WHPI: Scene-Setting for Comparative Solar Minima Focus

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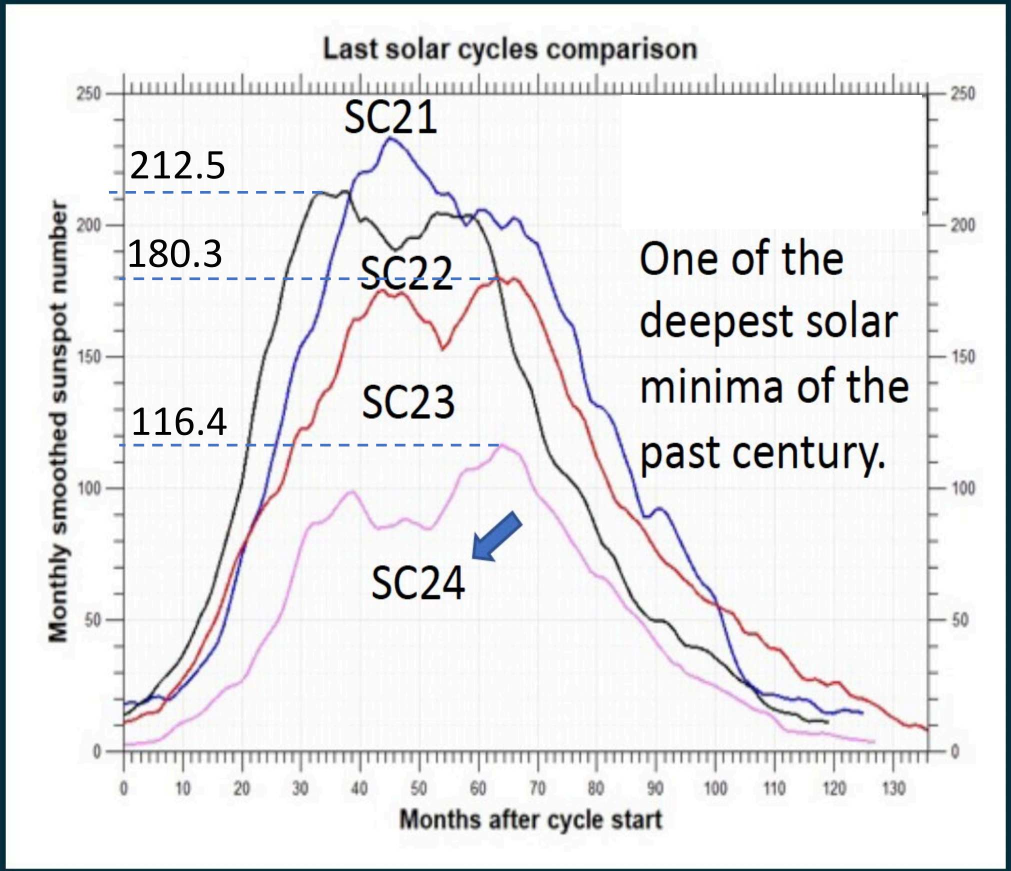
Descending Phase & Solar Minimum Geospace

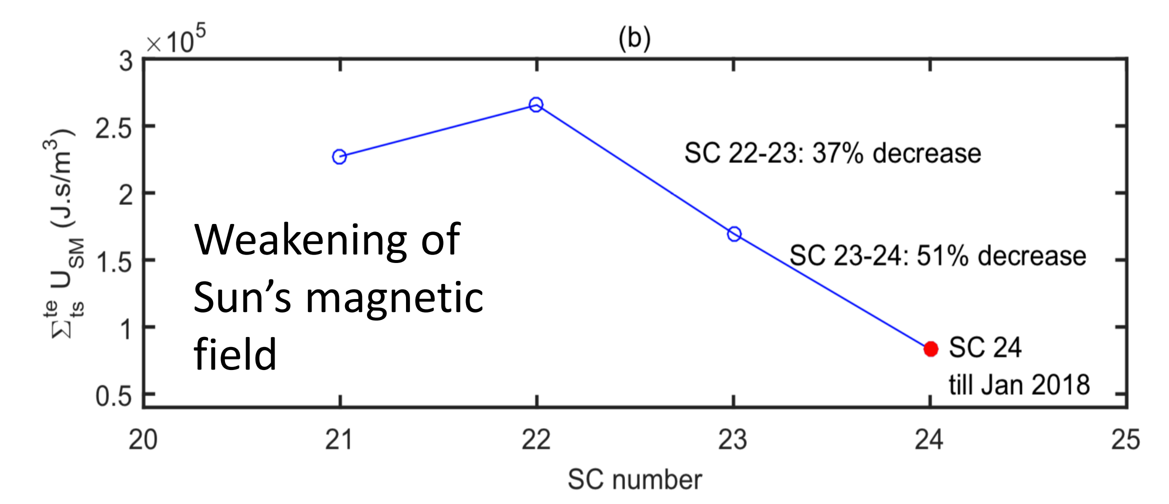
Focus on:

1) Continuing decrease in energy entering Geospace
2) The Coronal Hole – High Speed Stream – Geospace linkages

Drop in Energy Inputs to Geospace SC24 vs SC23



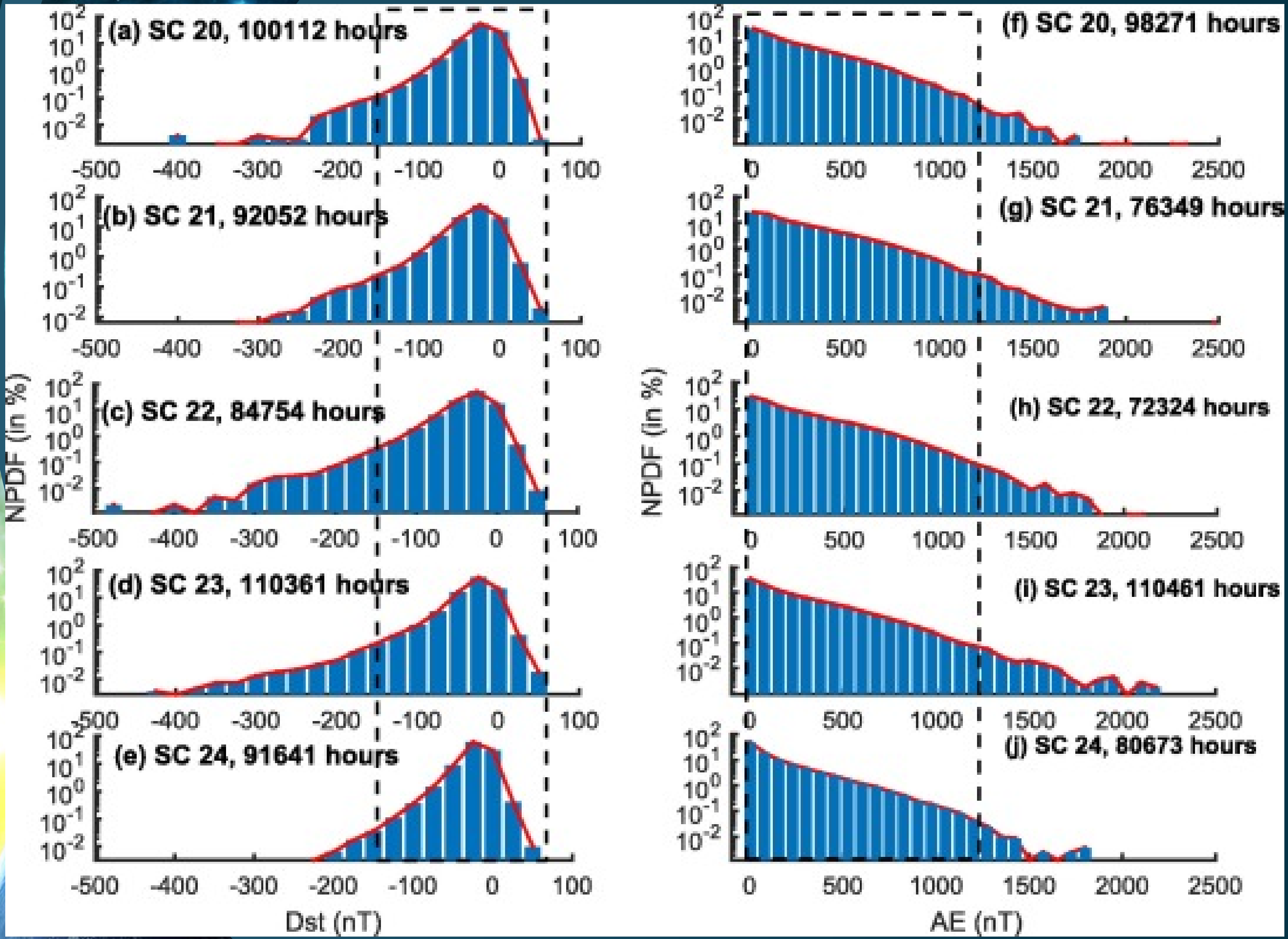
Parameter		Status during SC 24
S_{max}	SSN at max	≈36% reduction
U_{SM}	Solar wind magnetic energy density	≈63% reduction
$\Sigma\varepsilon$	Magnetospheric coupling function	≈54% reduction
EEJ_{max}	Equatorial Ionospheric current	≈31% reduction
Dst_{min}		≈46% reduction
AE_{max}		≈36% reduction
ΣE_{Joule}	Joule energy deposition	≈31% reduction
$\langle M \rangle$		>6.9
$\langle V_A \rangle$		<57 km/s
L_{CF}		<10.6 R_E



