Testing Simple Parameterizations for the Basic Characteristics of the Martian Ionosphere

(How does the martian ionosphere respond to changes in solar flux?)

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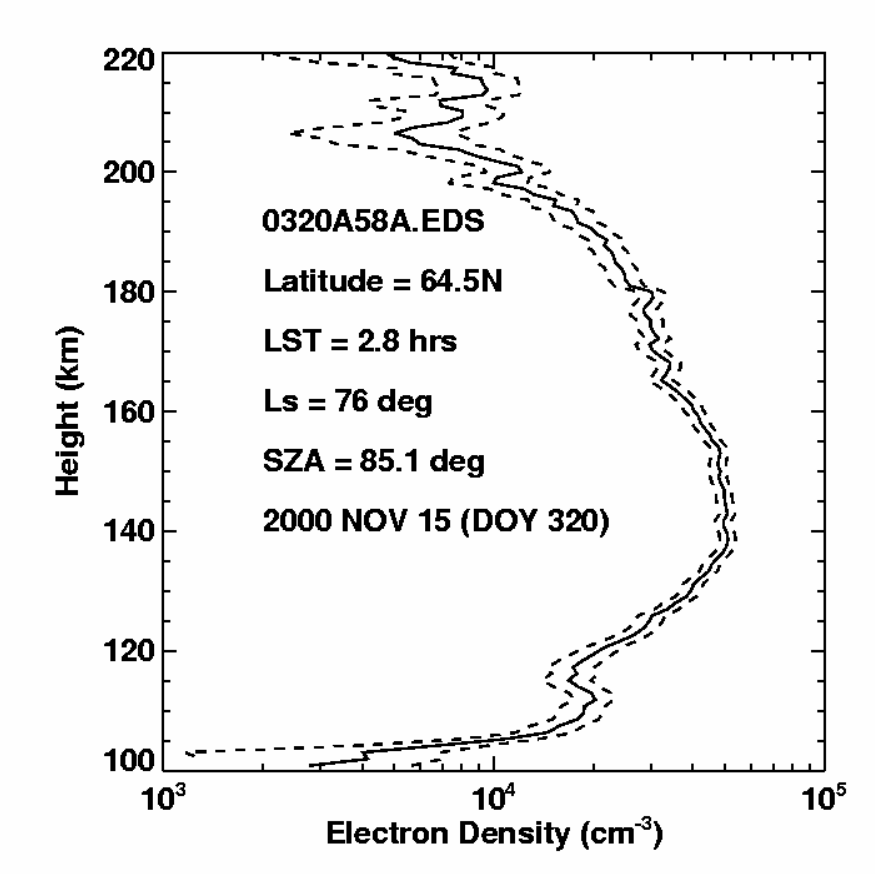
Introduction to Martian Ionosphere and MGS RS Data

MGS Data Coverage

60-85N, 60-70S
2-9, 12 hrs LST
70-180 deg Ls – over 2 yrs
70-87 deg SZA
Dec 98, Mar 99, May 99,
and Nov 00 – Jun 01



Simplified chemistry

CO_2 + hv -> CO_2^+ + e (fast)
CO_2^+ + O -> O_2^+ + CO (fast)
O_2^+ + e -> O + O (slow)

Typical Profile

Primary peak, well fit by alpha-Chapman function, 130-150 km, (4-14) x 1E4 cm^{-3}
Secondary feature (ledge, peak, etc) of variable significance, 110-120 km
Primary peak mainly from 30.38 nm (Helium) flux, secondary peak from few nm X-rays
Wavy topside with H decreasing as altitude increases

