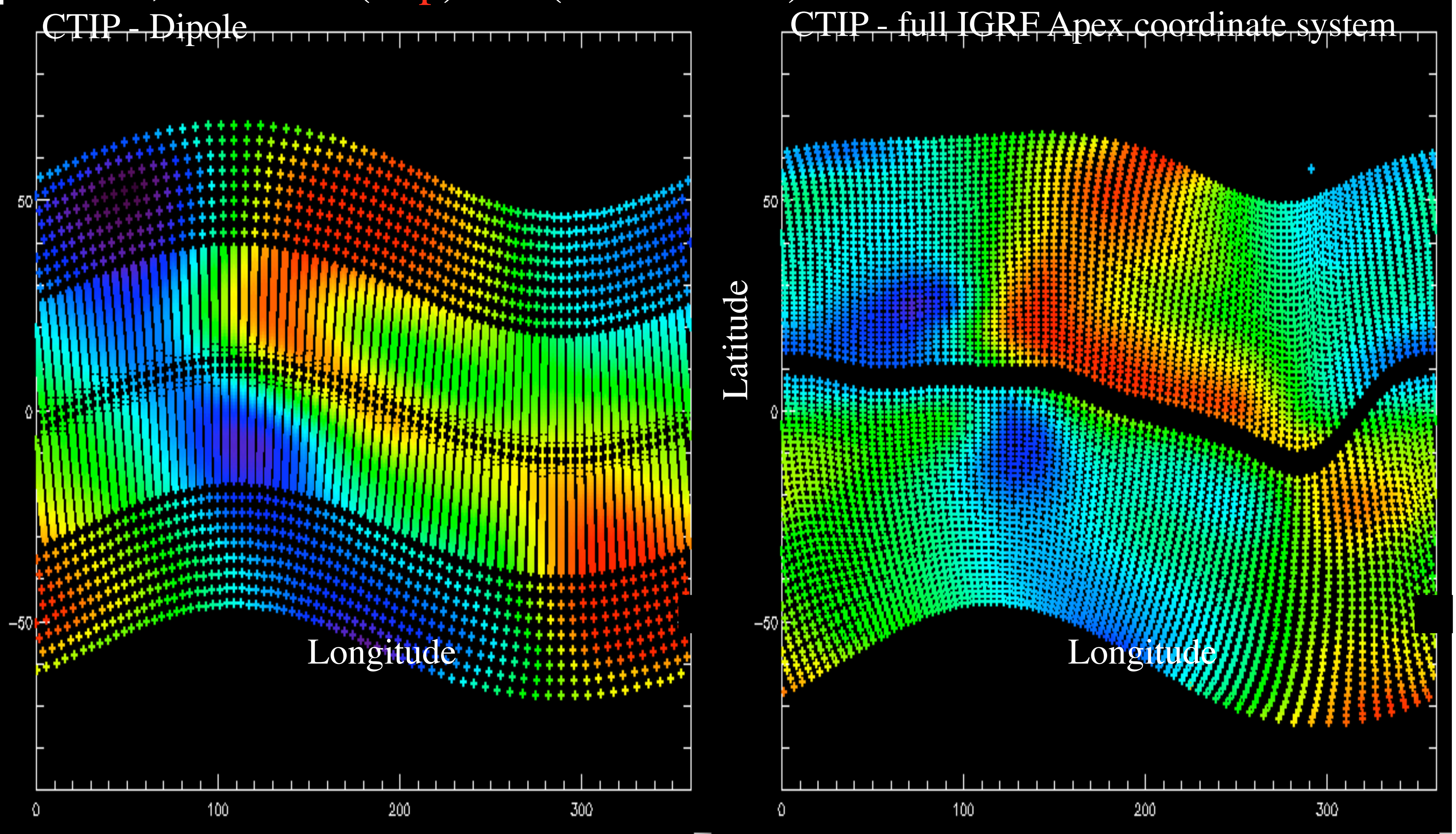
NEUTRAL TEMPERATURE (DEG K)
UT= 0.00 ZP= 7.00 AVE HT= 519.6
LATITUDE (DEG)
LONGITUDE (DEG)
LOCAL TIME (HRS)
MIN,MAX= 6.9183E+02 9.8102E+02 INTERVAL= 2.0000E+01
TGCM13 /ROBLE/TGCM13/PEQSN01 (DAY,HR,MIN= 5, 0, 0)
0.374E+03
UN+VN
MTGCM NEUTRAL TEMPERATURE (DEG K)
ZP= 6.0 UT=-12.00
LATITUDE
LONGITUDE
LOCAL TIME (HRS)
MIN 119.3, MAX 223.1, INTERVAL 10
HISTORY=/BOUGHER/SWBM97/EQUMIN
CENTER OF PROJECTION = 0.0, 0.0
180 M/S
VTGCM NEUTRAL TEMPERATURE (DEG K)
ZP= 7.0 UT=-12.00
LATITUDE
LONGITUDE
LOCAL TIME (HRS)
MIN 105.3, MAX 231.2, INTERVAL 10
HISTORY=/BOUGHER/SWBV97/EQUMIN
CENTER OF PROJECTION = 0.0, 0.0
220 M/S

Upping the complexity:

- Having understood the basic neutral atmosphere we need to look at the next order of effect
- We link in the ionosphere
- On Mars, for example, this may be quite simple
- But with a magnetic field we have other complications……

field-aligned wind (ie, blowing along the flux-tube) resulting from a typical CTIP F-region meridional (southwards) wind

ie, Vn-S Cos(Dip) Cos(Declination)

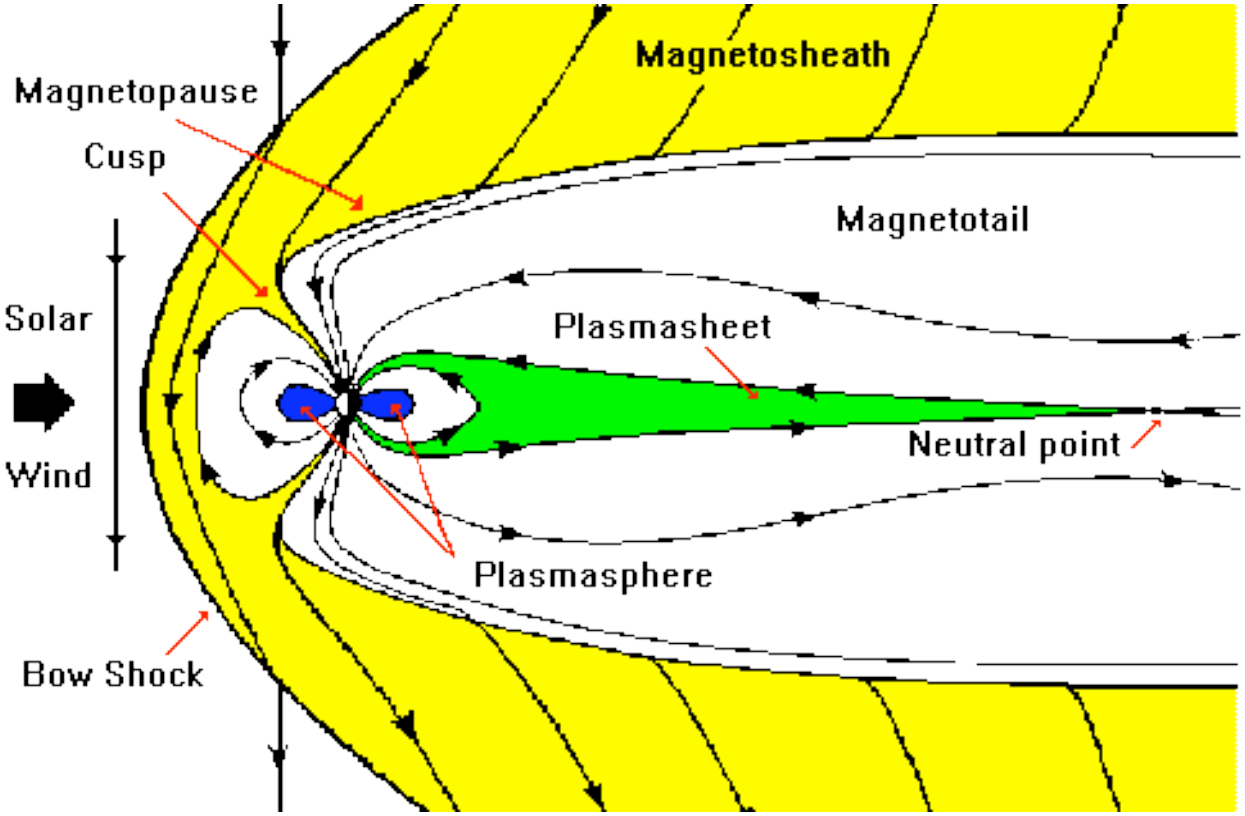


There is then a more variable, but direct, connection to the more stochastic solar variability.