Important implications for the configuration of the geospace system during low solar activity

B. Kakad et al.: J. Space Weather Space Clim. 2019, 9, A1

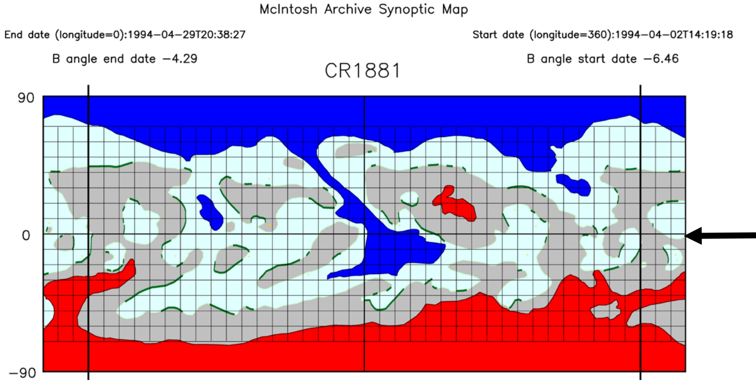
Changes in Geomagnetic Activity



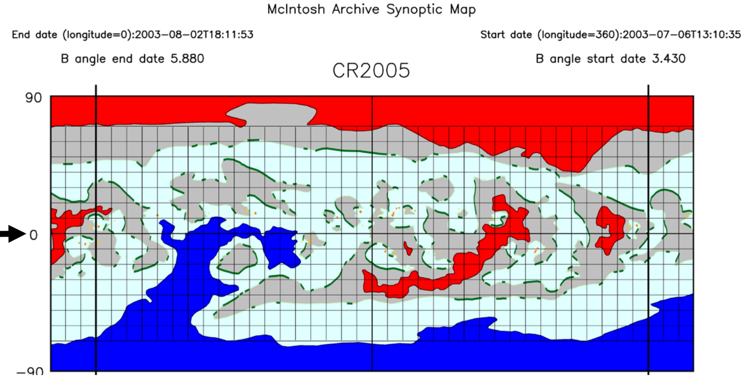
- (a)–(e) shows normalized probability distribution function (NPDF) associated with Dst index for SCs 20–24.
- (f)–(j) shows normalized probability distribution function (NPDF) associated with AE index for SCs 20–24.
- The probability of occurrence of one-hour intervals (in %) in different bins of Dst and AE are shown for SCs 20–24.
- If we sum the NPDF we get 100%, which corresponds to total number one-hour observations for each SC.

Kakad and Kakad, Adv Space Res, 2020

Descending Phase SC22



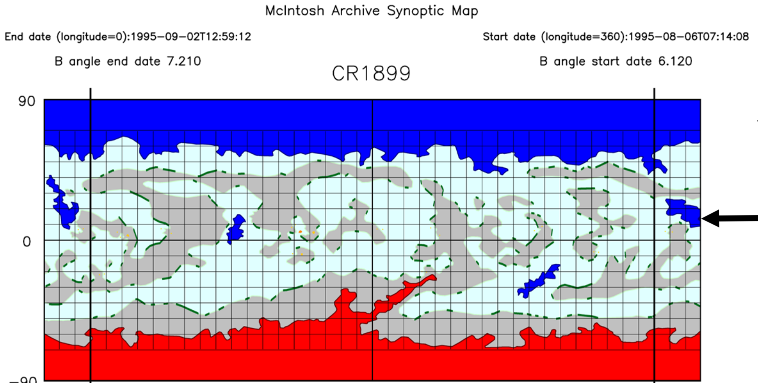
Descending Phase SC23



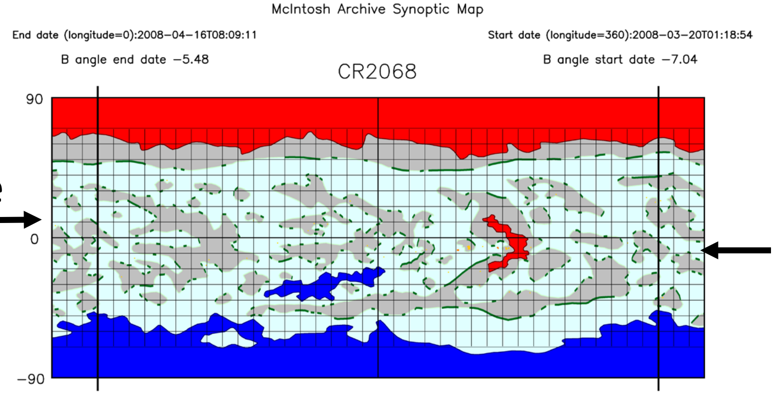
HSS
Peak

Size and location of CHs determine the solar wind parameters and geomagnetic effects measured at 1 AU

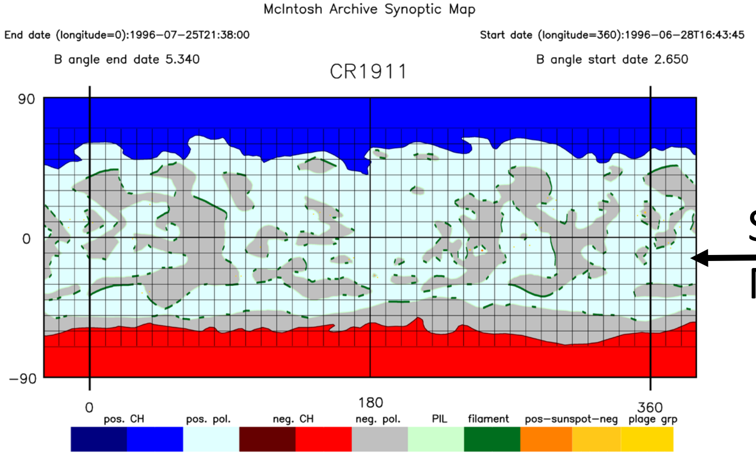
~ 6-7 day periodicity (4 HSS); 9 day (3 HSS); 13.5 day (2 HSS); 27 day (1 HSS)
None of the 12 minima preceding 23–24 exhibited prominent 9.0 and 6.7-d geomagnetic activity recurrence in aa-index [*Love et al., 2012*]



