First observations of the mid-latitude evening anomaly using SuperDARN radars

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SuperDARN workshop

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Outline

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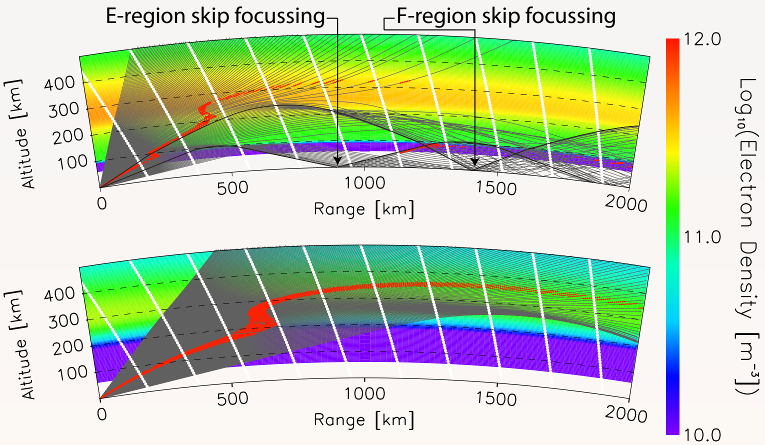
1. Introduction: a peculiar ground scatter feature
   - Mid-latitude HF propagation
   - Expected daily variation
   - Observed summer daily variation
2. SuperDARN observations at mid-latitude
3. Ray-tracing modeling of HF radio wave propagation
4. Comparison with previous observations
5. Proposed mechanisms
6. Summary

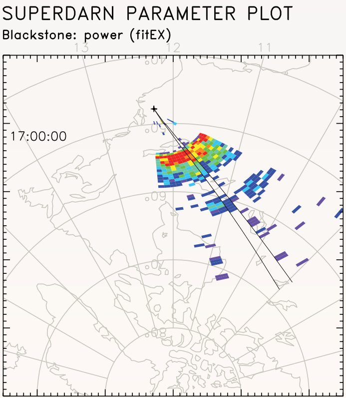
Mid-latitude HF propagation



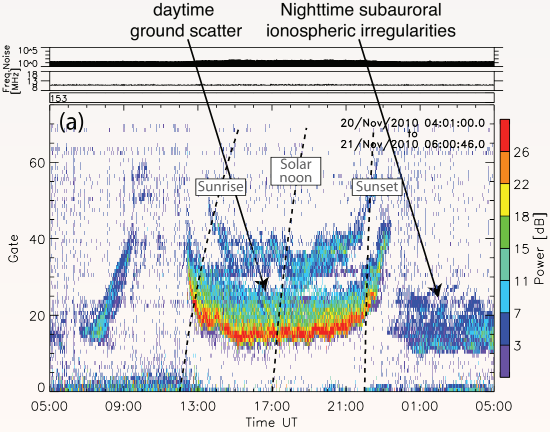
- Mid-latitude: daytime dominated by ground scatter
- Ground scatter can be used as a proxy for ionospheric diagnostic [e.g., TIDs]

Expected daily variation

- Ground scatter diurnal variation as observed by the Blackstone SuperDARN radar on November 20th, 2010. Apparent sunrise and sunset, as well as solar noon have been marked to emphasize solar dependency (NOAA/ESRL).

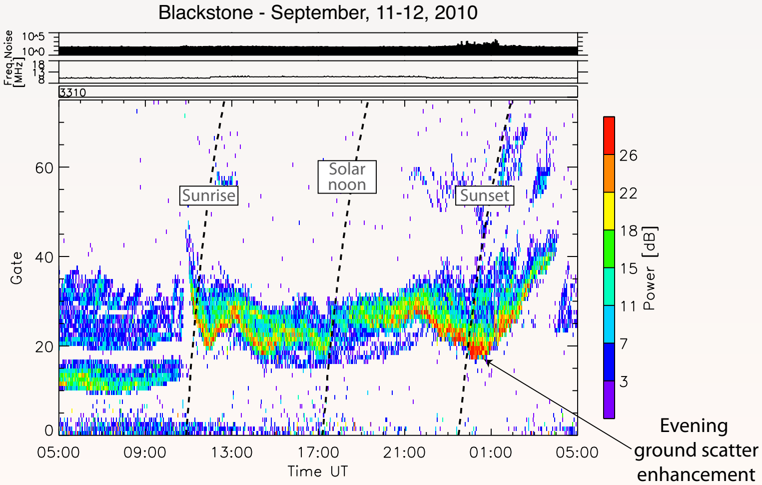


November, 20-21, 2010



Observed summer daily variation - evening enhancement

- Between May and September (2008–2010), mid-latitude ground scatter often exhibits enhancement in returned power after sunset over North-America (considering only quiet geomagnetic conditions).