Dependence of Electron Density on SZA and Solar Flux

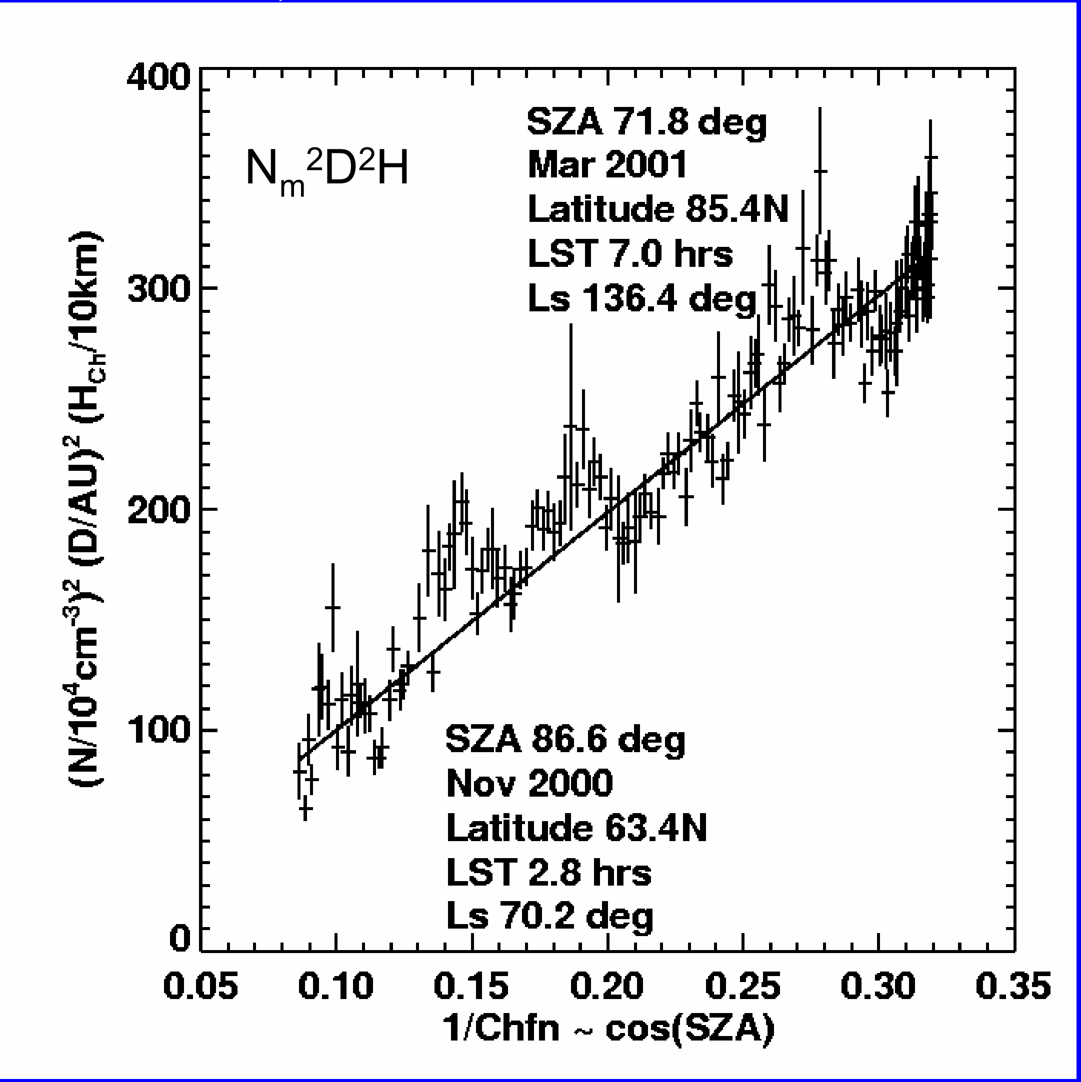
$$\alpha N^2 = \frac{F_{1AU}}{D^2}\frac{1}{Chfn}\frac{1}{He}\exp\left(1-\frac{z-z_0}{H}-\exp\left(-\frac{z-z_0}{H}\right)\right)$$

$$N_m^2 D^2 H = \frac{1}{Chfn}\frac{F_{1AU}}{\alpha e}$$

Chfn ~ 1/cos(SZA)
Simple Chapman theory describes the dependence of peak electron density, N_m, on SZA well.

Gradient is $F_{1AU}/\alpha e \sim 10^{-17}$ cm^{-5}
$\alpha \sim 2 \times 10^{-7}$ cm^3 s^{-1}, e ~ 3, so derived **$F_{1AU} \sim 6 \times 10^{10}$ cm^{-2} s^{-1}**

Solar2000 flux at 30.38 nm line for this period matches well: **(2-4) x 10^{10} cm^{-2} s^{-1}**



Residuals appear due to periods of relatively low or high solar flux.
Can this impression be quantified?

How Can E10.7 Be Compared Against Observed Peak Electron Densities?