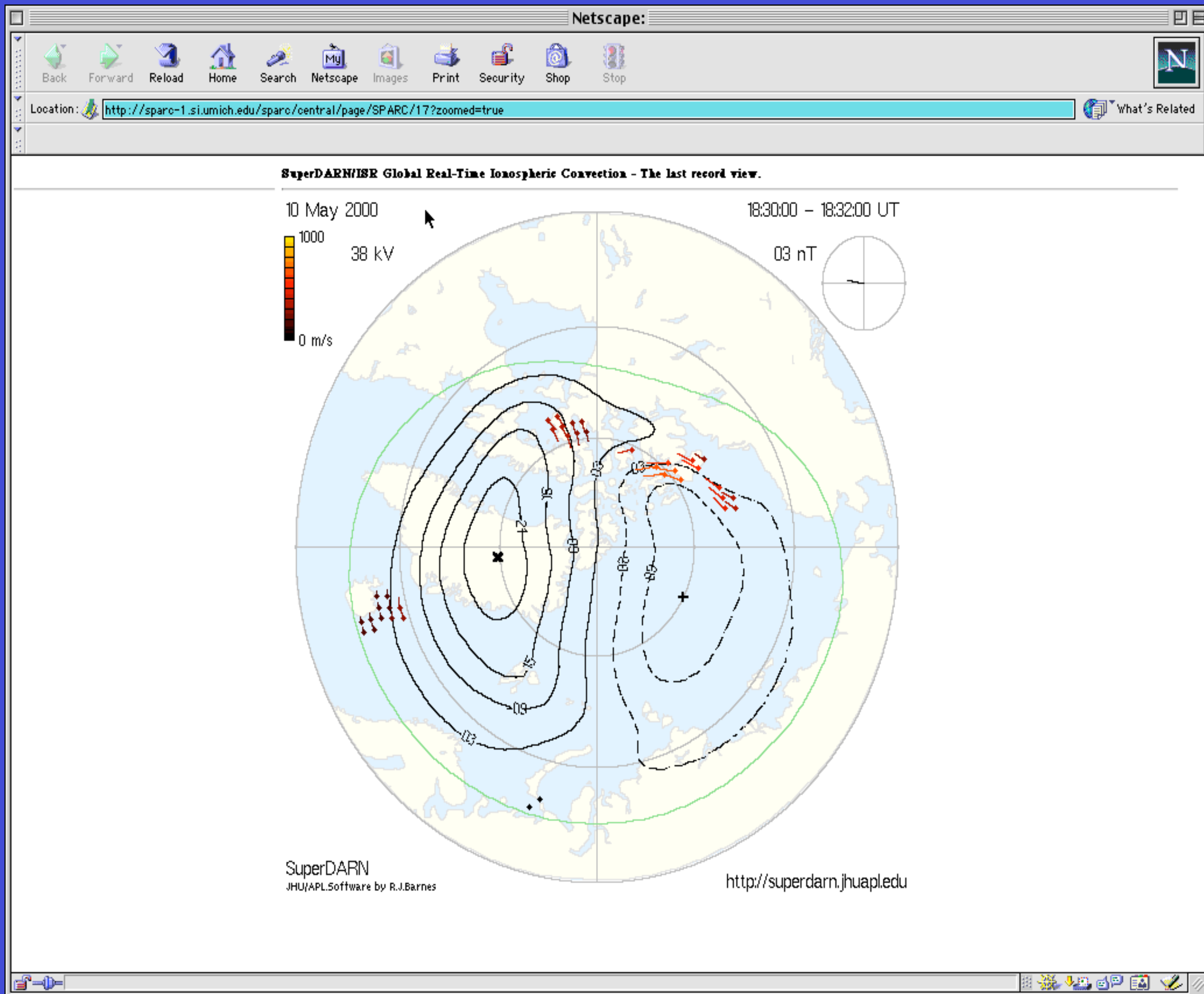
How does this linkage manifest itself in the atmosphere however?

We have both momentum and energy sources, mainly seen in the effects at high-latitude…

The solar-wind interaction with the magnetosphere is mapped down into the atmosphere



Obvious energetic inputs …


Netscape:
Back
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Netscape
Images
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What's Related
SuperDARN/ISR Global Real-Time Ionospheric Convection - The last record view.
10 May 2000
18:30:00 – 18:32:00 UT
1000
0 m/s
38 kV
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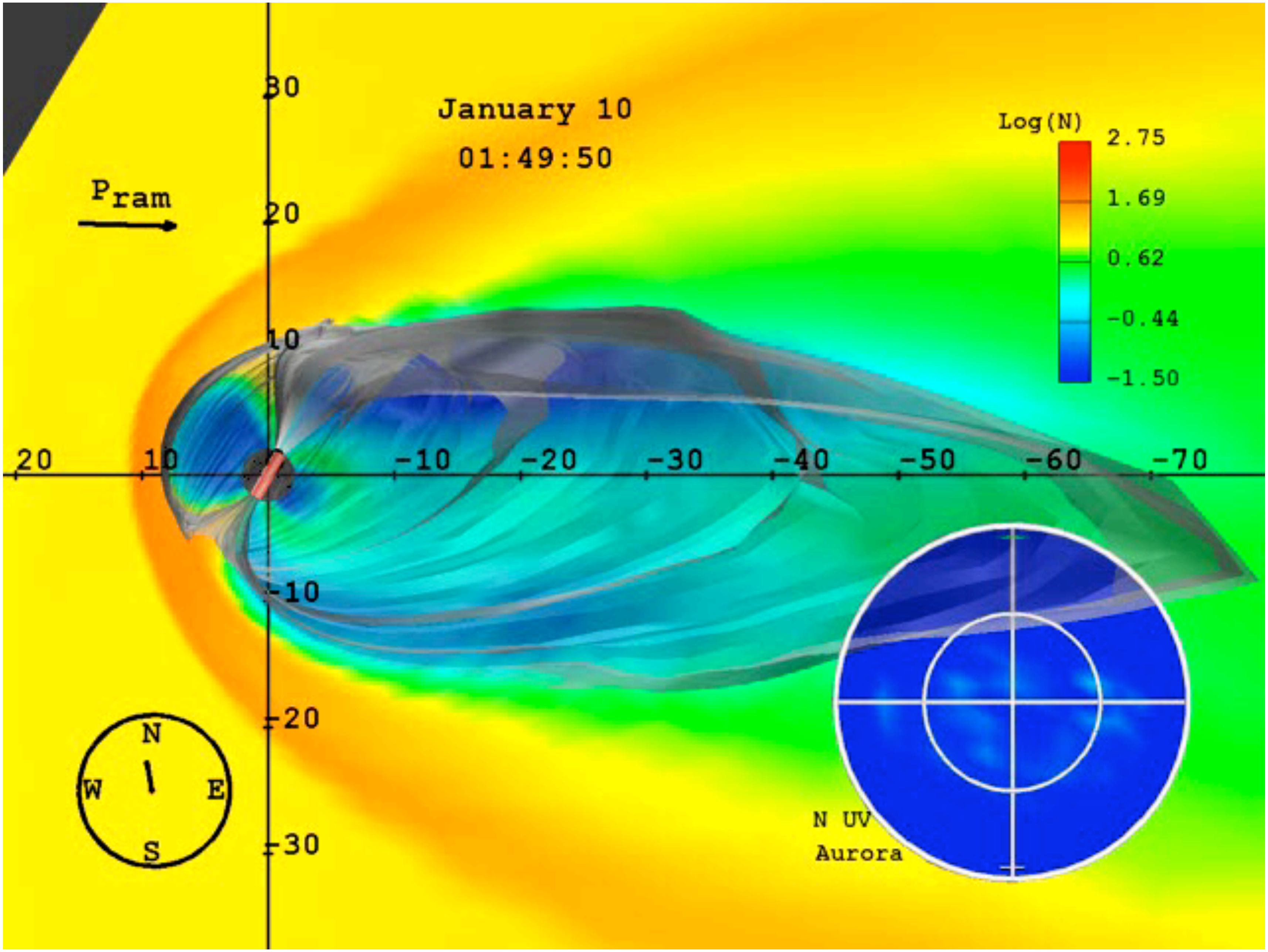
SuperDARN
JHU/APL Software by R.J.Barnes
http://superdarn.jhuapl.edu


January 10
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P_{ram}
Log(N)
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0.62
-0.44
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-40
-50
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N
W
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N UV
Aurora

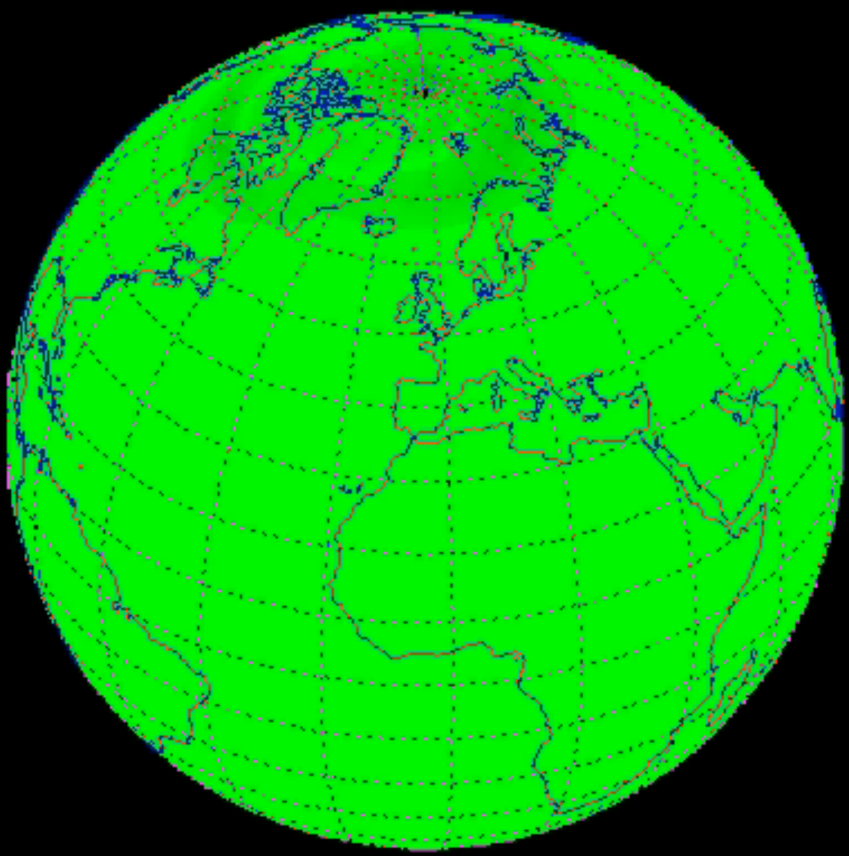
Coupled Thermosphere Ionosphere Plasmasphere model (CTIP)

Atmospheric temperature changes due to dynamic Auroral forcing

(i.e., Magnetic Storm)

↓

Global gravity wave propagation



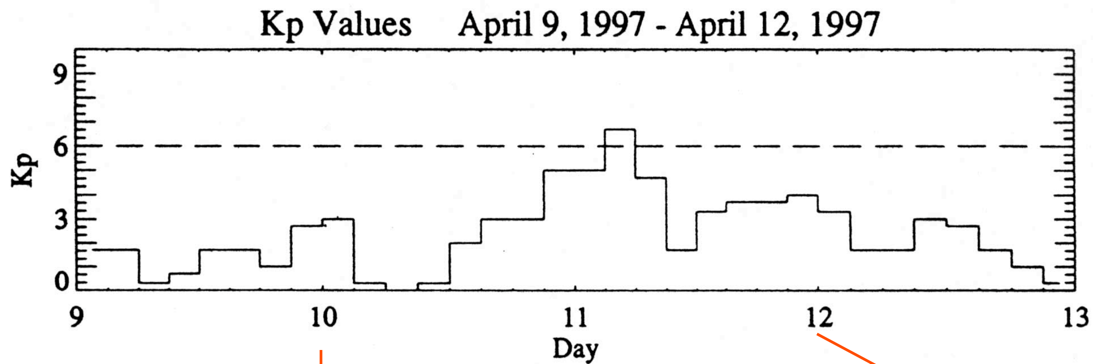
green/red +20K, blue -20K

Storm effects are complex and can be global

They affect the neutral atmosphere as well as the ionosphere

There is a lot of small-scale structure - even in the neutral atmosphere - which is difficult to describe accurately in detail