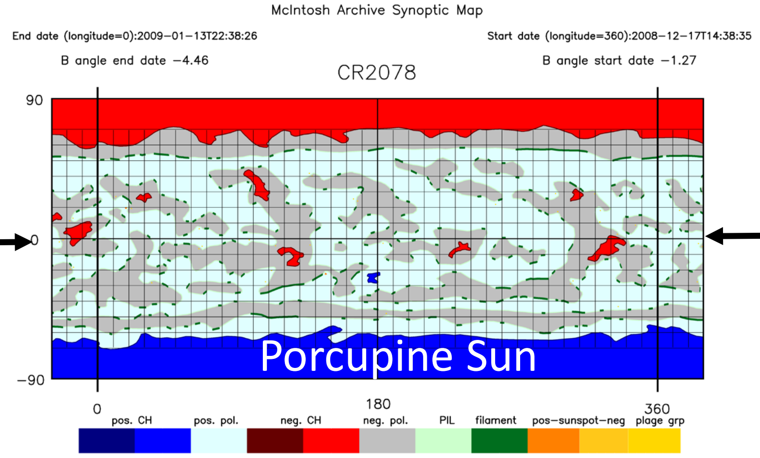
year
before
solar
min



WHI time interval

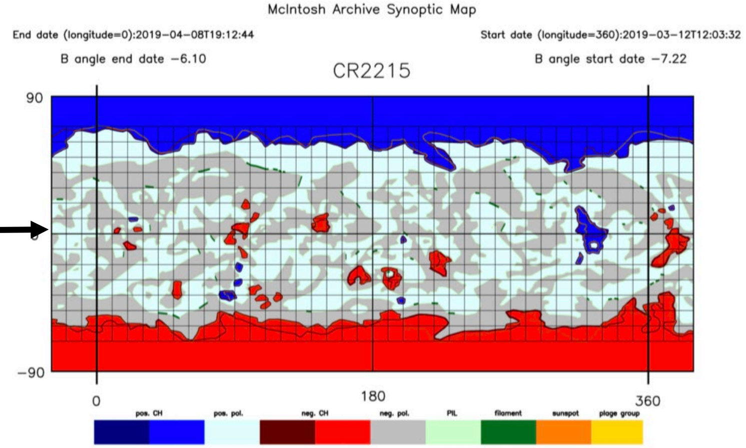


Solar
Mins



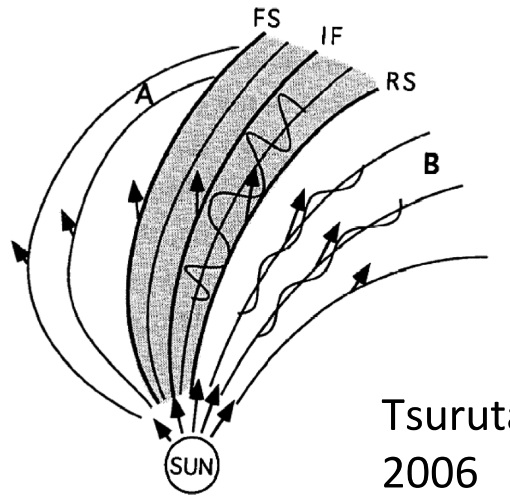
Solar
Mins

Descending Phase SC24

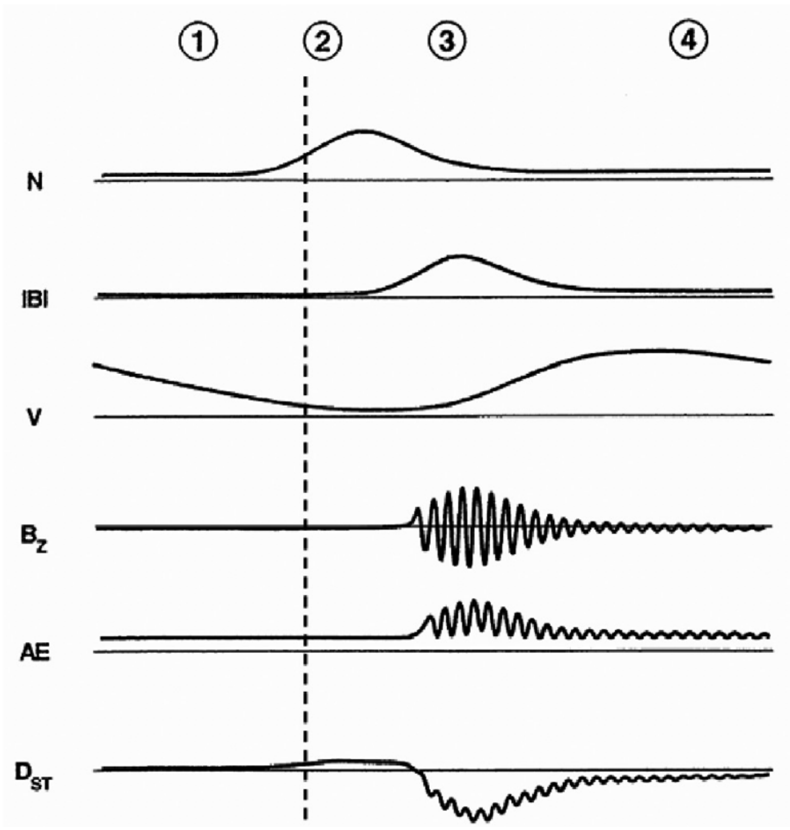


Hewins, et al., McIntosh Synoptic Map Minimum Study, Fall AGU 2019

CIR/High Speed Stream Features



Tsurutani et al., 2006



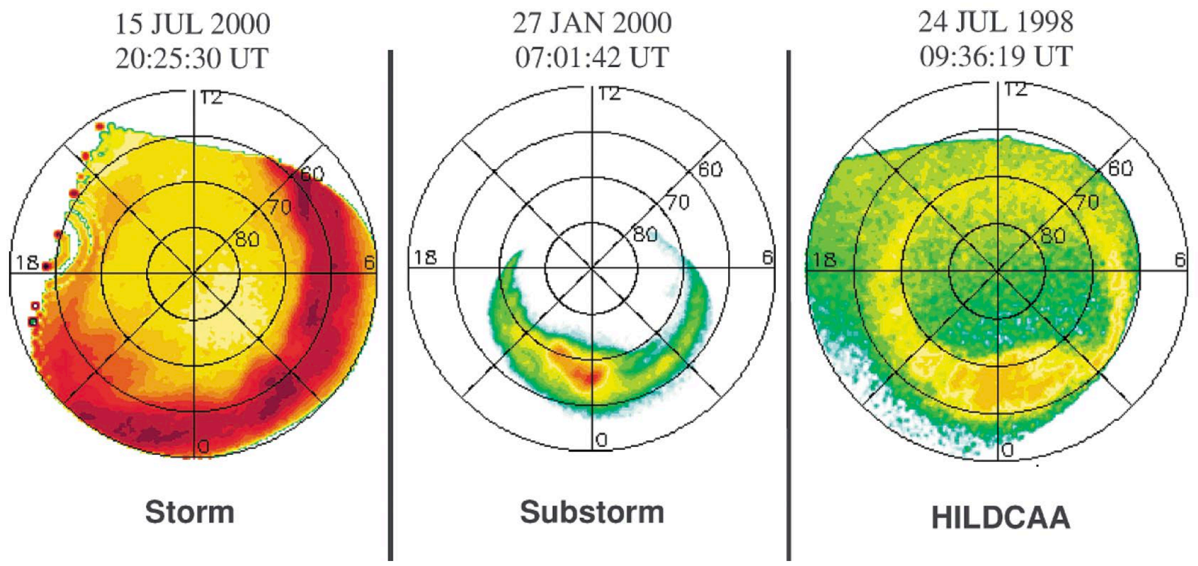
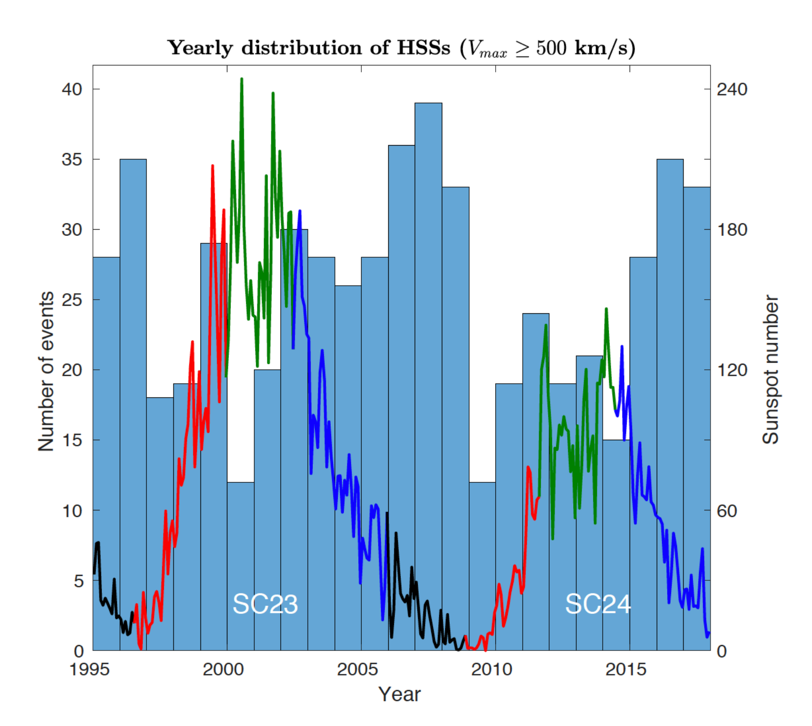


Figure taken from Guarnieri [2005] in Tsurutani et al., [2006].