$$N_m^2 D^2 H = \frac{1}{Chfn} \frac{F_{1AU}}{\alpha e}$$

$$N_m D \sqrt{H_{Ch} Chfn} \propto \sqrt{E_{10.7}}$$

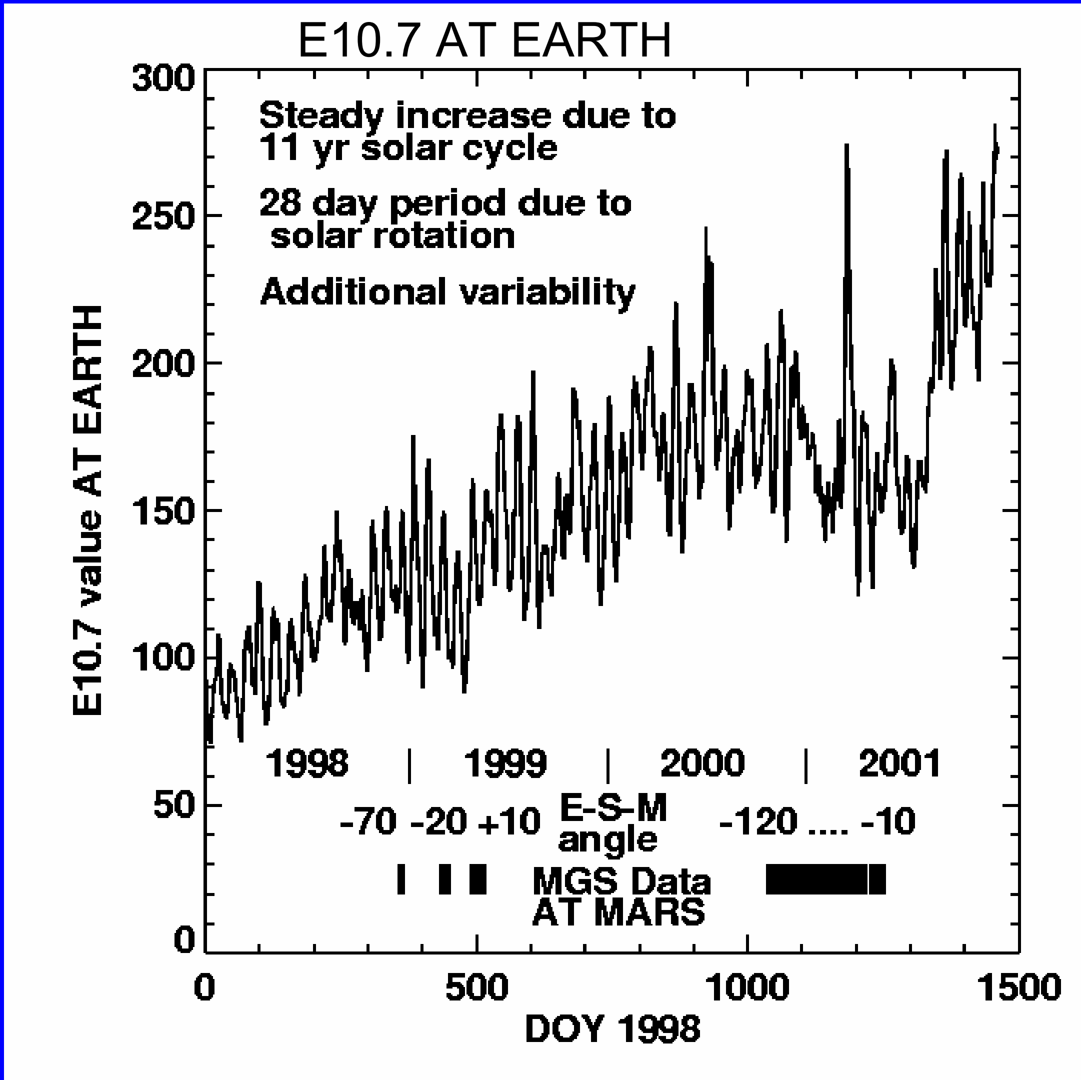
Aim: Is above equation satisfied?

E10.7 data AT MARS are not available, so can only test it if:

(A) Mars is at **opposition**, so E10.7 data AT EARTH is good proxy for Mars, or

(B) E10.7 AT EARTH is very **regular**, so that these values can be used AT MARS with an offset appropriate to the Earth-Sun-Mars angle

Also restricted by MGS data coverage… **Select 4 periods**



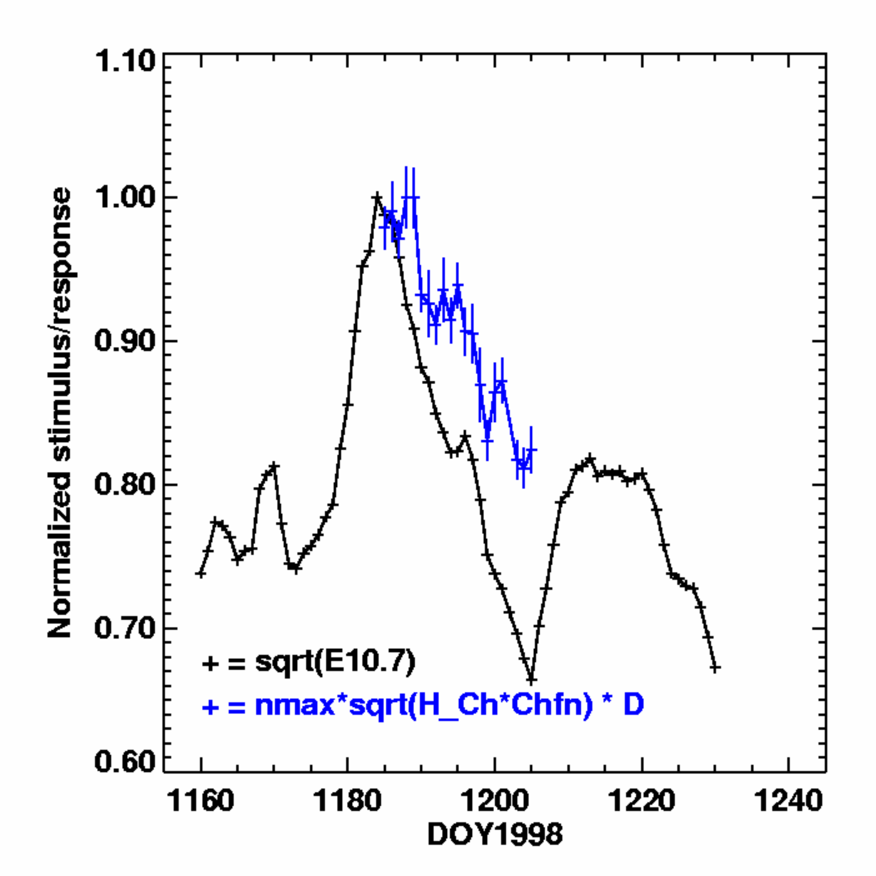
E10.7 in units of 10^{-22} W m^{-2} Hz^{-1}