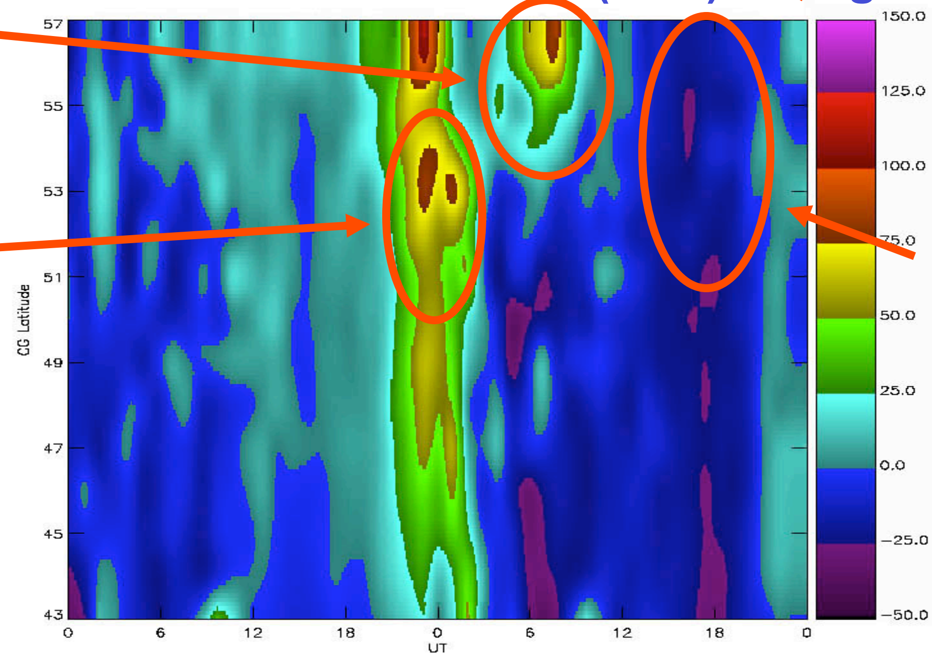
April 1997 Storm event



Total Electron Content (TEC) change

TEC enhancement (particle precipitation)

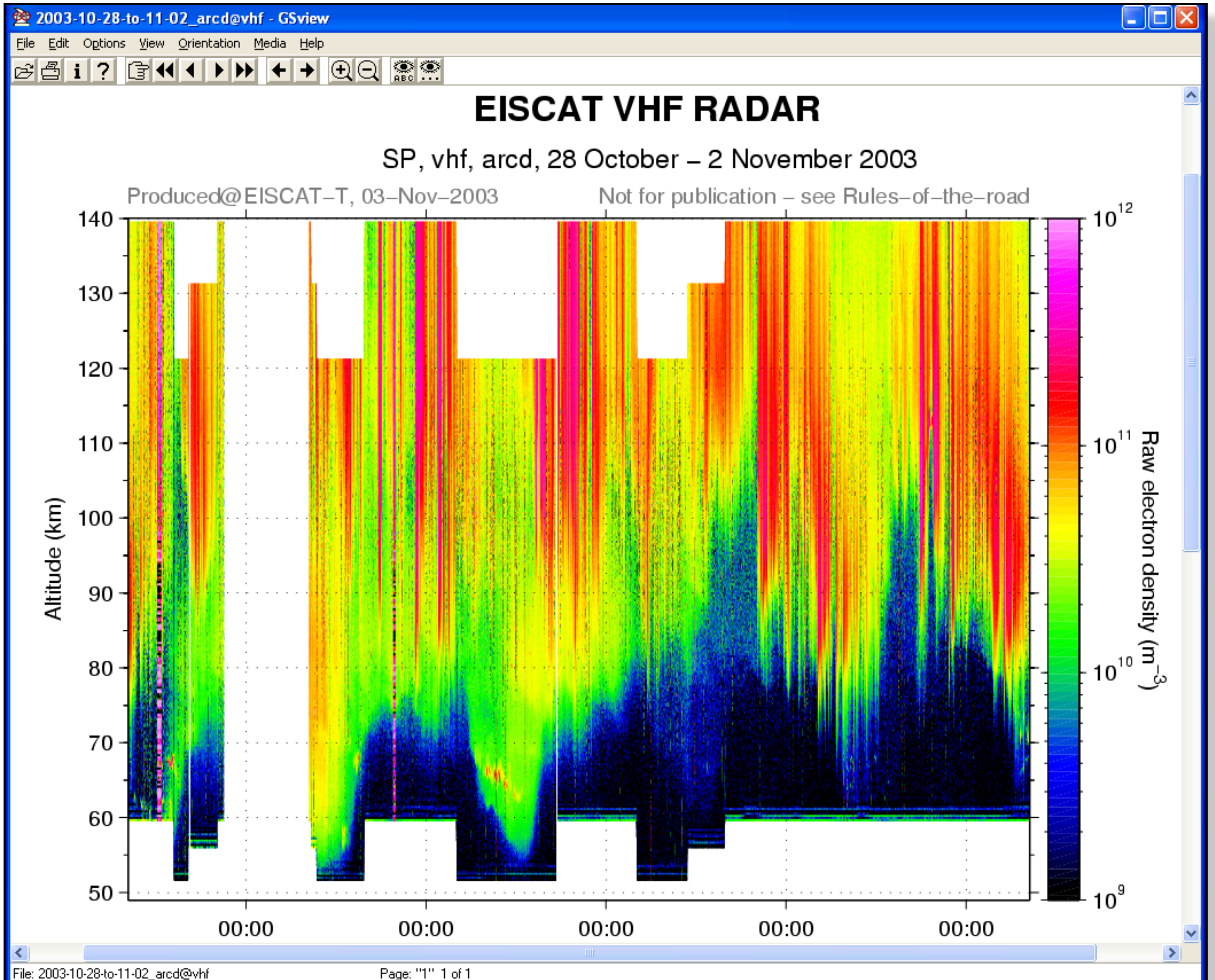
Dusk effect (neutral winds)



Negative phase (neutral gas composition)

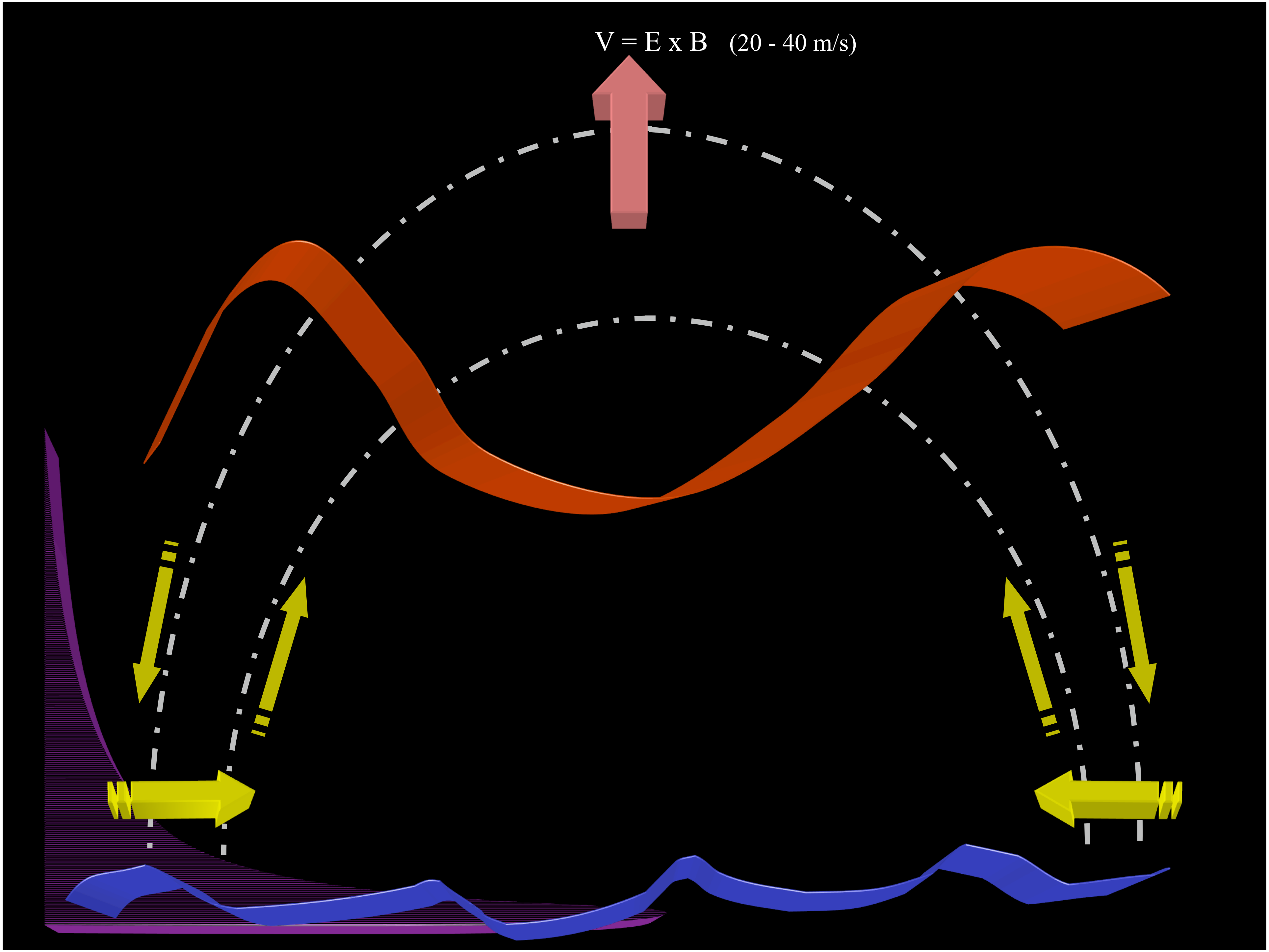
Sometimes extreme solar activity can lead to deeper penetration