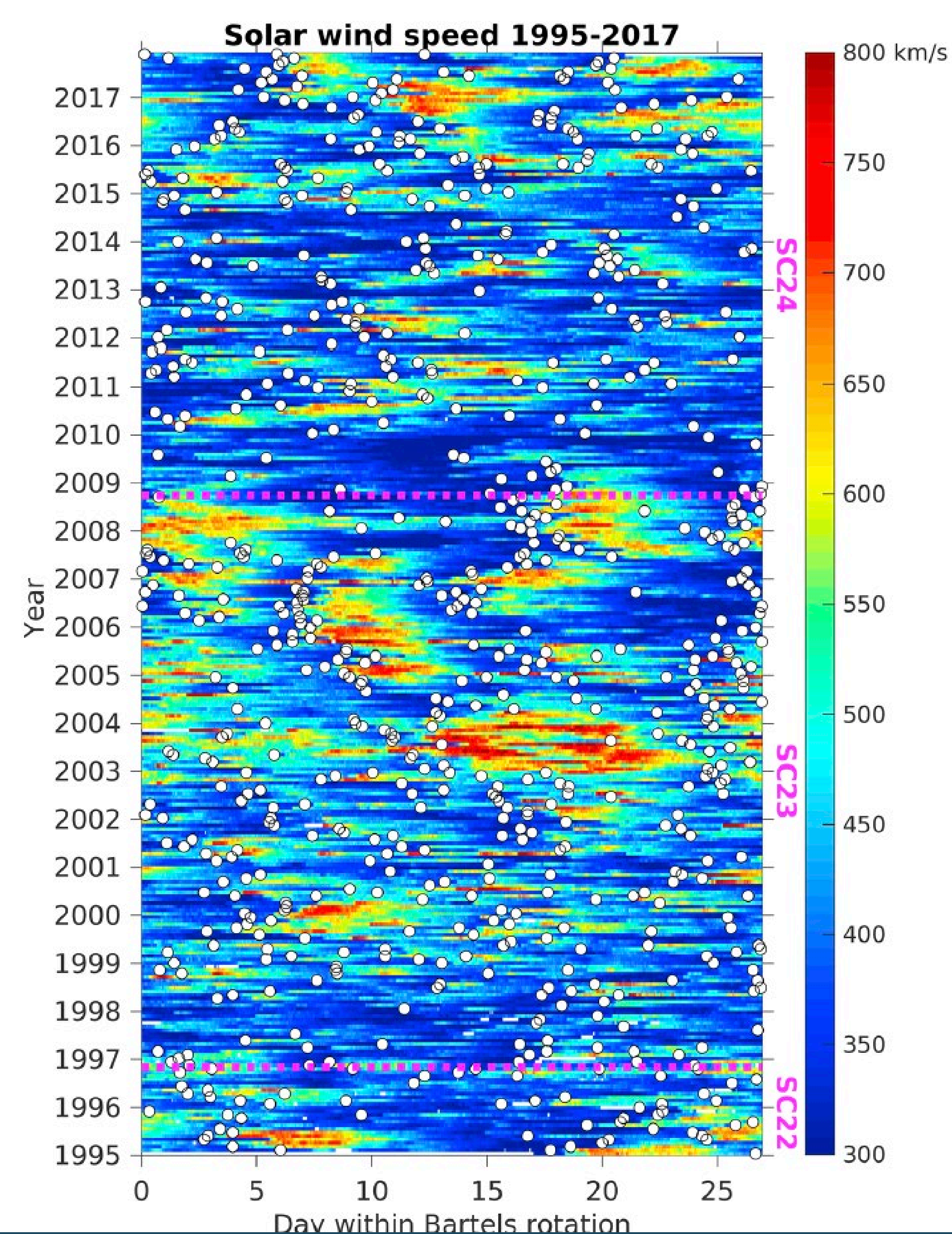
Tsurutani, B. T., et al. (2006), Corotating solar wind streams and recurrent geomagnetic activity: A review, J. Geophys. Res., 111, A07S01, doi:10.1029/2005JA011273.

High Speed Streams SC 23-24

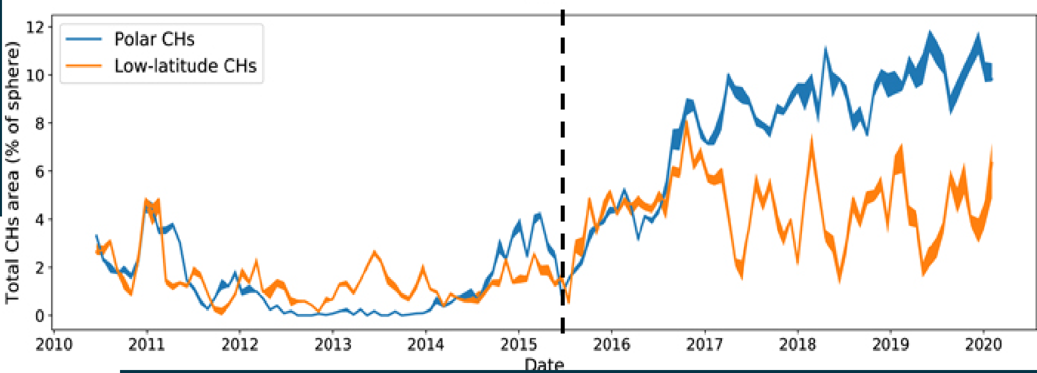
- Several features indicating recurring elevated solar wind velocities can be identified, in particular during year 1995, years 2003–2004, years 2003–2008, and from 2015 onward.
- During the maximum phase of SC24, most equatorial coronal holes had a lifetime of less than 100 days (<4 solar rotations),,