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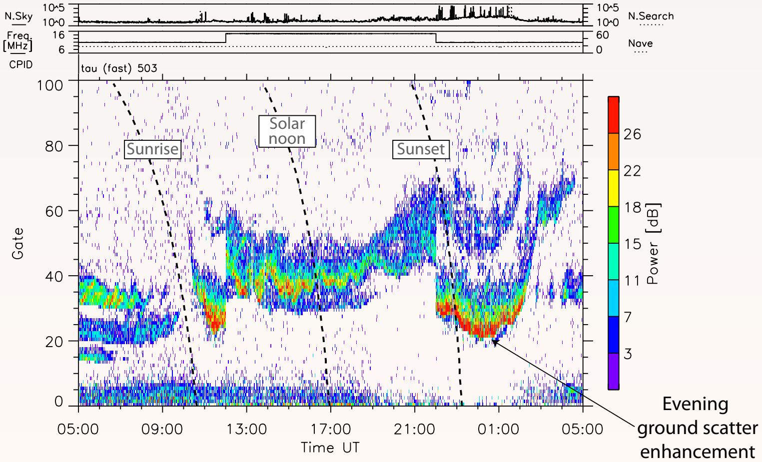
Wallops - September, 11-12, 2010



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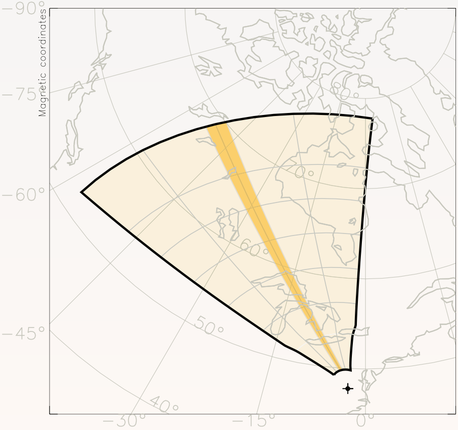
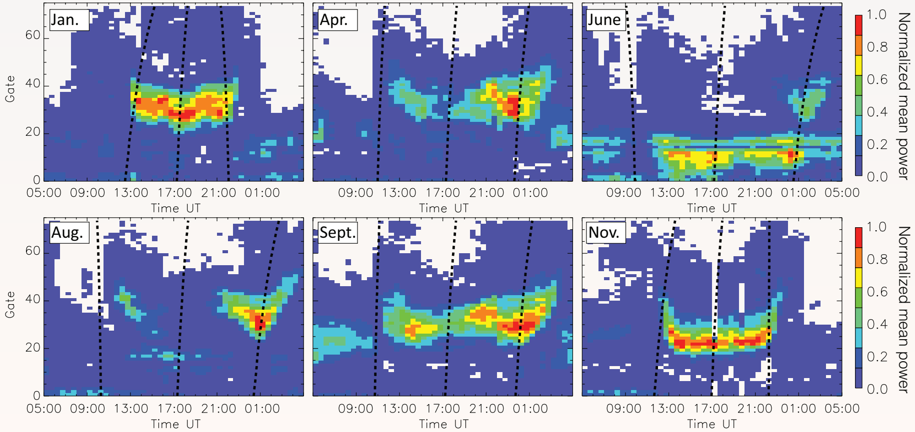
Dataset and processing



- Blackstone, beam 7 (azimuth -26°E).
- Frequency band 10.0–12.0 MHz.
- SNR $\geq$ 6 dB.
- Ground scatter only (use of GS flag in output files).
- Statistical daily variation of ground scatter for specific month in 2010.