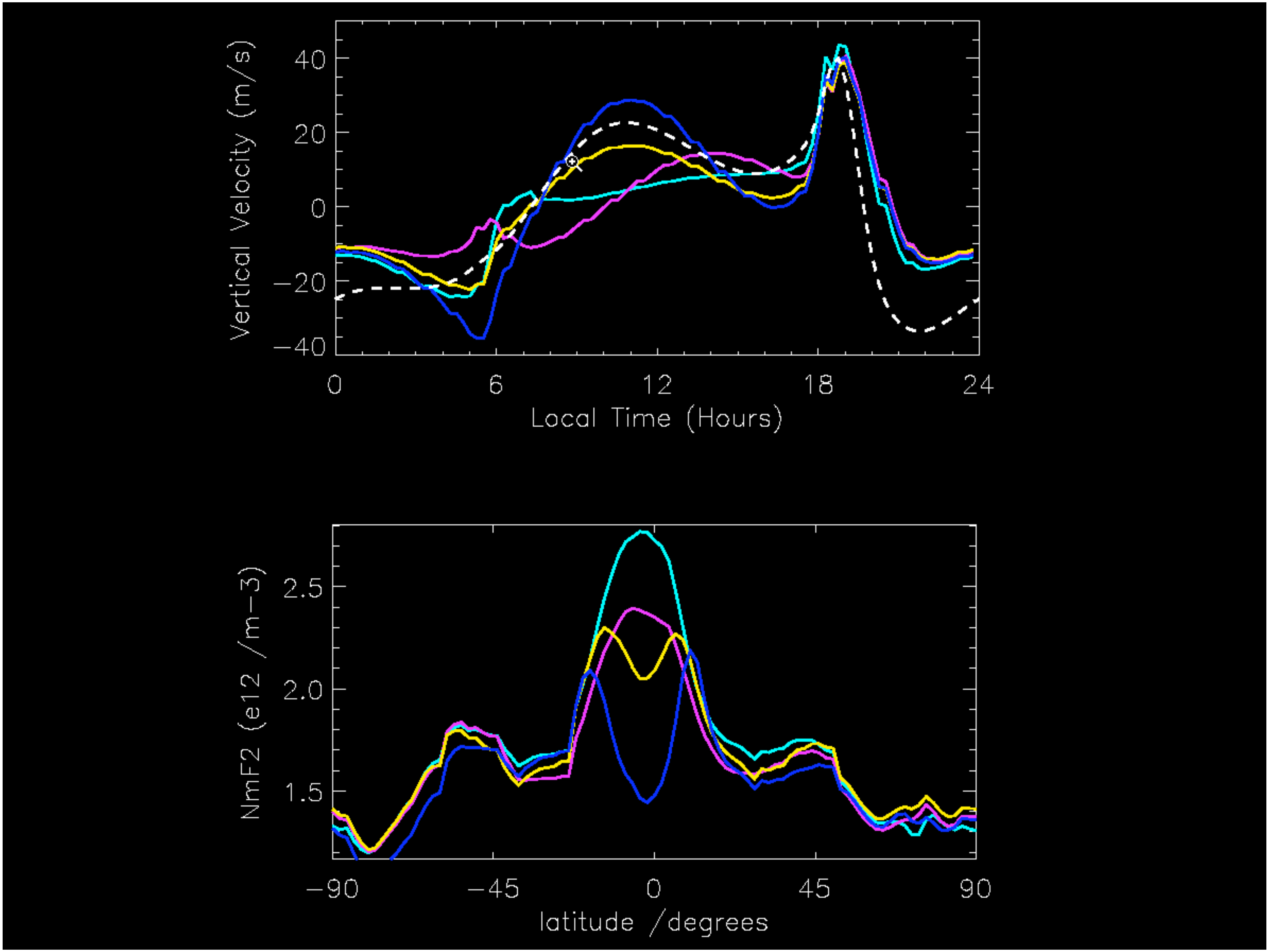
Sometimes Extreme Solar Activity can lead to quite deep penetration



We see evidence of penetration of "upper atmosphere" effects in several ways

Sometimes effects in the upper atmosphere can be seen as tracers of what is going on lower down:


V = E x B (20 - 40 m/s)



Vertical Velocity (m/s)
40
20
0
−20
−40
0
6
12
18
24
Local Time (Hours)
NmF2 (e12 /m−3)
2.5
2.0
1.5
−90
−45
0
45
90
latitude /degrees

CTIP STORM ELECTRODYNAMICS

Runs looking at how winds at high and mid-latitudes affect storm-time electrodynamics

(A) Ezonal - storm - quiet (2hours into major magnetic storm)

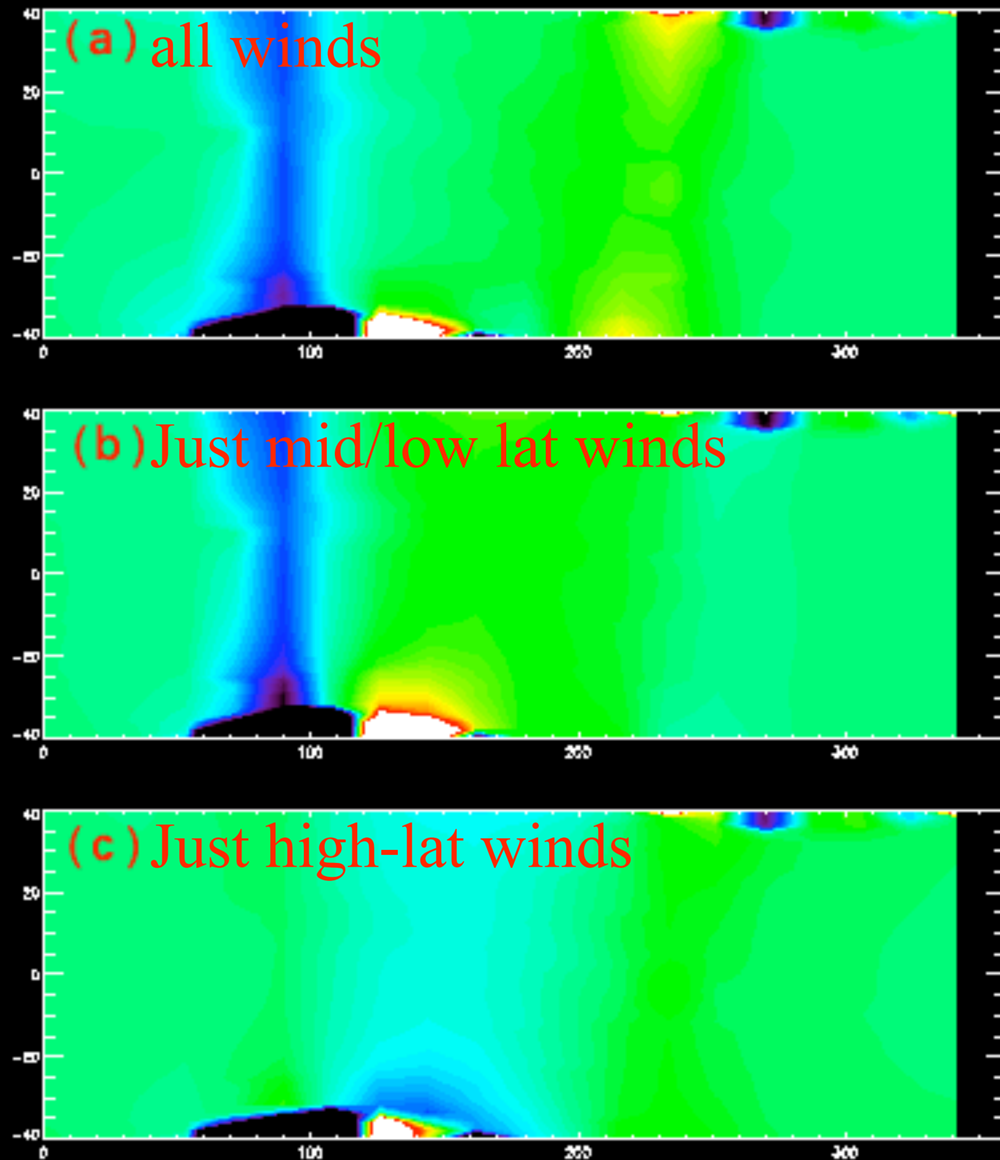
(B) As (A) - but only winds equatorward of 60deg contribute to electrodynamics

(C) As (A) - but only winds poleward of 60 deg contribute to electrodynamics

Result: Similarity of (A) and (B) shows that High -latitude electrodynamics are insignificant in storm-time electrodynamics; Mid/low lat winds are Key.

Large blue stripe in (A) and (B) indicates that Pre -reversal enhancement collapses during Storm. Two hours into the storm information has only propagated to fairly high mid-lats. This strongly suggests that the pre-reversal enhancement feature is connected to winds at fairly high-lats (50 - 60 deg).