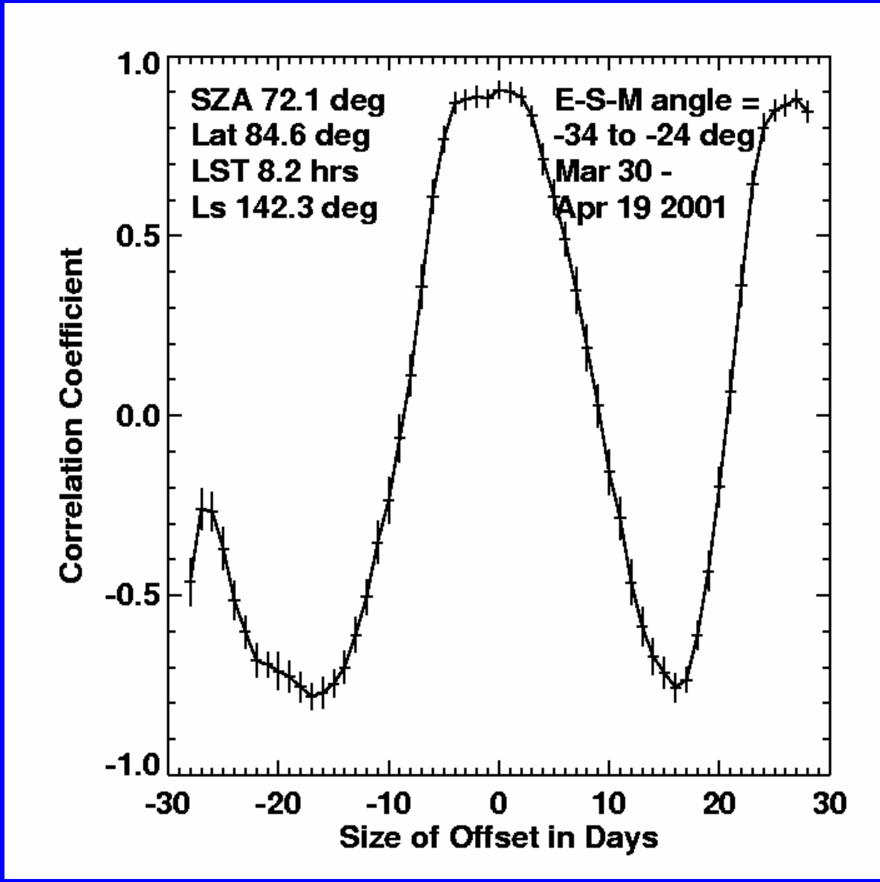
Technique

- Calculate daily average of $N_m D$ sqrt(H_{Ch} Chfn) and corresponding daily average of sqrt(E10.7) for each day in selected period
- Calculate **correlation coefficient** between these two data series
- Repeat, **shifting the E10.7 series** in time by set number of days
- Find timeshift at which correlation coefficient is greatest
- Convert actual E-S-M angle to predicted timeshift using 28d solar rotation and **compare observation to prediction**

  ESM/360 deg x 28d = Predicted timeshift

Period #1, Mar 30 – Apr 19, 2001 (Regular E10.7)