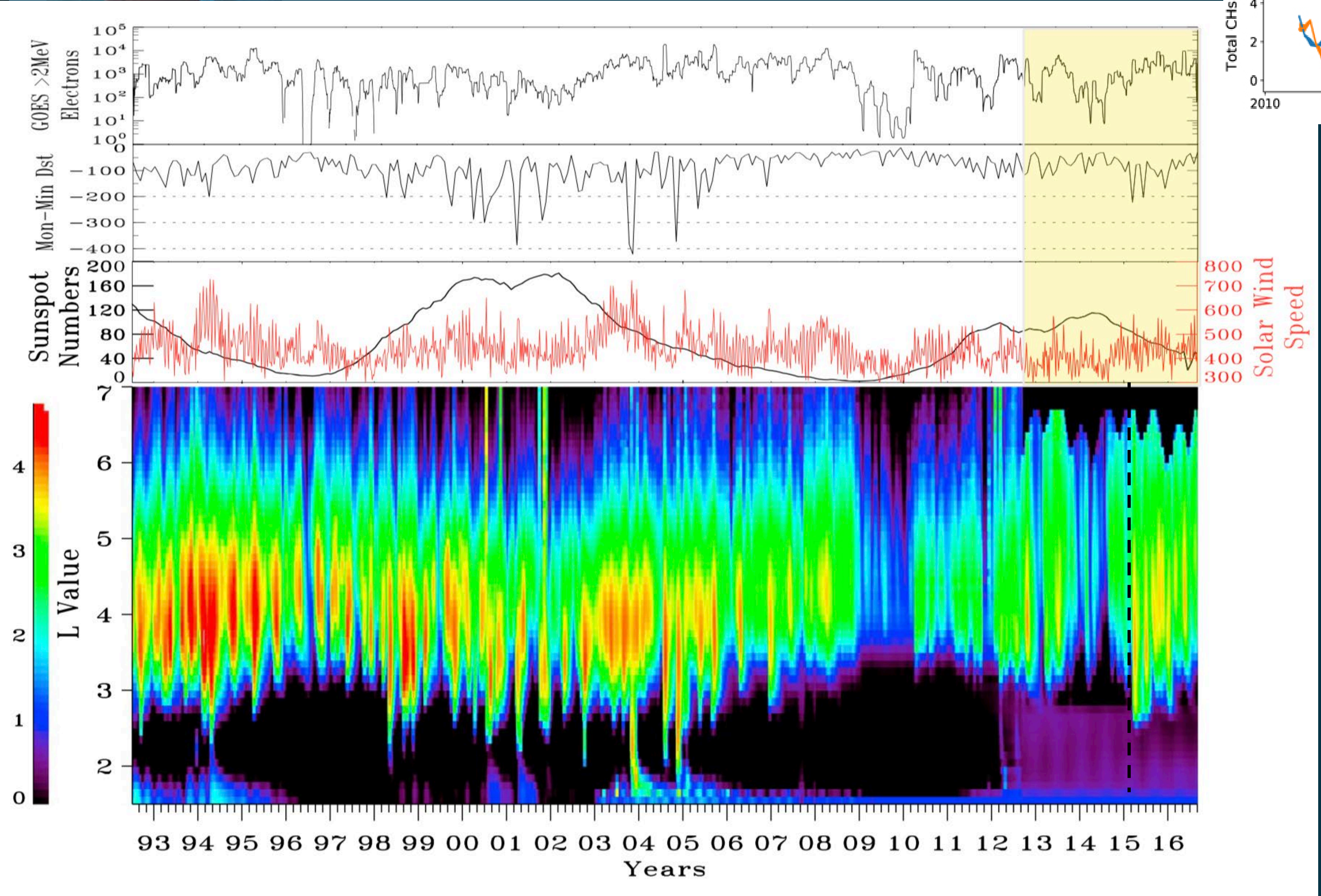
Grandin, et al., JGR, 2019



CH/HSS & Radiation Belts



Egor Illarionov *et al* 2020 *ApJ* **903** 115



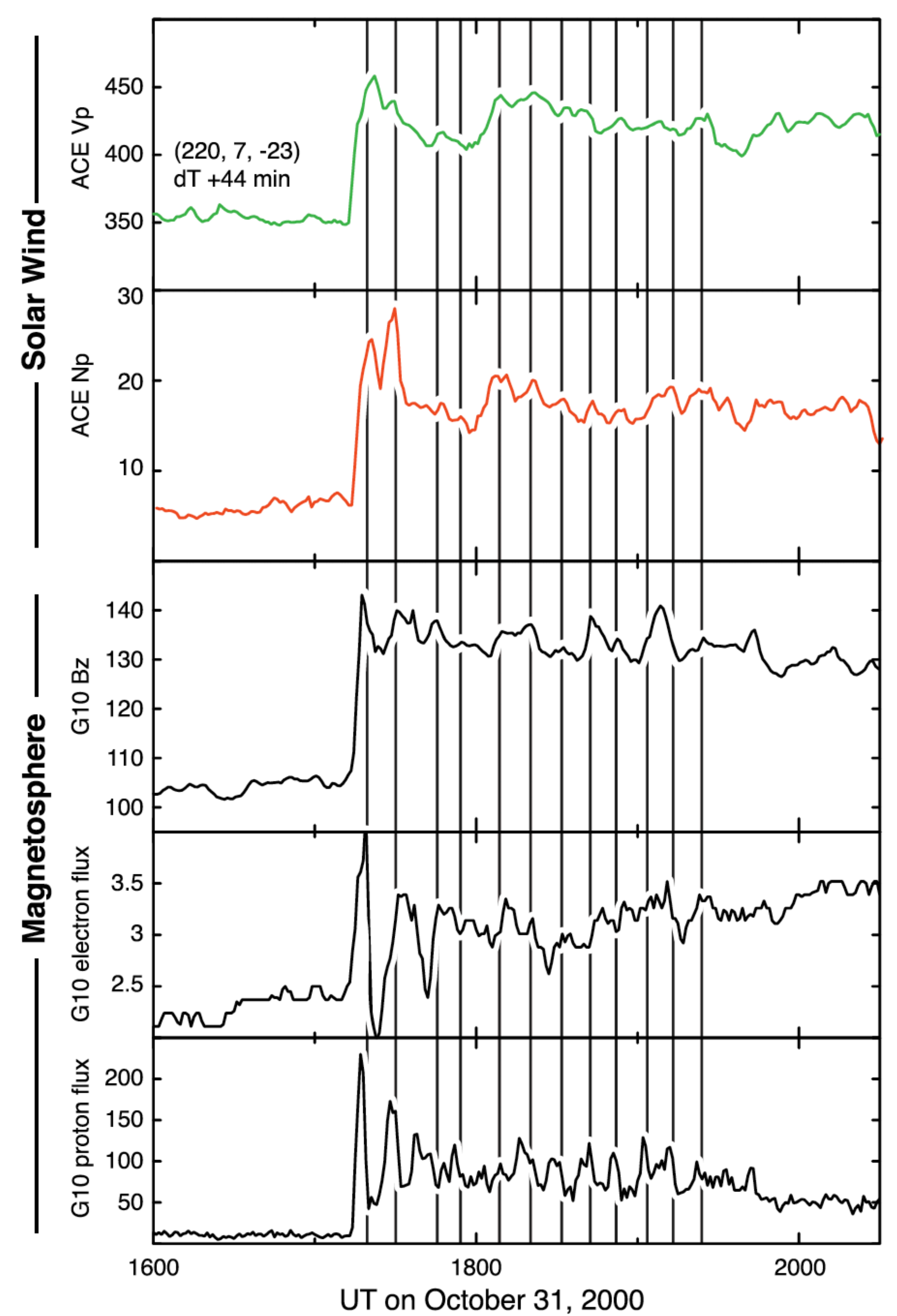
No ~2 MeV electrons inside of L ~ 2.6 since 2005

Three solar wind criteria are presented to determine whether ~2 MeV electron enhancements will occur inside L of 2.6 [Zhao and Li, 2013a]:

- Bmax > 24 nT,
- Eymax > 9 mV/m
- Êy > 7 mV d/m.

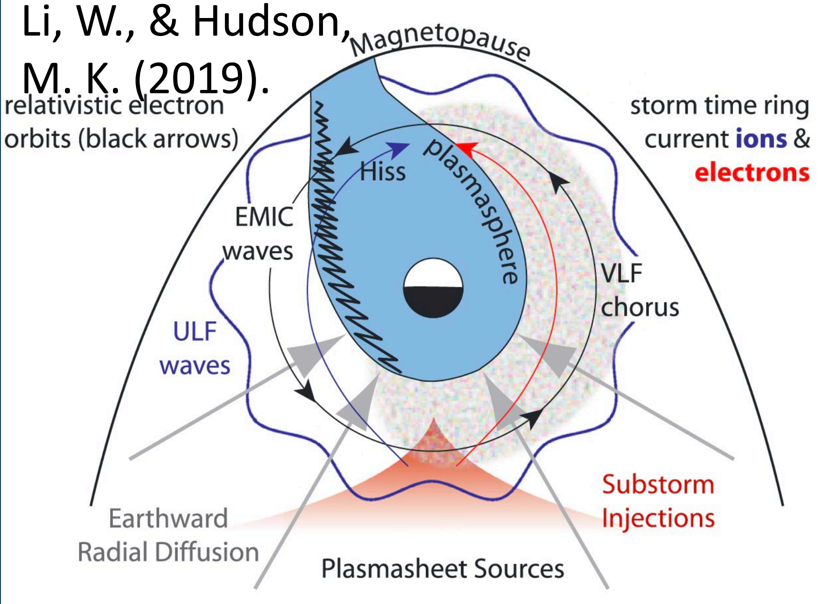
Where Êy is Ey integrated with time and calculated within 1.5 day before and after Eymax and calculated only when Ey > 0.5 mV/m, which means it only includes the positive part of Ey.

Li et al., JGR,2017



ULF in the Solar Wind & Magnetosphere during HSS

Li, W., & Hudson, M. K. (2019).