Zonal Electric fields (Storm - Quiet diff)



There is of course direct evidence of penetration of magnetic effects to the ground:

Ground currents in UK (Thompson BGS)

342 Alan W. P. Thomson, Allan J. McKay and Ari Viljam

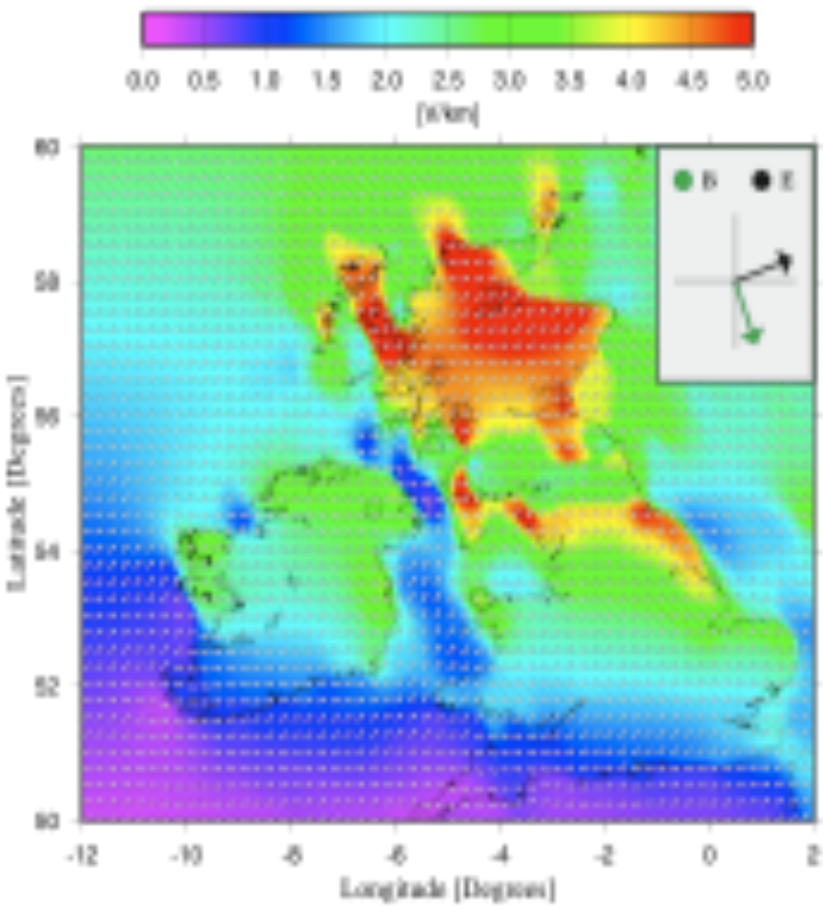


Fig. 2. S
estimated
360 s. Th
amplitude
inset show
netic field
1D model

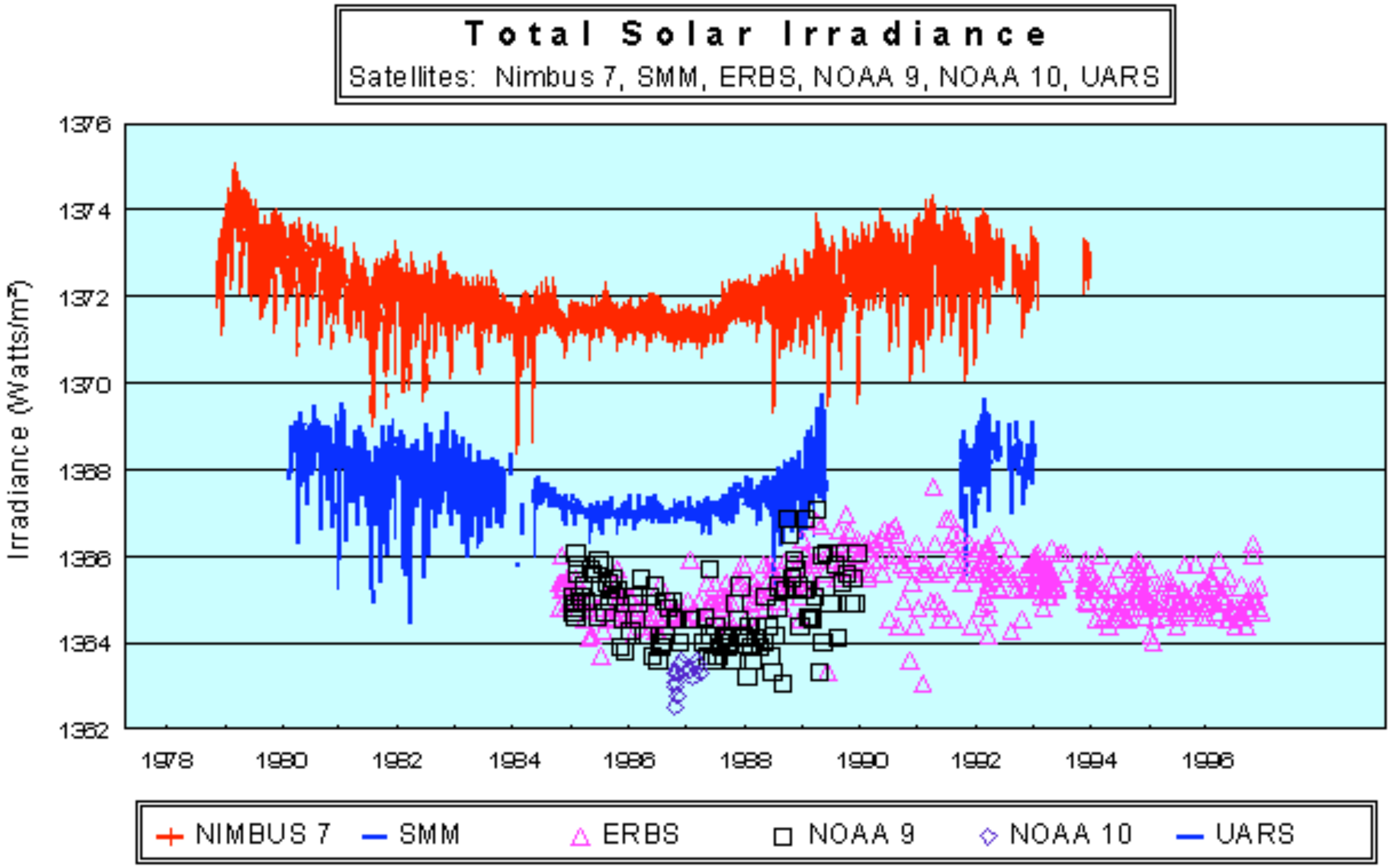
What about subtler effects though - on the atmosphere, on people?

Effects do seem to penetrate even to the lower atmosphere.

This is difficult to explain. Solar variability as a cause of longer period changes in conditions in the lower atmosphere and especially climate change has long been discounted.

Why??

Measurements of The Solar Constant



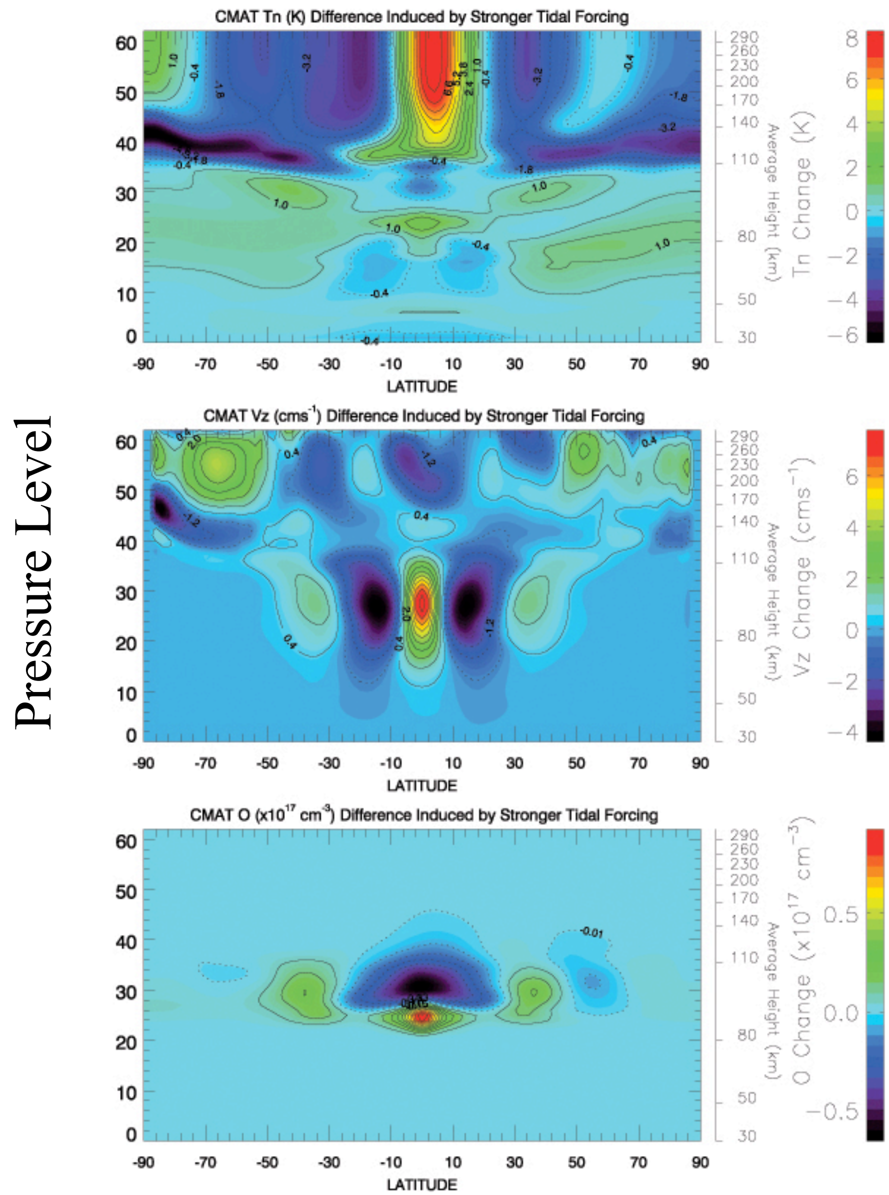
So the tail wags the dog?

- But there is a lot of evidence for solar control of "climate" and long term changes in the lower atmosphere
- Cricket scores correlate with the solar cycle
- Revolutions correlate with sunspot activity
- What???

Possible causes of links between solar variability and climate change

- Variability of solar spectra - maybe amplified
- Energetic particles and effects on NO, O_3 or some other component?
- Cosmic ray seeding of clouds?
- Magnetospheric influence on the global electric circuit?
- Trapping of wave energy by the mesopause?
- Planetary waves, gravity waves, tides, turbulence
- Subtle control of processes by EUV/XRays which are amplified in the atmosphere (atmospheric transistor)
- Chemical transport?