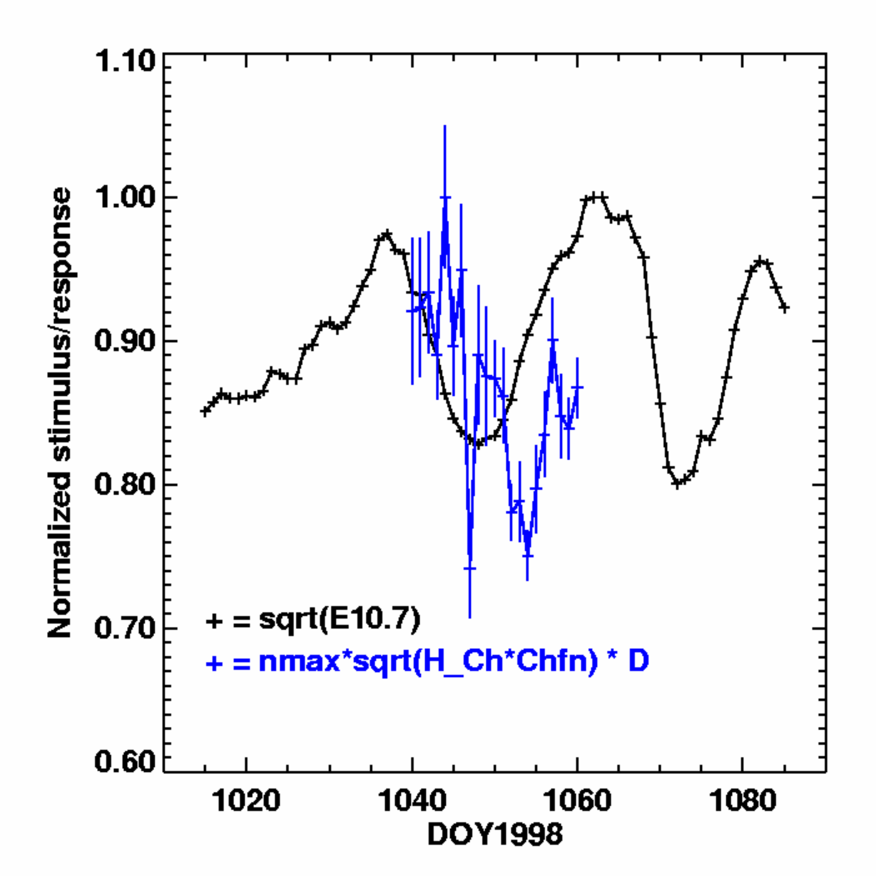


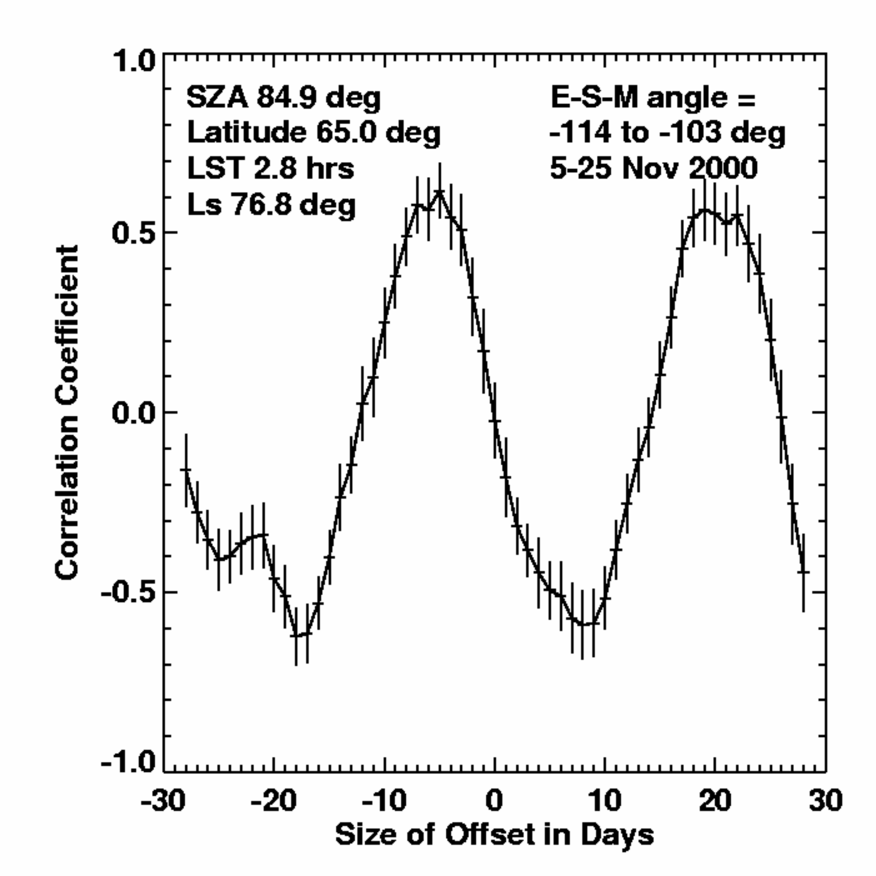


Peak correlation occurs for shift of **-4d to +2d**
Predicted peak is at **-3d to -2d**
Observation and prediction are **fairly consistent**

Solar flux is **not perfectly regular** with 28d period
7d breadth of peak makes precise work difficult

Period #2, 5 – 25 Nov, 2000 (Regular E10.7)