Observed seasonal variation in 2010

- Enhancement appears clearly in the end of summer and fall and is also observed in early spring. Strong E-region absorption masks F-region signal in june.



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Model description

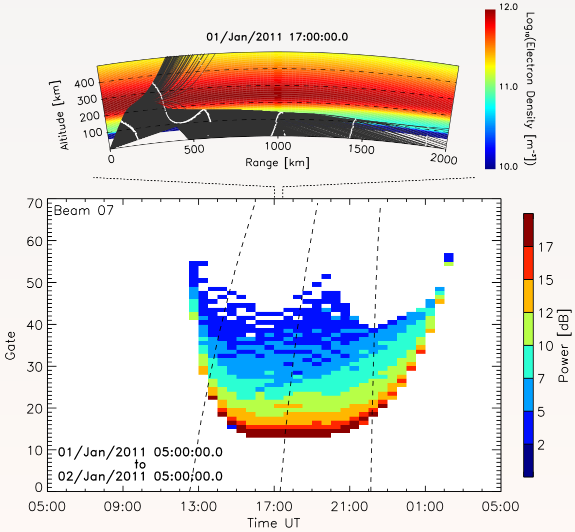
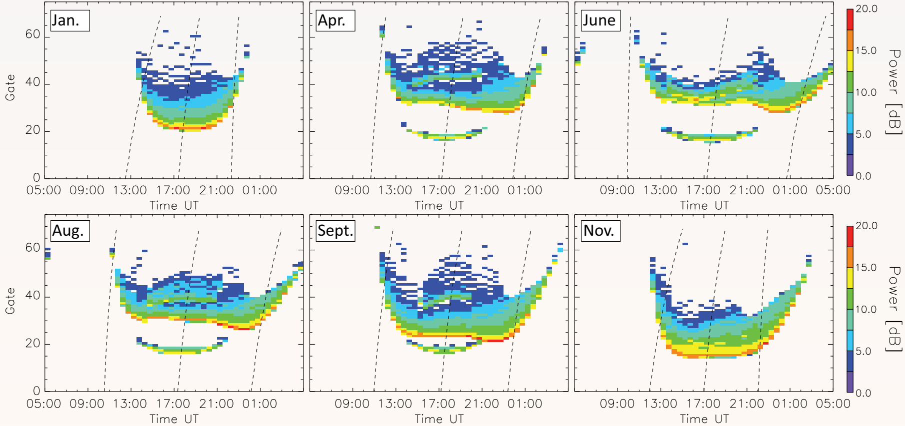


Figure: Ray-tracing output for Blackstone radar, beam 7.

- Ray-tracing from *Jones* [1996].
- Coupled with International Reference Ionosphere (IRI) model [*Rawer et al.*, 1978, *Bilitza*, 2001].
- For 11 MHz radio wave between 10° and 55°.
- Rays reaching the ground are counted and binned in 45 km long range gates for 1 hop only.
- Absorption and ground properties are ignored.

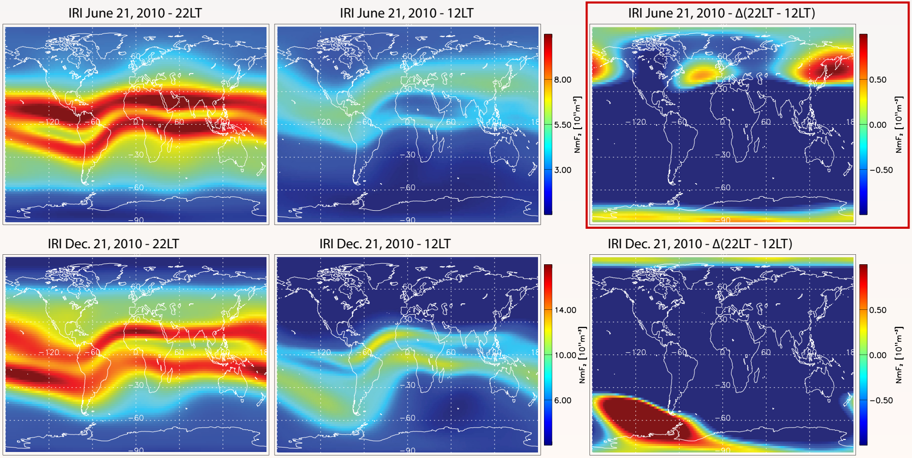
Modeled seasonal variation in 2010

- Enhancement is very strong from June to August, and weaker in September. Note that since absorption is ignored, the presence of the E region does not mask F-region related ground scatter.