Coupling of dynamics and chemistry:
Effect of increasing tidal forcing

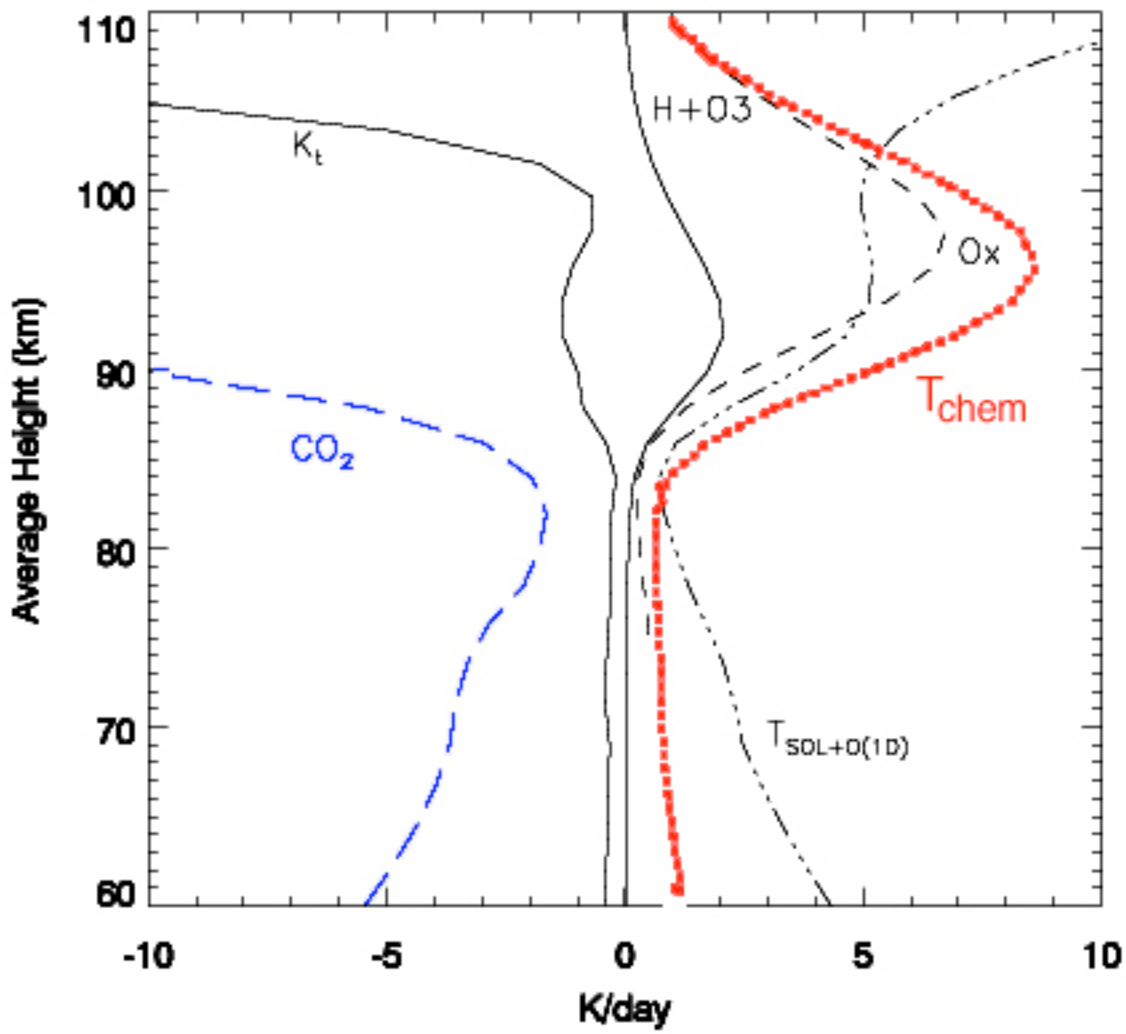


Temp Change (30-300km)

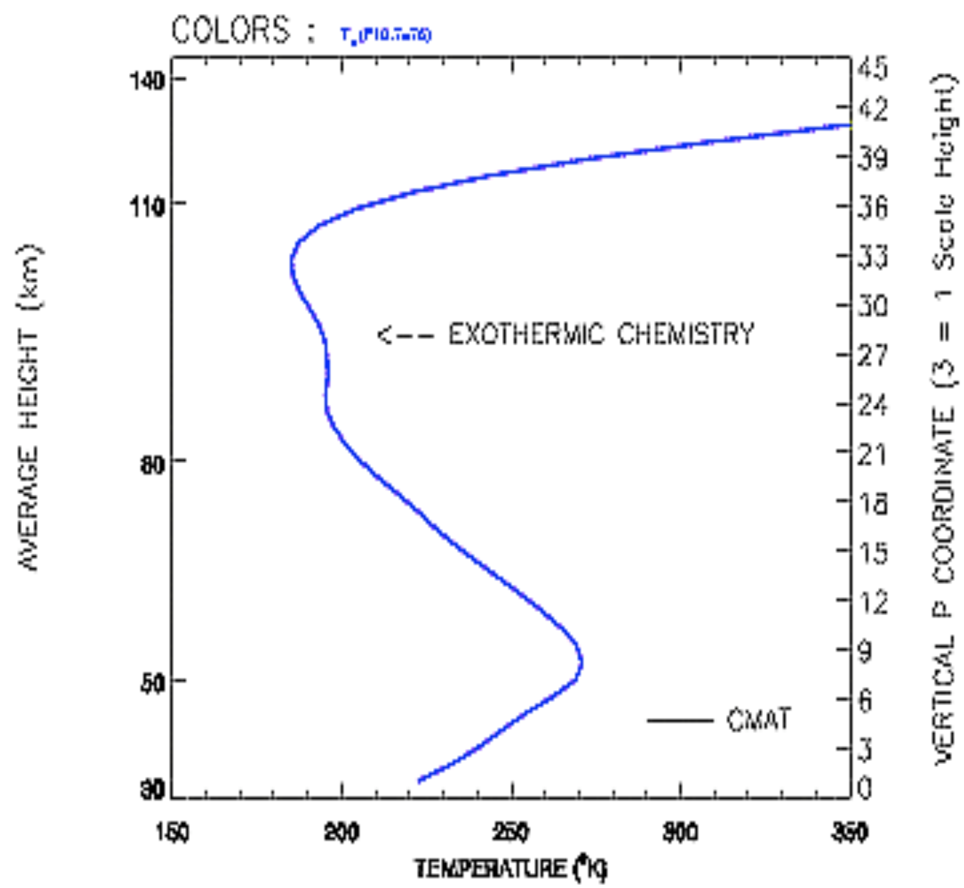
Vz Change (30-300km)

[O] Change (30-300km)

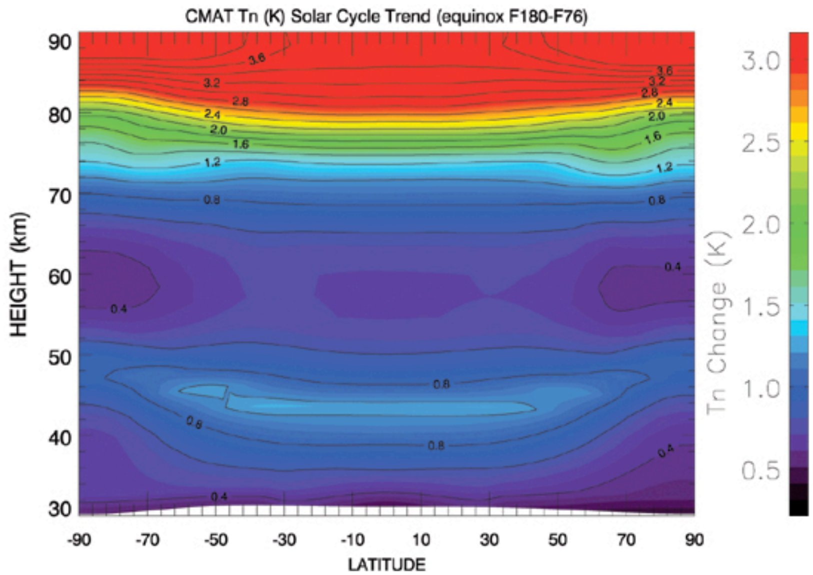
CMAT heating and cooling rates in MLT region: influence of chemistry on background atmosphere



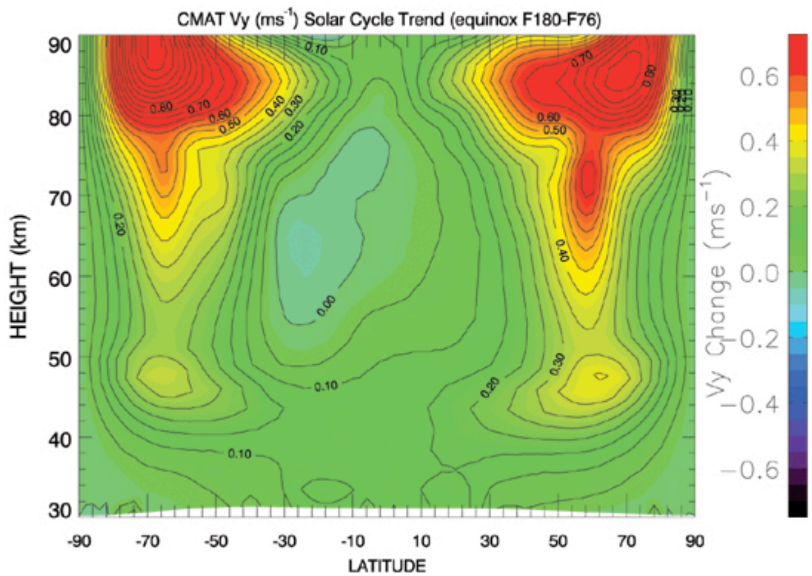
Transport plus exothermic heating: effect of atomic oxygen on the MLT region