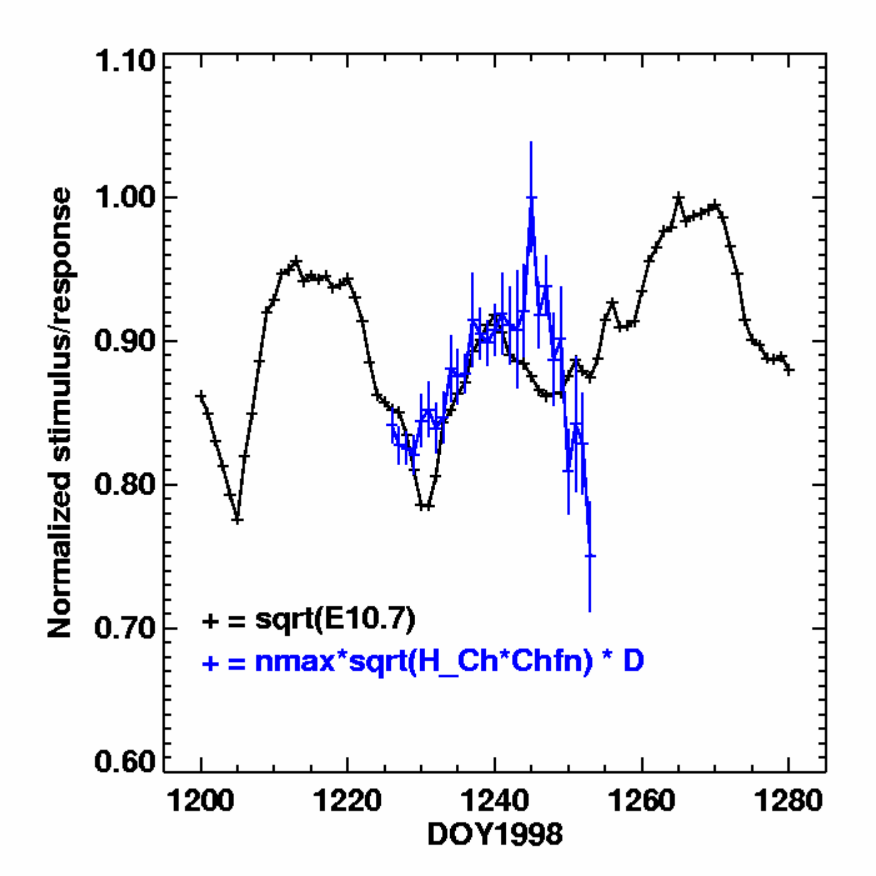


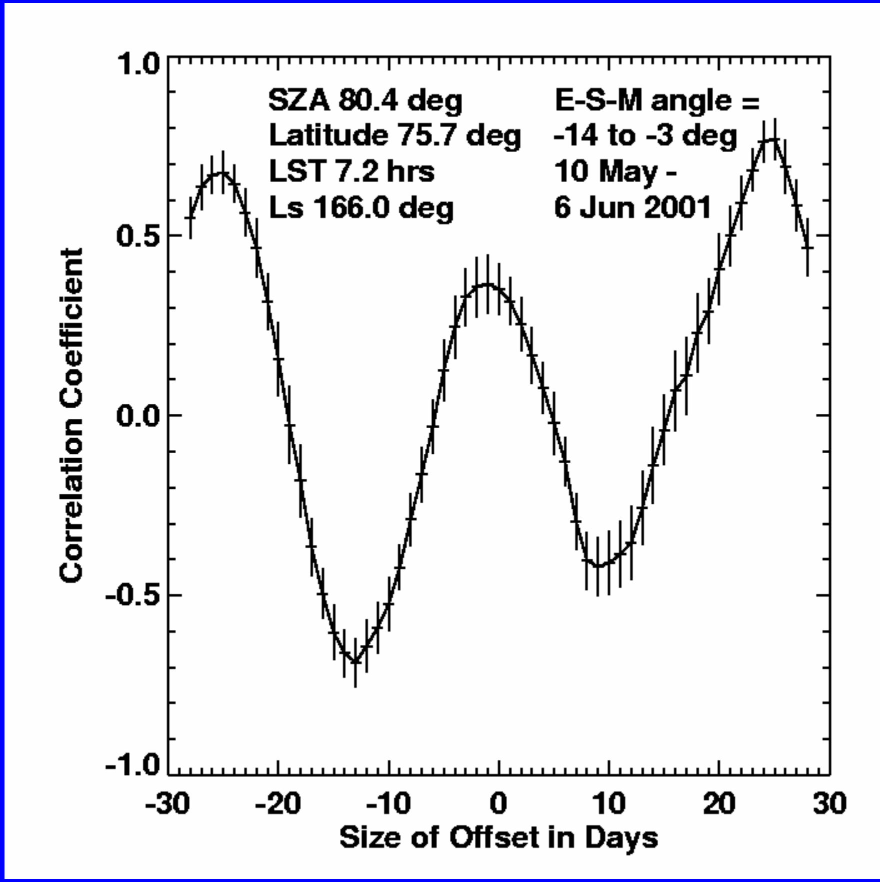


Peak correlation occurs for shift of **-8d to -3d**
Predicted peak is at **-9d to -8d**
Observation and prediction are **fairly consistent**

Range in E10.7 is smaller in this case than before, and correlation is worse
Note that E10.7 is only a proxy and the ionosphere actually responds to a range of wavelengths, with a different response for each wavelength

Period #3, May 10 – Jun 6, 2001 (Opposition)