Key Points:

- Stream interaction regions (SIRs) are shown to contain periodic density structures, typically in the Pc5 (~5-20 min)
- Periodic density structures following sudden solar wind density enhancements directly drive compressional magnetospheric oscillations
- Important for energetic particle acceleration, loss, and transport, particularly in the outer radiation belts
- Periodic density structures are ambient features of the solar wind (not waves) formed below 2.5 solar radii and survive to 1 AU. Then amplified and compressed by the higher-speed flow behind it

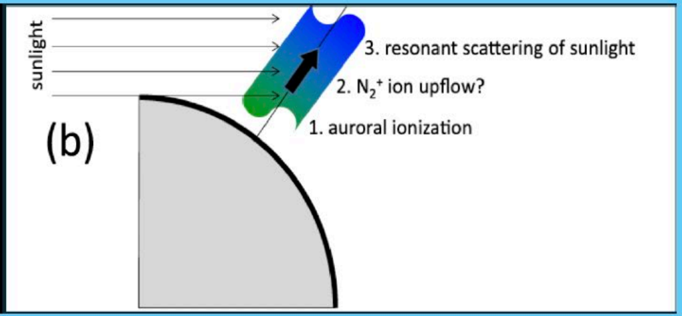
Kepko & Viall, (2019) and references therein.

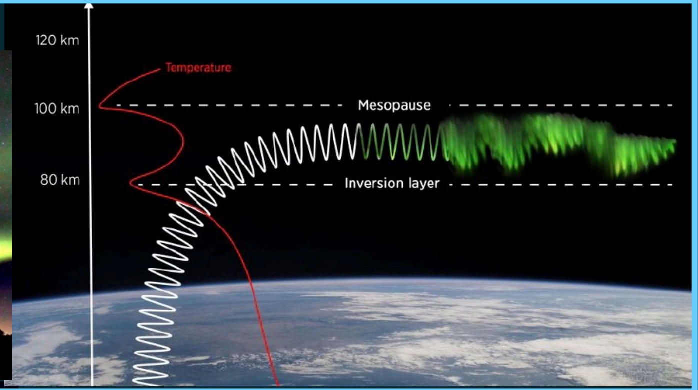
Sky Watchers Report Unusual Upper Atmospheric Phenomena – Related to weak SC 24?

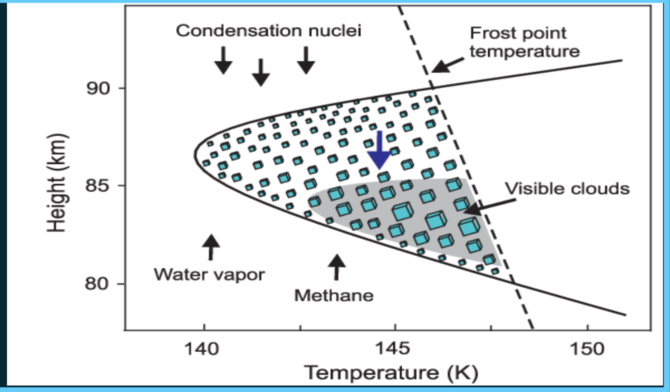
- Rare electric-blue auroras (N_2^+ emission) – Wavelength not targeted by space-based auroral imagers. Connection to enhancements recently seen in N^+ and molecular ions by ePOP during the unusually weak Solar Cycle 24 [*Yau, JGU,* 2019]?

- New auroral forms – Improvements in cameras enable resolving unusual auroral forms & fine scale structures. Are neutral atmospheric waves shaping new auroral forms [*Palmroth et al.*, 2020]?

- Mid-latitude noctilucent clouds – Photographers all over the world reporting intense NLCs at mid-latitudes (down to 37° N). Why? Usually seen above 55° N [*Russell et al.,* 2014].

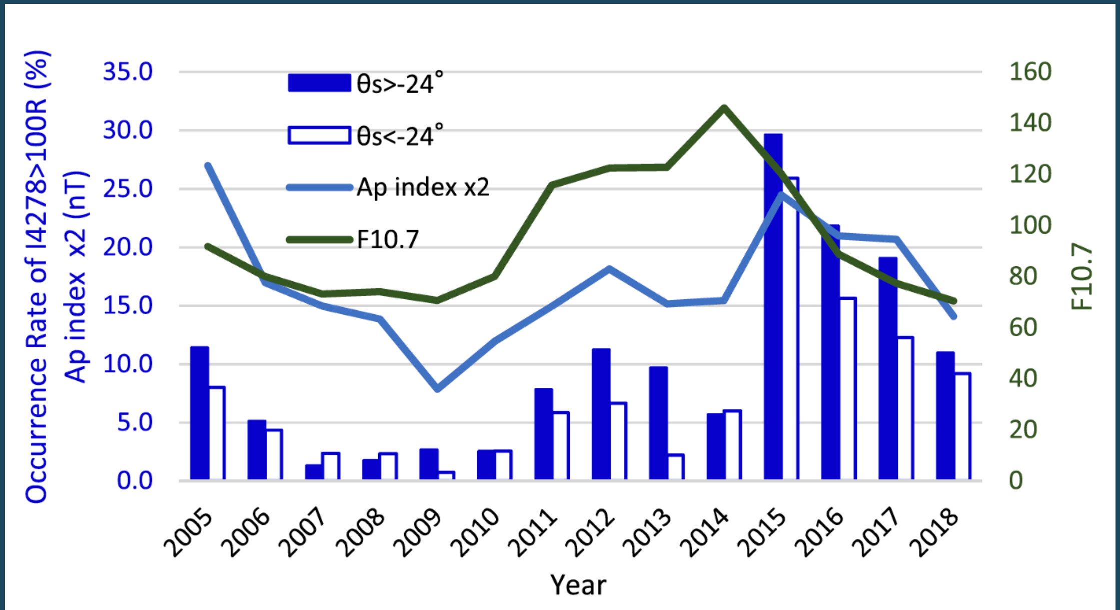


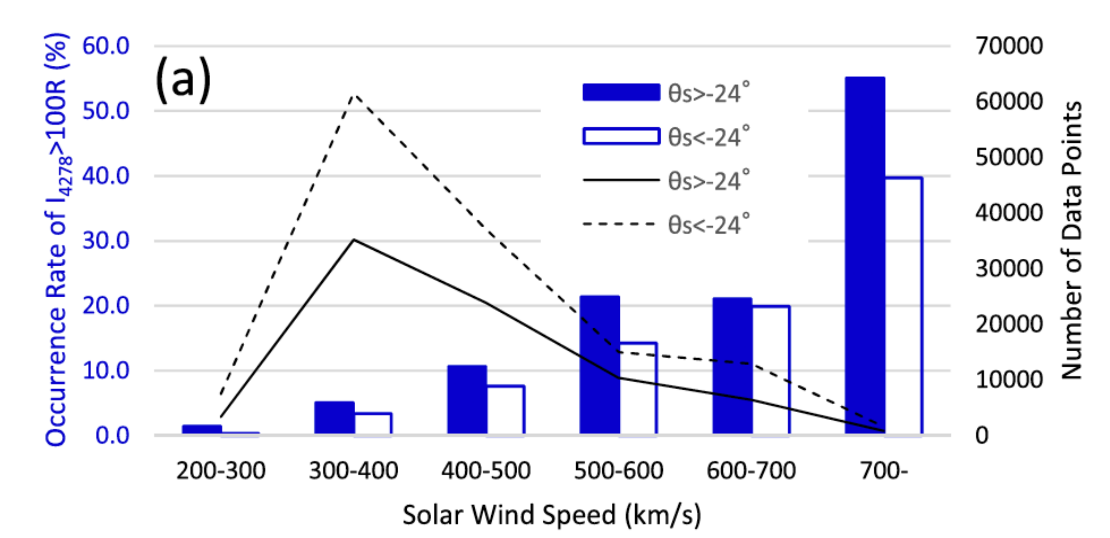




HSS & Blue Auroras

Blue airglow observations equatorward of auroral zone





Shiokawa et al., 2019

Imaging and Rapid Scanning Mass Spectrometer (IRM) on board the Enhanced Polar Outflow Probe (e-POP), observes molecular ions in the topside ionosphere at high latitudes from January 2014 to December 2017):

- in much greater abundances than predicted by empirical models of the ionosphere,
- during both active and quiet times.
- largest count rate events in greater frequency in the pre-midnight sector (20-22 magnetic local time (MLT)) during main and recovery phases of large geomagnetic storms.