Solar cycle effects on middle atmosphere temperature and zonal wind



Neutral temperature: difference F180-F76



Zonal wind: difference F180-F76

Importance of Nitric Oxide, NO

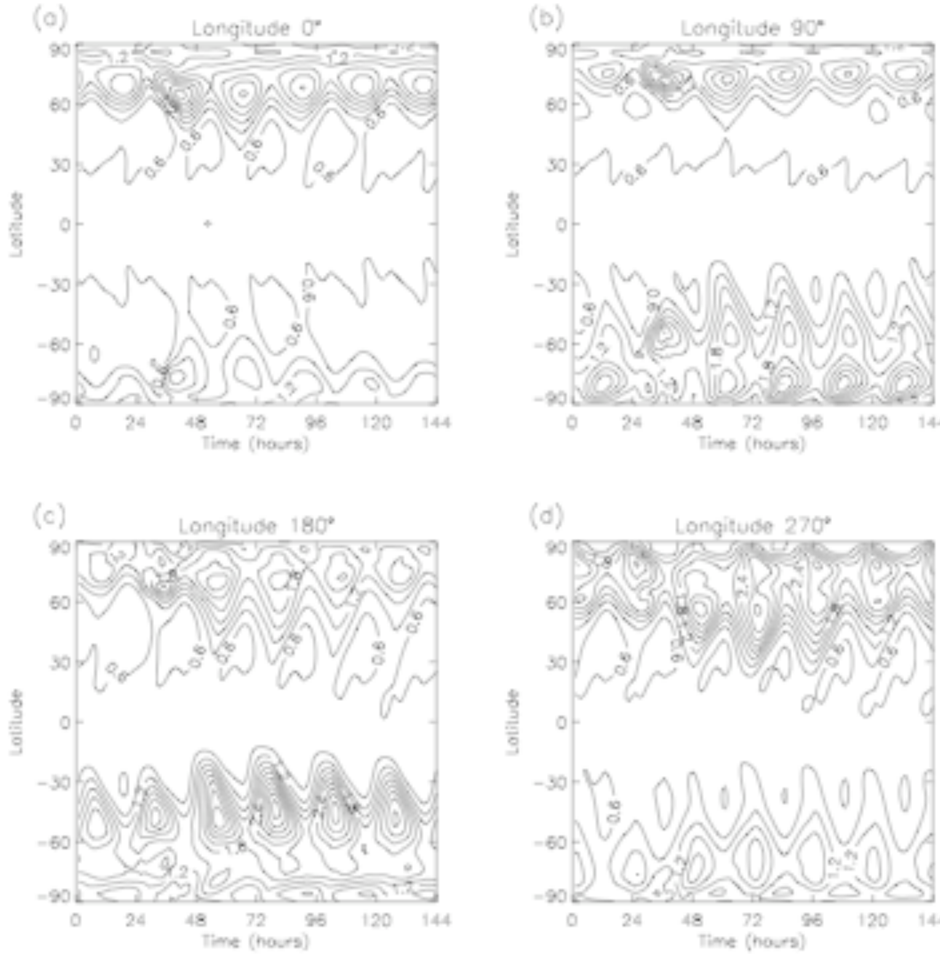
- Low ionisation threshold - ionisation potential 9.6eV
- Has a direct impact on ionisation density of the E and D regions (latter thro' Lyman alpha ionisation)
- Radiative emission at 5.3 microns is an important cooling mechanism for the lower thermosphere - can reduce heating efficiency at 130km by factor of 4 in the summer hemisphere, and important coolant after storms
- In winter nighttime can last many hours and be transported downwards to the stratosphere where it can contribute to catalytic destruction of the ozone layer

The problem with NO….

- NO has proven notoriously difficult to model accurately
- NO in the MLT region shows a large degree of variability with season, solar cycle, solar rotation and auroral activity
- Low latitude NO is largely the result of X-rays (2-10 nm) penetrating to 130km and subsequent photoelectron flux
- This is complicated by the fact solar illumination also contributes to the mechanisms which destroy NO
- NO is also produced by auroral precipitation and so is correlated with auroral activity
- Aurorally-produced NO can be transported by meridional winds to mid- and maybe low-latitudes
- There is a lot of disagreement about how far it can be carried
- Possible alternative mechanism where NO is carried downwards from above 140km where it is created in response to increased T and [O]
- Most previous studies have been 1-D and so miss the dynamical redistribution

Modelled Nitric Oxide changes at 300km altitude during 1999 Solar Eclipse

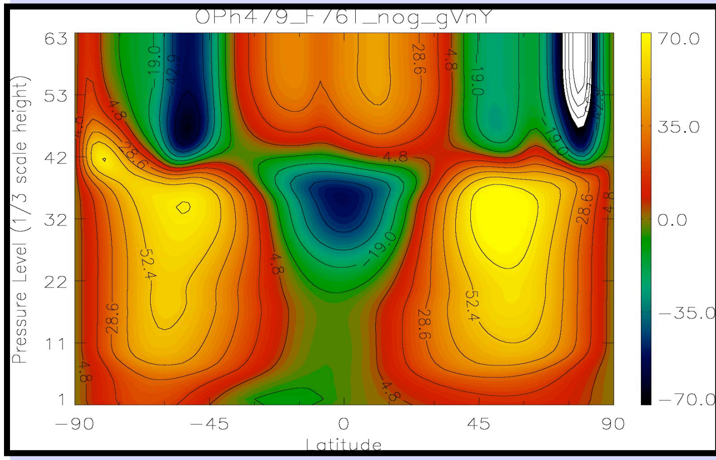
NO response at 4 different longitudes over the simulation period:



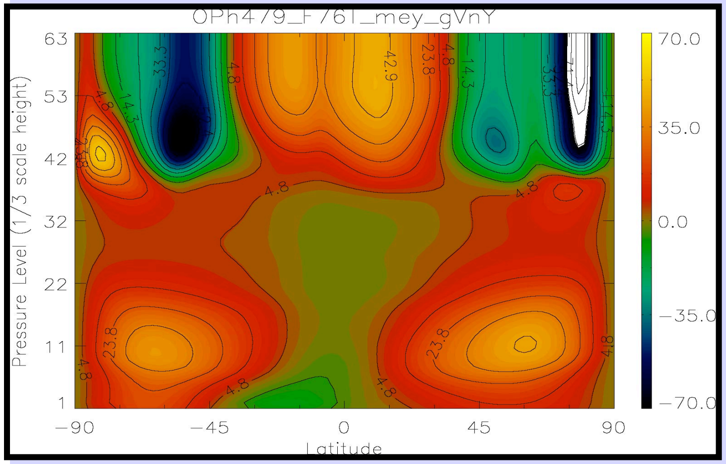
We can illustrate importance of waves in the atmosphere

- Small-scale disturbances at the ground can expand as they rise to be a major controlling factor high up ….
- This couples with electrodynamics to give a complex picture

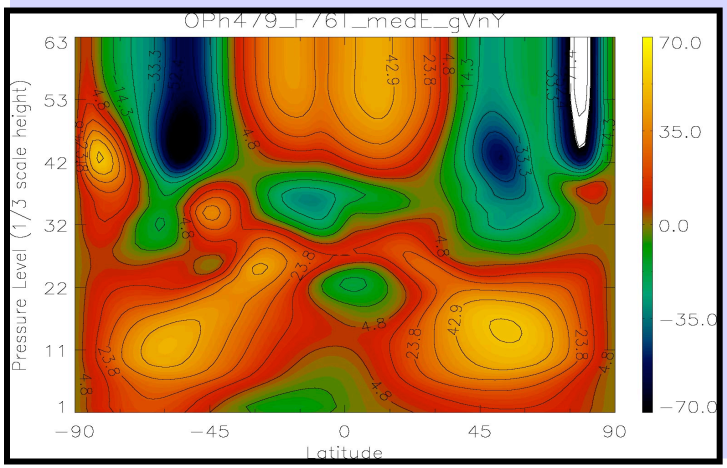
Effect of Gravity Wave Drag



A

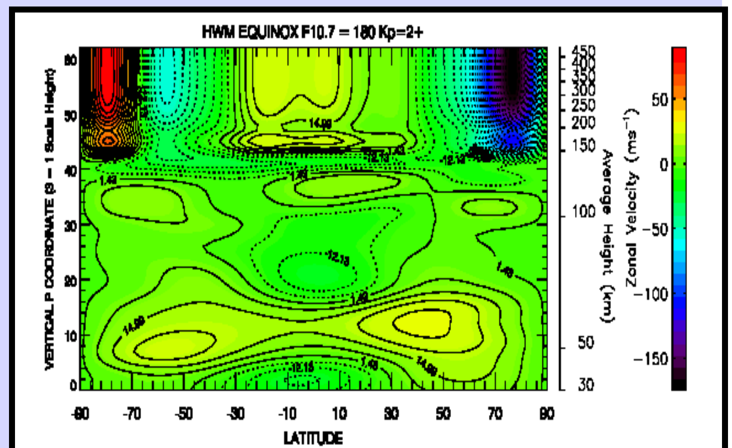


B



C

- Zonal mean zonal winds during equinox were calculated using the CMAT model
- 3 tests were preformed: no gravity waves (A), the Meyer 1999 scheme (B) and the Medvedev & Klaassen 2000 scheme (C)
- C produces the best agreement with the HWM empirical model at near the equator, but B produces more realistic mid-latitude zonal jets