IRI

- Global distribution of electron densities at 300 km altitude obtained with the IRI model [*Bilitza*, 2001]. The two rightmost maps are generated by subtracting electron densities at 12LT from those at 22LT to represent the intensity and coverage of the summer evening enhancement in both hemisphere.



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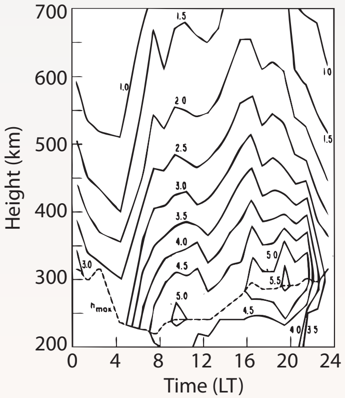
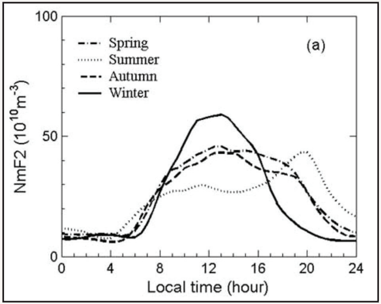
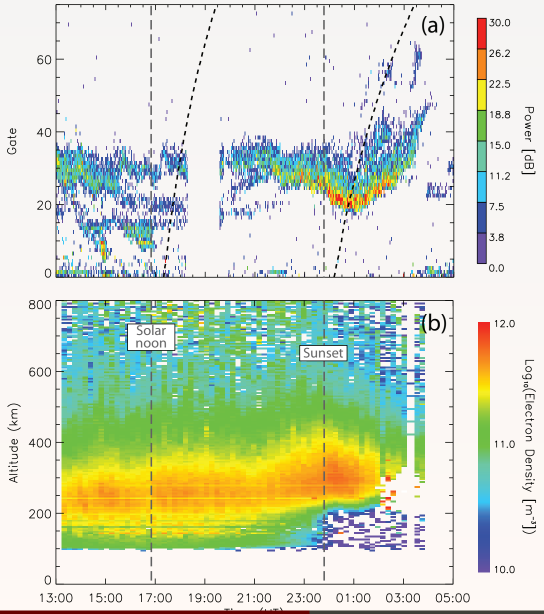
Millstone Hill observations





- First published report on mid-latitude evening enhancement in electron densities at Millstone Hill. Plotted are critical frequencies for July 1963 [from *Evans*, 1965].
- Statistics using Millstone Hill data of NmF2 daily variations at solar minimum [from *Lei*, 2005].

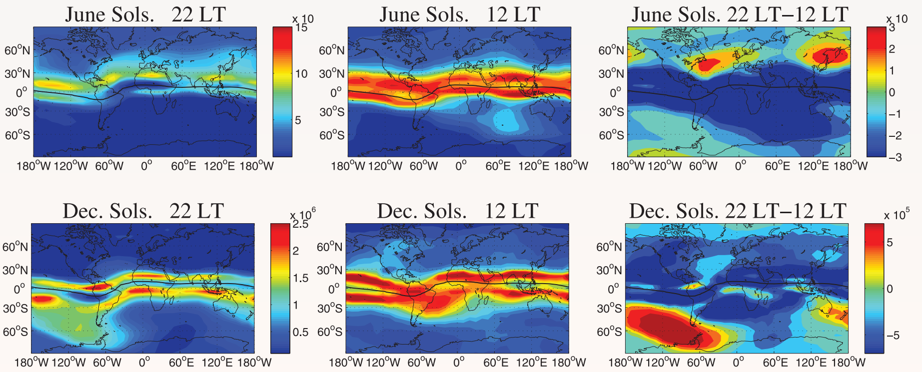
Millstone Hill observations (August 13-14, 2010)



- Blackstone SuperDARN observations exhibiting an evening enhancement in ground scatter.
- Millstone Hill observations. Notice the maximum electron density occurs after sunset.