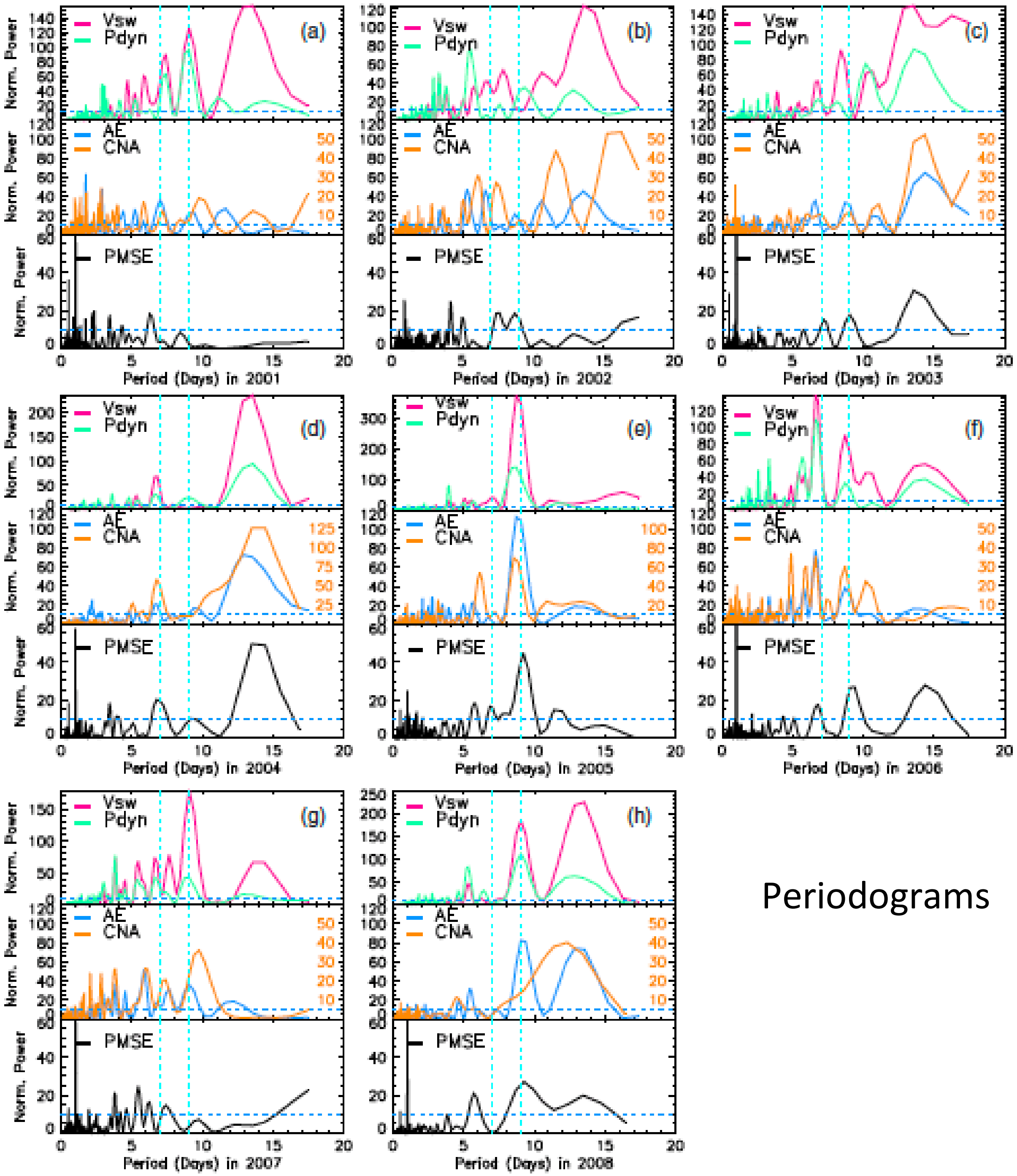
V. Foss, Molecular Ions in Ion Upflows and their Effect on Hot Atomic Oxygen Production, MS Thesis, University of Calgary, 2019

Note: Model results suggest that changes in the concentrations of molecular ions in the E-region may produce changes in conductivity and in the behavior of electric dynamo fields at low and equatorial latitudes.

7- and 9-Day Periodicities in Polar Mesospheric Summer Echoes (PMSE) – Link to HSS

Key Points:

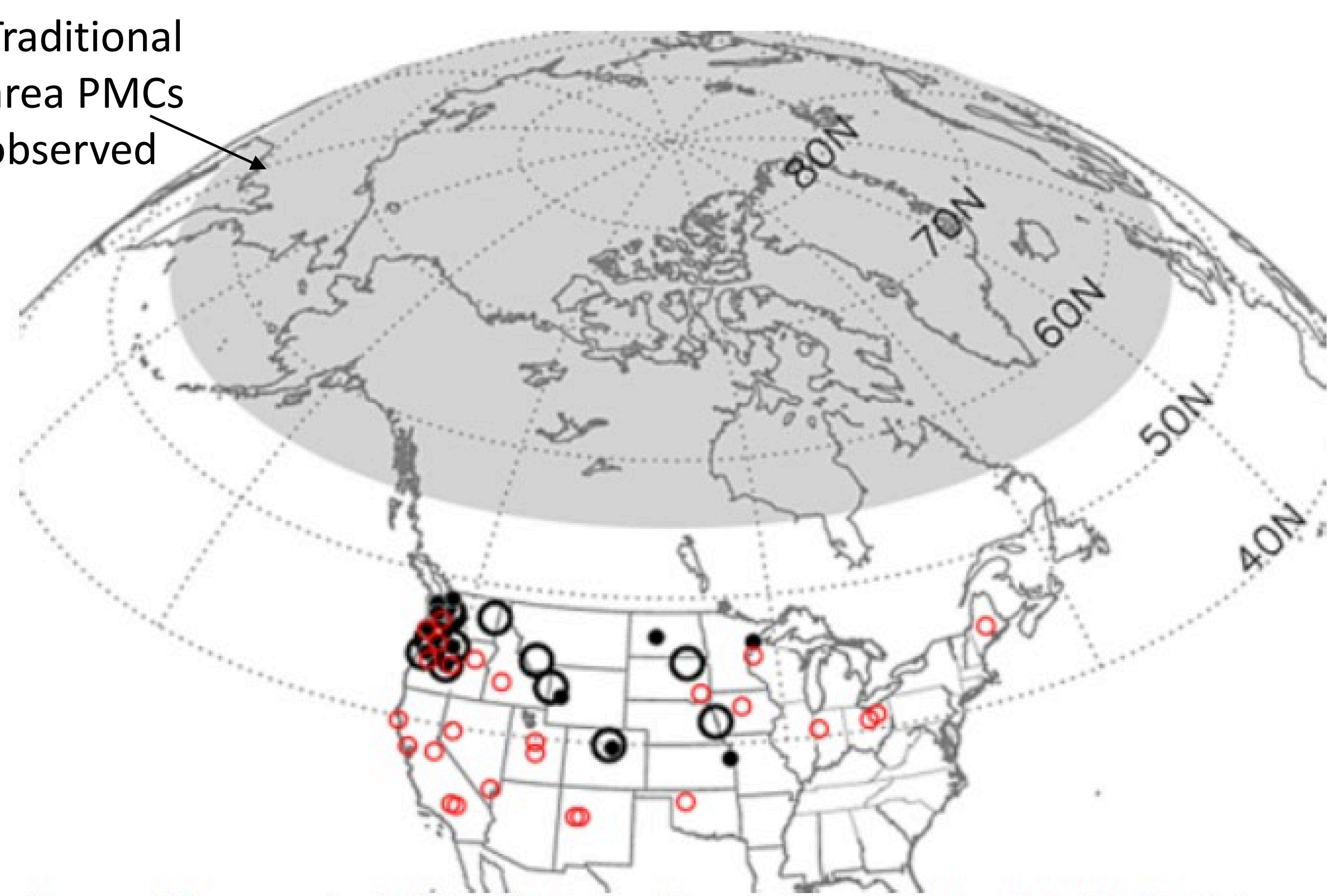
- PMSEs are observed by 52MHz VHF radar measurements at Esrange (67.8°N, 20.4°E), Sweden
- PMSE periodicities of 7 and 9 days are found in 2005-2006 and 2008
- CIR/HSS-driven geomagnetic disturbances induce strong D region ionization
- PMSE is sensitive to the impact of CIR/HSS-driven geomagnetic disturbances
- Correlations at 7 and 9 days vary from year to year but generally increase as solar minimum is approached.