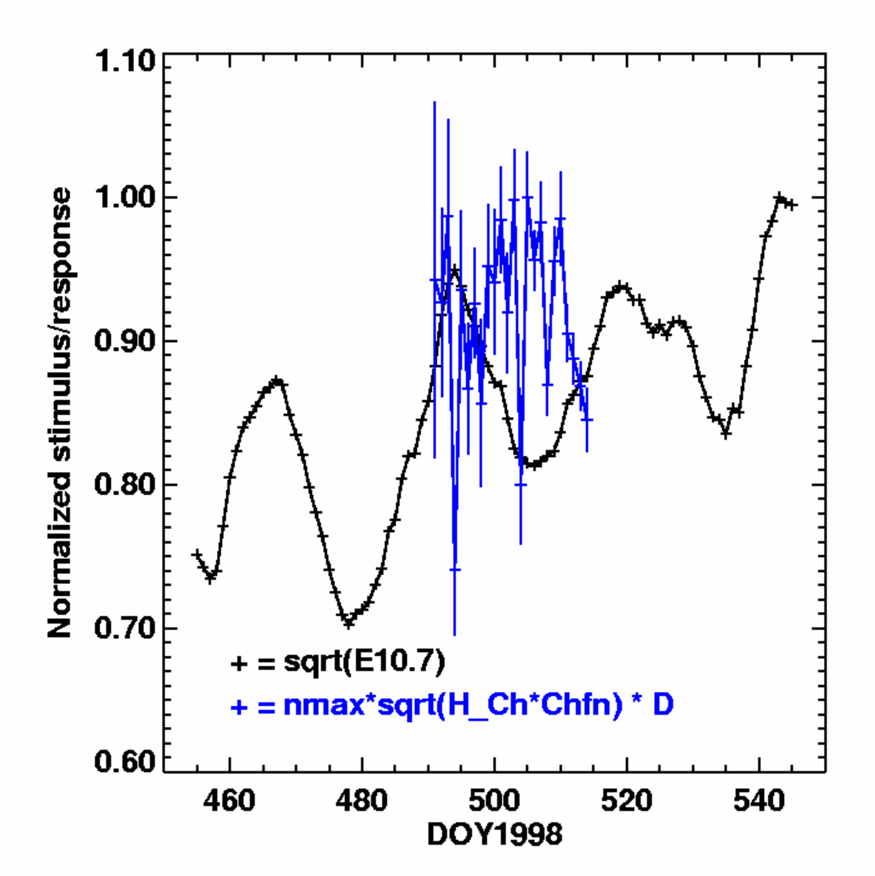


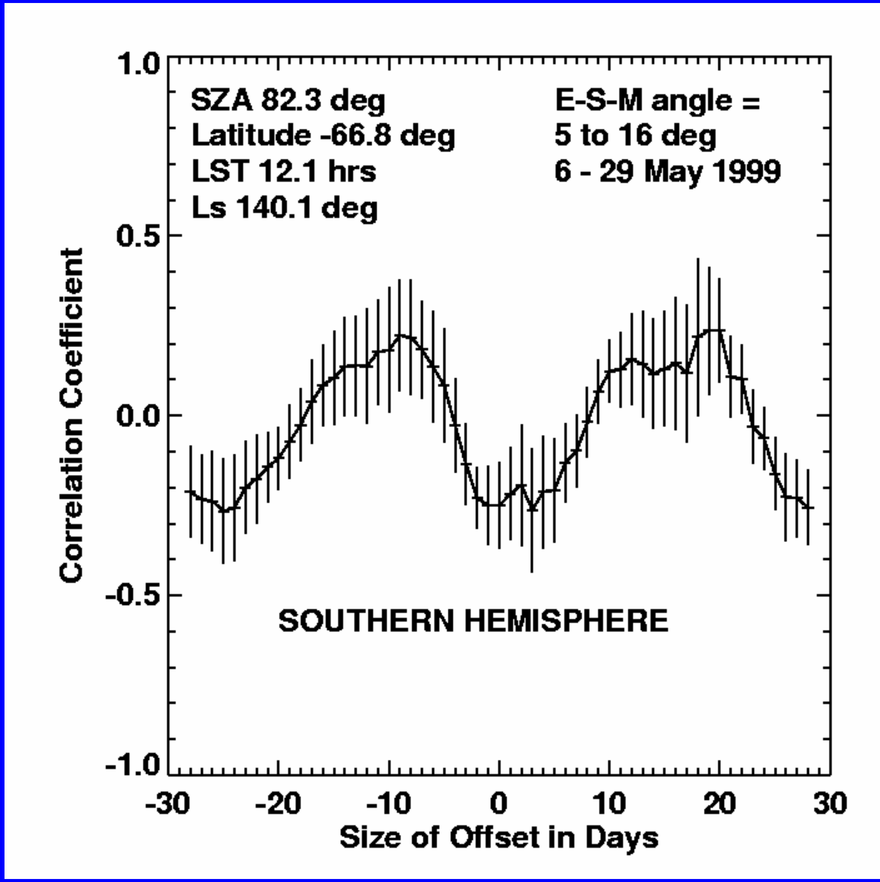


Peak correlation occurs for shift of **-4d to +2d**
Predicted peak is at **-1d to 0d**
Observation and prediction are **fairly consistent**

Range in E10.7 is again smaller in this case than before, and correlation is again worse

Period #4, 6 – 29 May, 1999 (Opposition)





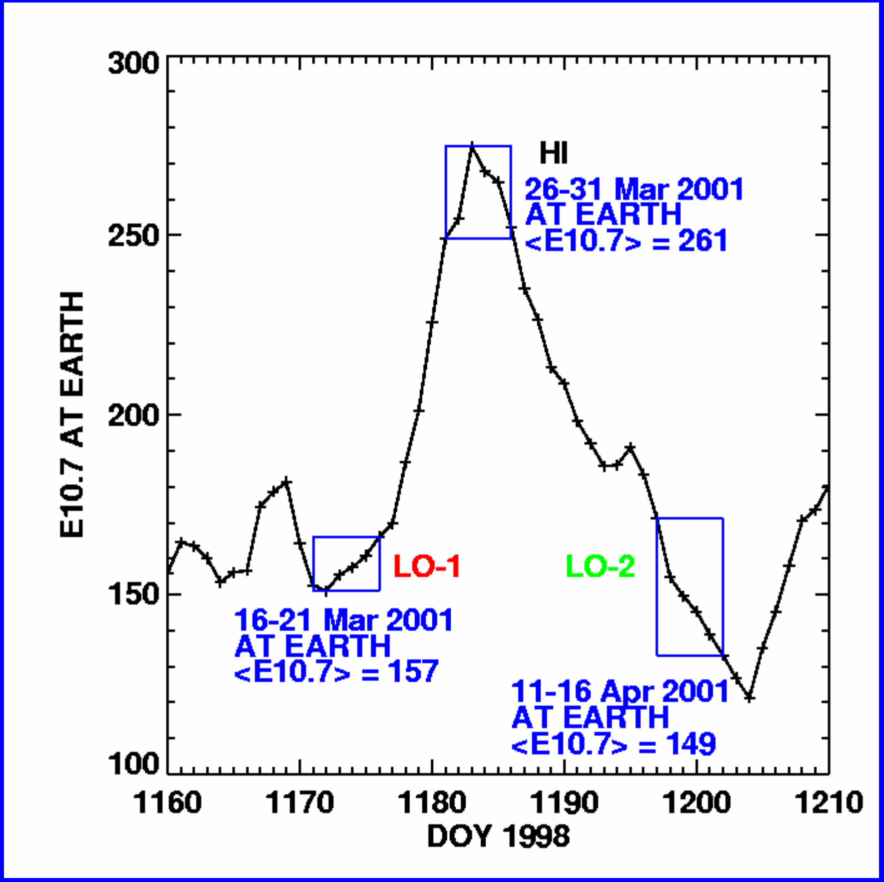
Peak correlation occurs for shift of **-18d to -4d**
Predicted peak is at **0d to 1d**
Observation and prediction are **inconsistent**