CHAMP [*Liu et al.*, 2009]

- Distribution of Ne at 400 km at night (22LT), day (12LT), and the difference between them for (top) June solstice and (bottom) December solstice [*Liu et al.*, 2010].

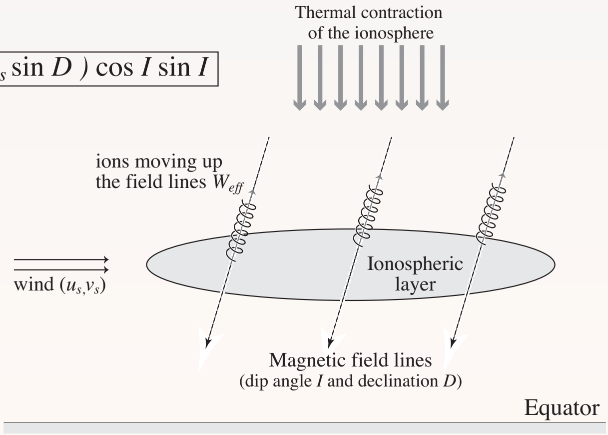


Outline

Previously proposed mechanism

- *Eccles* [1973] demonstrated that equatorward thermospheric winds are the main factor in the observed evening enhancement.
- *Liu et al.* [2010] suggested importance of dip and declination configuration to explain the longitudinal structure.

$$W_{eff} = (v_s \cos D \pm u_s \sin D) \cos I \sin I$$

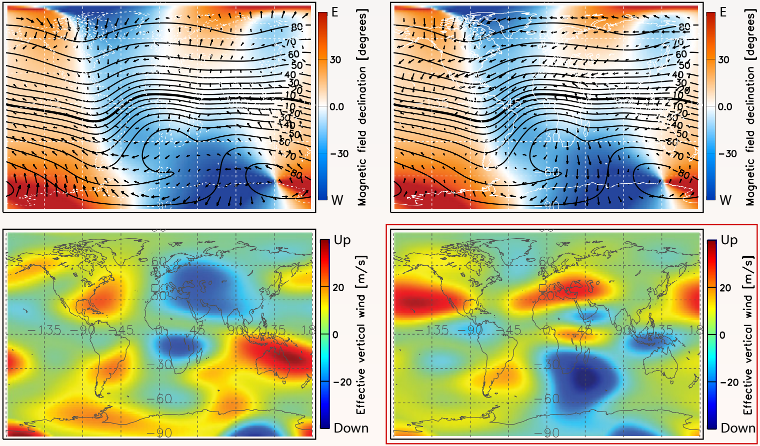


HWM + IGRF

- (Left panels) Vector wind velocities at 20 LT at altitude 150 km for the summer and winter solstices, plotted over magnetic dip isoclinic and magnetic field lines declination. (Right panels) Effective vertical winds.

HWM07 + IGRF: 21/Dec./2010 – 20LT – z=150 km

HWM07 + IGRF: 21/Jun./2010 – 20LT – z=150 km



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Summary

First reported observation of F region summer evening enhancement with mid-latitude SuperDARN HF radars.

Ray-tracing modeling coupled with IRI provides reliable representation of ground scatter from quiet ionospheric conditions.

- Observations of the summer evening enhancement in electron density from Millstone Hill ISR matches SuperDARN observations.
- Future experiments in collaboration with the Millstone Hill Observatory could provide a more detailed understanding of the mechanisms involved.

The ongoing expansion of the SuperDARN mid-latitude chain will provide a better picture of the longitudinal coverage of the ground scatter evening enhancement.

Global models suggest that the geomagnetic field structure combined with thermospheric winds is an important factor in the development of the evening enhancement.

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The end...