Periodograms

Lee, et al., (2015)

Unexplained spread of NLCs below 55º



NLC sightings in northern summer

- 2003, 2007, 2008, 2011
- 2009
- July 2019

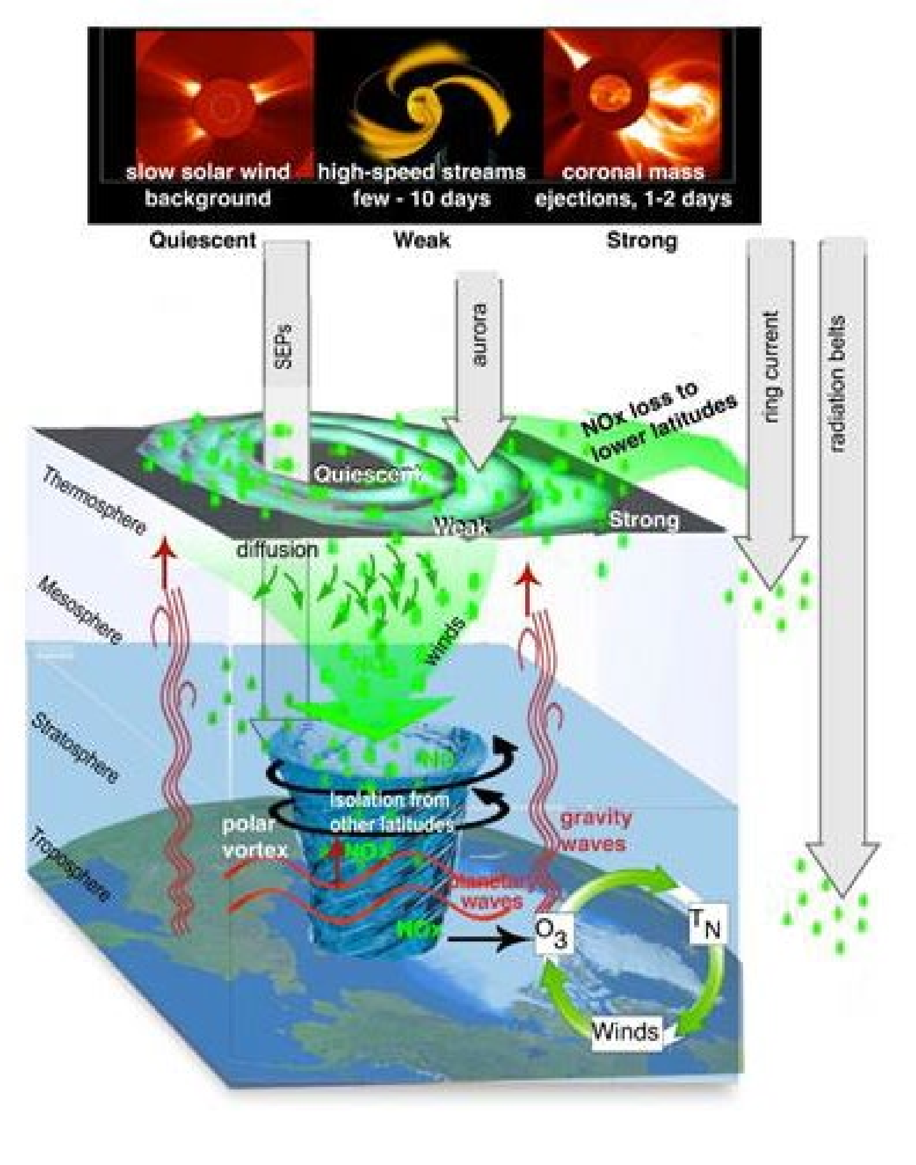
(Source: Russell et al., JGR Atmospheres, 2014 modified to show sightings in June 2019. (https://spaceweatherarchive.com/2020/03/26/noctilucent-clouds-over-the-south-pacific/)

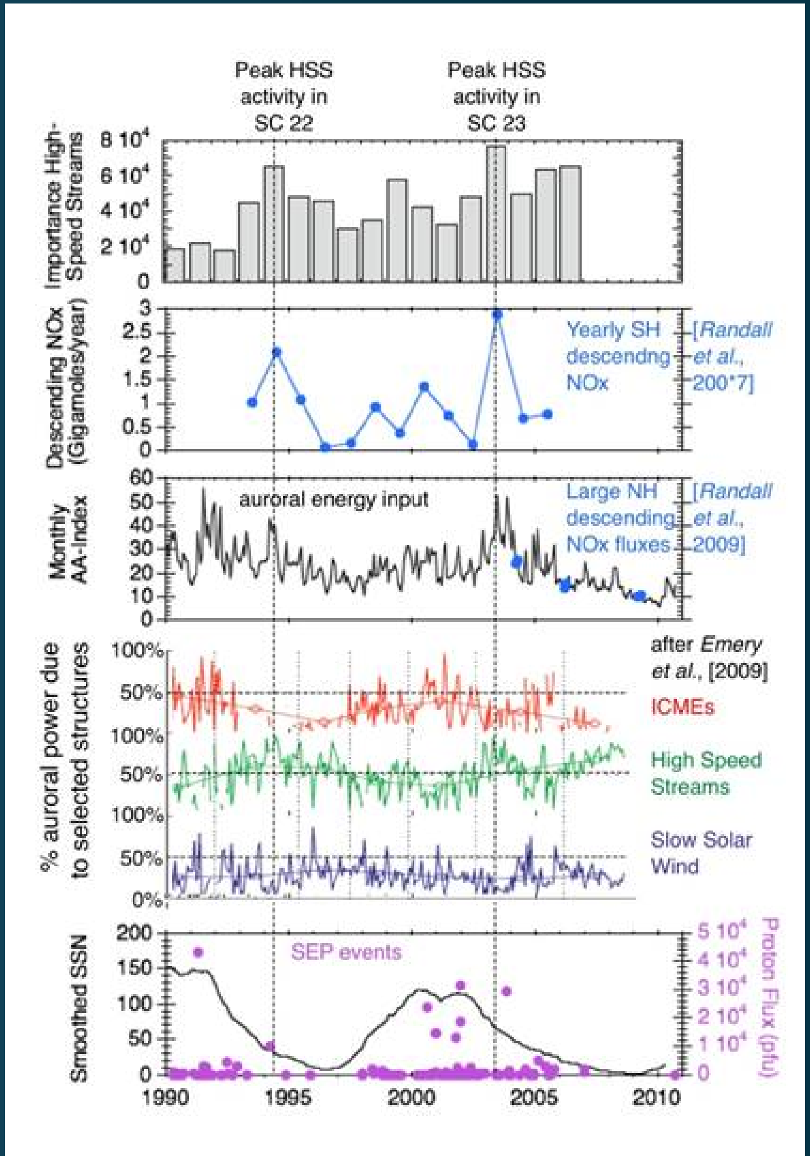
Statistically significant increase in number of PMCs in region 40º-55ºN over 10 year period 2003-2011 [Russell, et al., 2014]

- Appeared driven by Temp decrease
- Solar activity decreased from active to quiet – one factor

Ex: June 2019, NLCs over Rome, Italy; Las Vegas, Nevada; Albuquerque, New Mexico; Paris, France; and outside Los Angeles, California. Lowest seen at 37.2 N MLAT

HSS, Auroral NOx, and Stratospheric Ozone





- SH descending NOx due to source. Polar vortex stable.
- Impacts of EPP on the atmosphere are also modulated by meteorological conditions
- Feb–Mar 2006. Exceptional NOx mixing ratios in the NH upper stratosphere
- Minimal geomagnetic activity suggesting that EPP NOx auroral source not significantly elevated.
- Arctic polar vortex at stratopause exceptionally strong, implying greater confinement of air in the polar night.
- Will meteorology be modified by climate change?

Descending Phase & Solar Minimum Geospace

Focus on:

1) Continuing decrease in energy entering Geospace. Decrease in storm & substorm activity. Implications for the structure of the ITM
2) The Coronal Hole – High Speed Stream – Geospace linkages
   a) Solar wind periodicities tell us how deep geomagnetic activity penetrates into the atmosphere
   b) Radiation belts haven't penetrated below L~2.6 since 2005.
   c) Blue auroras imply high-altitude molecular ions (ePOP observers more frequently than expected)
   d) Appearance of unusual auroral forms (linkages to neutral waves)
   e) Noctilucent clouds (~80 km altitude) – 7 & 9 day periodicities – appearance at unusually low latitudes
   f) Auroral NOx & Ozone loss (upper stratosphere) linked to HSS and meteorology

Thank you!