Implications of Comparison of Ionospheric Physical Model Simulations and Data During the Last Solar Minimum

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Special thanks to Sarah Gibson (HAO) and Louis Gentile (AFRL)
What’s up with the ionosphere?

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Special thanks to Sarah Gibson and Louis Gentile
INTRODUCTION:
Few slides from Sarah Gibson presentation at the 2010 Space Weather Workshop... No doubt, this has been an unusual minimum.

SOME OTHER INDEXES AND A COUPLE OF MODEL RUNS...
F10.7, MSIS, ap

IONOSPHERIC DATA FOR DIFFERENT PARTS OF THIS MINIMUM AND THE PREVIOUS MINIMUM.
DMSP (few slides from Louis Gentile at 2010 C/NOFS Workshop), Champ and some results from CTIPe, NmF2, VTEC

CONCLUSIONS

FINAL CONCLUSION
A Multifaceted Minimum: from Sun to Earth in 2008-2009

Sarah Gibson

SARAH GIBSON -- 2010 SWW

• 2008: A Deep Solar Minimum Begins...
  • Whole Heliosphere Interval
  • Sun Quiet but Complex
  • Heliosphere Still Ringing

• 2009: A Long Minimum Continues to Evolve..
  • Complexity Loses Coherence
  • Low-latitude Solar Open Flux Fades
  • Heliosphere Hits Bottom

• 2010: Activity Returns: Minimum is Over
Current solar minimum: unusually deep

Sunspot Number: 2008 had 266 spotless days - most since 1913

At the Sun...

Solar irradiance: may be depleted relative to past minima (note difference is still small relative to min-max variation)

B at solar poles ~40% weaker than last cycle in 2008


MDI data: Courtesy Giuliana de Toma
Current solar minimum: unusually deep

In the solar wind...

CR 1888-1914
SC 22

CR 2038-2088
SC 23

Density (#/cc)

|B| (nT)

0 2 4 6 8 10

0 0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4

Current solar minimum: unusually deep

At the Earth.

Earth’s ionosphere thin and cool
Space “closer than you think” by about 100 miles (NASA-CINDI)

Long-term satellite-drag data
Sat#02150, Z=360 km

Earth’s thermospheric density is ~10 times lower than can be accounted by climate change

CC < 5%/decade
2008: ~50%

Courtesy Stan Soloman, Tom Woods
Geomagnetic Activity
ap-index
Solar Wind Effects on Plasma Density Depletions: C/NOFS
Results with Related Observations from DMSP
C/NOFS Science Workshop 18-20 May 2010

L. C. Gentile, W. J. Burke, C. Zens, P. A. Roddy, J. M. Retterer, G. R. Wilson
O. de La Beaujardière, Y.-J. Su
AFRL/RVBX
Space Vehicles Directorate
Air Force Research Laboratory
C/NOFS and DMSP Observations

- Unexpected C/NOFS results
  - Deep plasma density depletions observed post-midnight to dawn, very few near sunset (until March 2010)

- Recent DMSP observations
  - No evening sector plasma bubbles
  - Dawn sector climatology dynamic
  - Different processes drive ionosphere-thermosphere system at dawn in solar minimum

- In deep solar minimum, even small changes in solar wind/IMF affect dynamics of equatorial plasmas and electric fields

C/NOFS Mission

- Unique opportunity to observe unusual solar minimum
- Provides fundamental new knowledge of Earth’s ionosphere
- Facilitates development of fully-integrated models and forecasts
DMSP Evening Sector

Solar Max vs Solar Min

DMSP EPB Rates 1999 - 2002

Most EPBs occur in Atlantic-Africa sector and when terminator aligned with magnetic field

DMSP solar max EPB climatology confirms Tsunoda’s 1985 model

Solar min climatology sparse, but consistent

This solar min is the lowest yet!

Mean = 210152.8606, Std = 85743.7139

Boulder (BC840): 2009-06-01 to 2009-06-30

Mean = 271627.8115, Std = 186836.9285
Camden(CN53L): 1997-06-01 to 1997-06-30

Mean = 288568.3308, Std = 130669.3443

Camden(CN53L): 2009-06-01 to 2009-06-30

Mean = 221314.0242, Std = 78404.4325
VTEC
(USTEC grid point, EOFs, data from 120 stations ingested)

Lat.30°N, Lon.100°W

- 2007: MEAN = 10.26926, STDDEV = 3.69356
- 2009: MEAN = 9.70532, STDDEV = 3.38032

01-31 July
VTEC, hourly mean
(USTEC grid point, EOFs, data from 120 stations ingested)

Lat.30°N, Lon.100°W

- **2007**
  - MEAN: 10.26926
  - STDDEV: 3.69356

- **2009**
  - MEAN: 9.70532
  - STDDEV: 3.38032

JULY
VTEC
(USTEC grid point, EOFs, data from 120 stations ingested)

Lat.30°N, Lon.100°W

- 2008: MEAN: 7.78616, STDDEV: 3.12769

TEC [TECU]

December
VTEC
(USTEC grid point, EOFs, data from 120 stations ingested)

Lat.30°N, Lon.100°W

2006
MEAN: 9.02964  STDDEV: 4.23598

2008
MEAN: 7.78616  STDDEV: 3.12769

TEC [TECU]

Universal Time

DECEMBER
VTEC
(dsrc, Boulder, CO, thin layer, data from a single station)

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VTEC-hourly means
dsrc, July 2007

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VTEC-hourly means
dsrc, July 2009
VTEC-hourly mean
dsrc

- July-2007
- July-2009

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VTEC
(pie1, Pietown, NM, thin layer, data from a single station)

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VTEC-hourly means
pie1, Dec 1996

VTEC-hourly means
pie1, Dec 2008

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VTEC-hourly mean

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December-2008

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Conclusions (1)

- Yes, it was a unusual solar minimum, in that the Sun was quiet for long enough for the 81-day and 12-month running mean of sunspot number and F10.7 to decrease to the same as the daily value.

- Thermosphere-ionosphere empirical and physical models sometimes use an average of the daily and 81-day mean to specify EUV flux. This number might be a little lower because of the extended minimum.

- Some models and data appear to show a lower, cooler thermosphere (e.g. CINDI, satellite drag). Some of that could be due to the above, but does not account for 50% (in slide 7).
Conclusions (2)

- CHAMP neutral density shows no evidence for substantially lower neutral density at the minimum compared to 1 year before.

- Although some ionosonde stations at some times can show a slight decrease in ion concentration and variability, the response is not consistent. The picture is further complicated by geomagnetic activity, since lower geomagnetic activity increases plasma density in summer and decreases it in winter. This change can mask the small solar cycle signature when comparing with the previous minimum.
Final Conclusion

- Apart from the slightly lower EUV flux implied by very low smoothed F10.7 or sunspot number, there is no evidence that the thermosphere/ionosphere response was unusual this minimum.
Orbital drag accelerations for a satellite in the earth's atmosphere are related to satellite properties and neutral density by:

\[ a_D = \frac{1}{2} \left( C_D A / M \right) \rho \ V^2 \]

- \( a_D \) is the drag acceleration
- \( \rho \) is the atmospheric total mass density
- \( A, M, C_D \) and \( V \) are the satellite's area, mass, drag coefficient and velocity respectively.

\( C_D A / M \) is the ballistic coefficient.