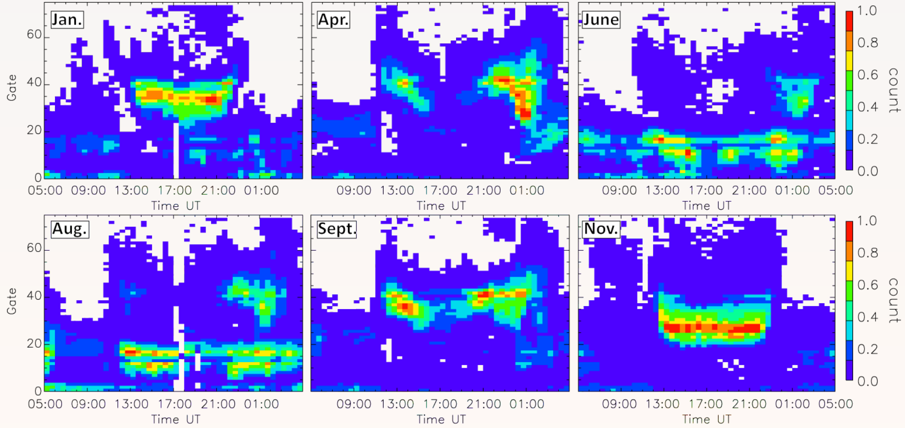
THANK YOU FOR YOUR ATTENTION

We are very grateful for valuable inputs provided by the Millstone Hill team, Dr. Philip Erickson, Dr. Anthea Coster, and Dr. Shun Rong Zhang.

This research was supported by the National Science Foundation under grant AGS-0946900.

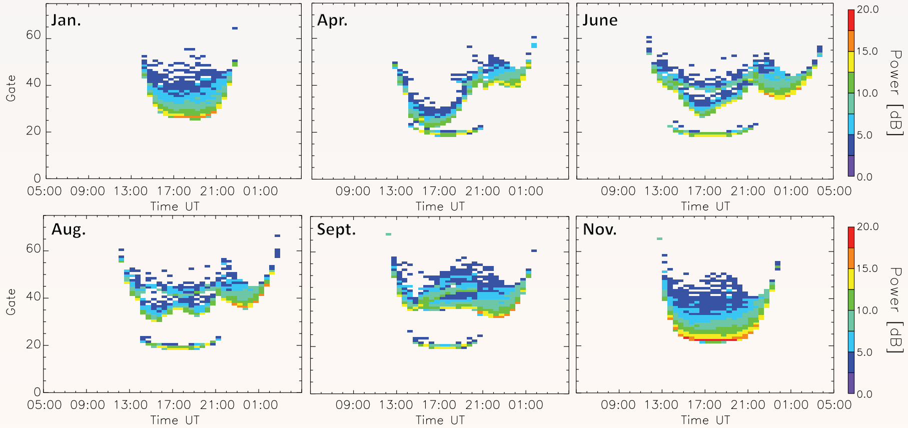
Observed seasonal variation in 2009

- Strong E-region absorption prevents F-region related ground scatter from being significant during the summer. Enhancement is still visible in early spring and fall.



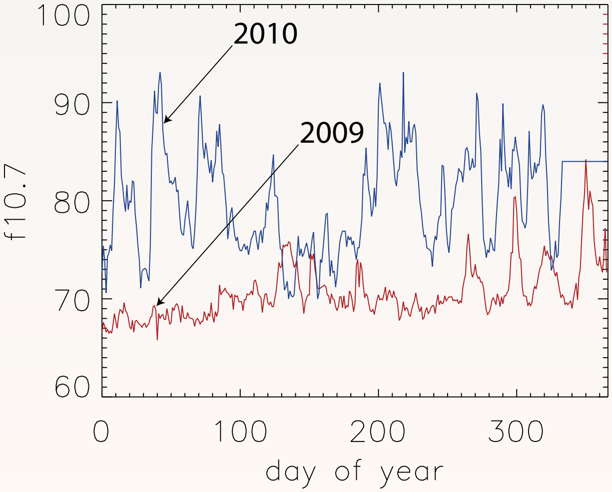
Modeled seasonal variation in 2009

- Similar to 2010 results in terms of occurrence of the enhancement. These modeling results also present further ranges than in 2010, as observed in the SuperDARN data.



f10.7 from 2010 to 2009

- From NOAA/NGDC. This explains the difference in ray-tracing results between 2009 and 2010.



Previously proposed mechanism

- *Liu et al.* [2010], assumed 100m/s wind eastward and equatorward during the night (solid curves) and westward and poleward during the day (dashed line). Results show a good correlation with the longitudinal structure of the evening enhancement.