Zonal mean zonal winds for March equinox from HWM empirical model

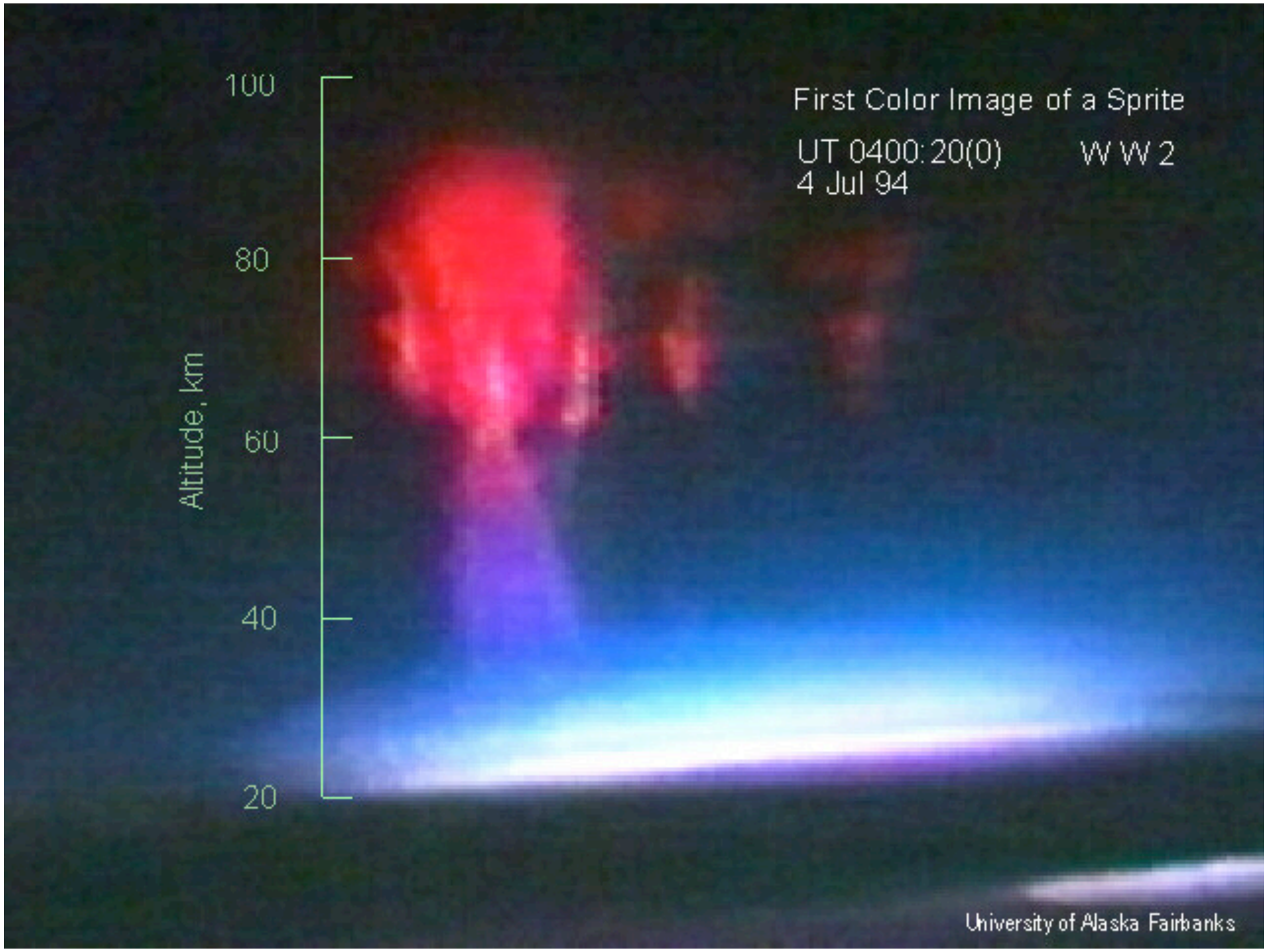
Other oscillations in the atmosphere

- There are besides AGWs (Atmospheric Gravity Waves a number of other wave- or oscillatory motions in the atmosphere:
- Tides
- Planetary waves
- Interactions between these different types
- Planetary waves are importance in many lower atmosphere “climatological” features like the polar vortex, sudden stratospheric warmings etc

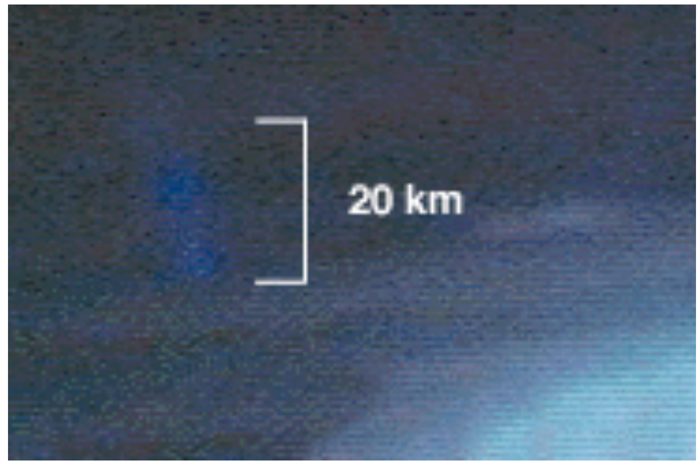
A more direct connection? Maybe mediated by Electric/Magnetic Effects?

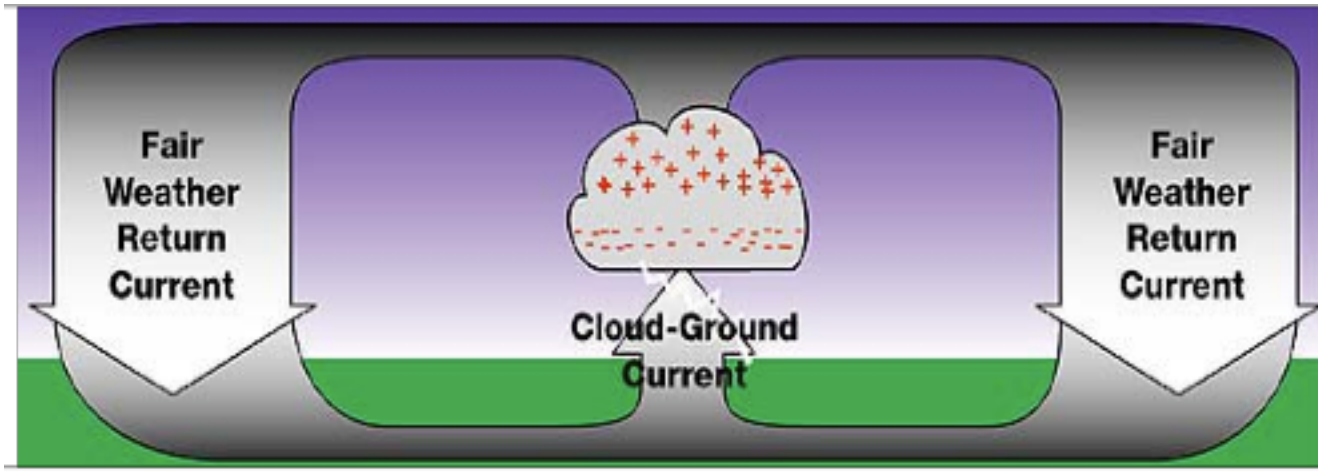
The Suggested "Global Electric Circuit"

Sprites


100
80
60
40
20
Altitude, km
First Color Image of a Sprite
UT 0400:20(0)
W W 2
4 Jul 94
University of Alaska Fairbanks

Blue jets





Above: Diagram shows fair weather circuit, also called "global electrical circuit", showing normal potential between the ground and atmosphere. Credit: NASA/MSFC (Dooling)

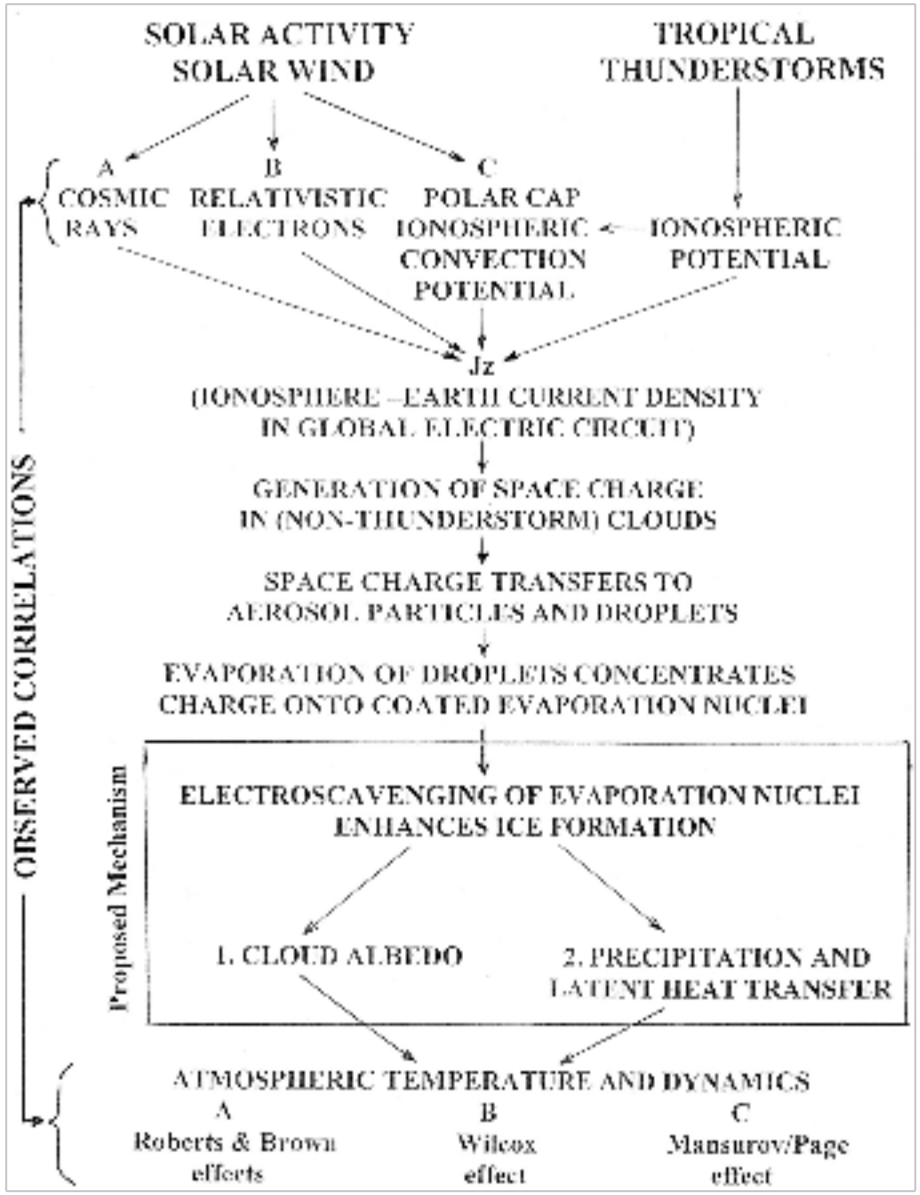


Figure 1. Processes connecting the solar wind with the global electric circuit, cloud microphysics, and weather and climate.

Conclusions

- The Thermosphere is important as a staging post in the chain of solar -terrestrial energy and momentum interchange.
- We can look at the sun as affecting the Earth at three levels of complexity:
- The first - average diurnal, seasonal and solar cycle variability which depends on solar insolation - we understand quite well
- Smaller time-scale variability due to solar wind changes we have a broad understanding of, but it is difficult to model the details
- Long-term “drifts” in solar variability and possible solar-induced climate change effects we are just coming to grips with. It is difficult to see how we can understand such a complex system without detailed modelling
- There is evidence of links between solar variability and ground effects which are still not really understood