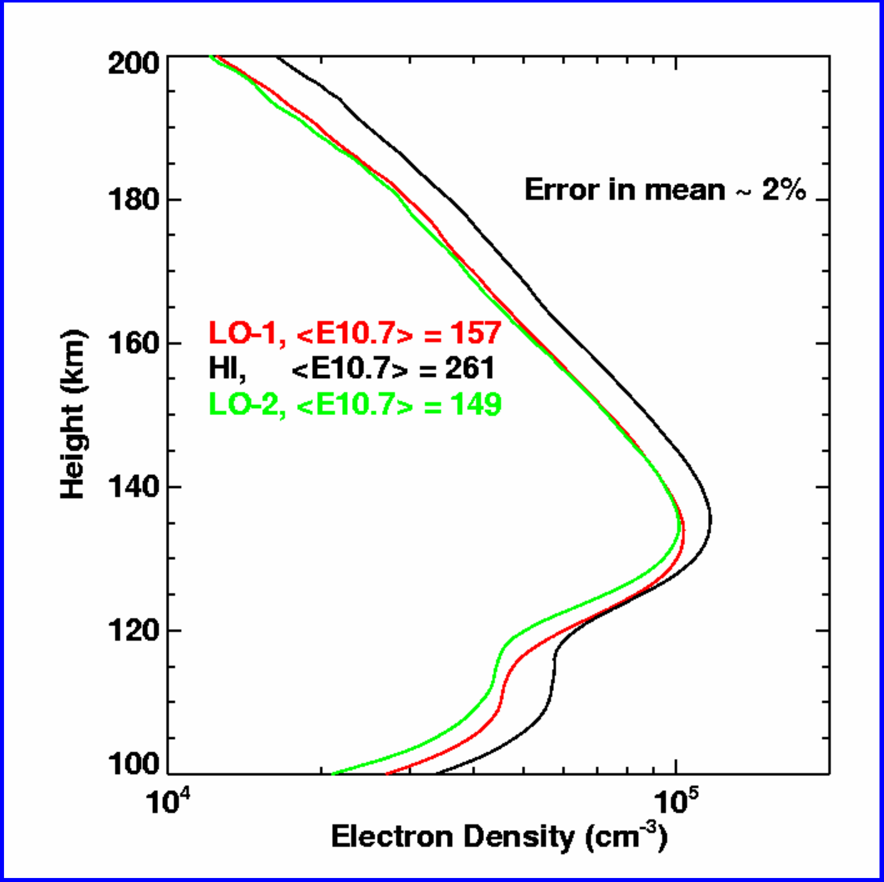
Uncertainties on observed electron densities are very large (20% at peak, not typical 5-10%)
Magnetic fields more important in Southern Hemisphere

Results of Solar Rotation Studies

- Effects of solar variability due to solar rotation on the ionosphere have been detected.
- To get reasonable correlation, need either opposition or very regular solar flux
- Correlation greatest when range in E10.7 is greatest
- Southern hemisphere opposition in May 1999 shows no correlation – B fields?
- Ne at secondary features show similar, but noiser, correlations

Comparison of Low and High Solar Activity





Solar flux goes from low to high to low values in one month
Average all profiles from Mars in selected periods – shifting by two days
HI/LO ratio of peak electron density ~ 1.15 and of sqrt(E10.7) ~ 1.30
Heights of primary peak and secondary feature don't change significantly
Chapman-derived scale heights (10-11 km) at peak don't change significantly
Topside plasma scale height few km greater in HI case than low cases, so HI/LO ratio of electron densities increases as altitude increases

Conclusions

- Dependence of peak electron density on SZA follows simple Chapman theory well
- Effects of solar variability due to solar rotation on the ionosphere have been detected. They are easiest to detect when changes in solar flux over a rotational period are greatest. One case in the southern hemisphere does not fit the general pattern.
- Mar – Apr 2001 period has such large changes in solar flux that it is an excellent “test case” for studying the ionospheric response to changes in solar flux