There's an Ionosphere in Each Hemisphere

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Topics

- Global Ionospheric Storms are exaggerated cases of the current seasonal pattern.

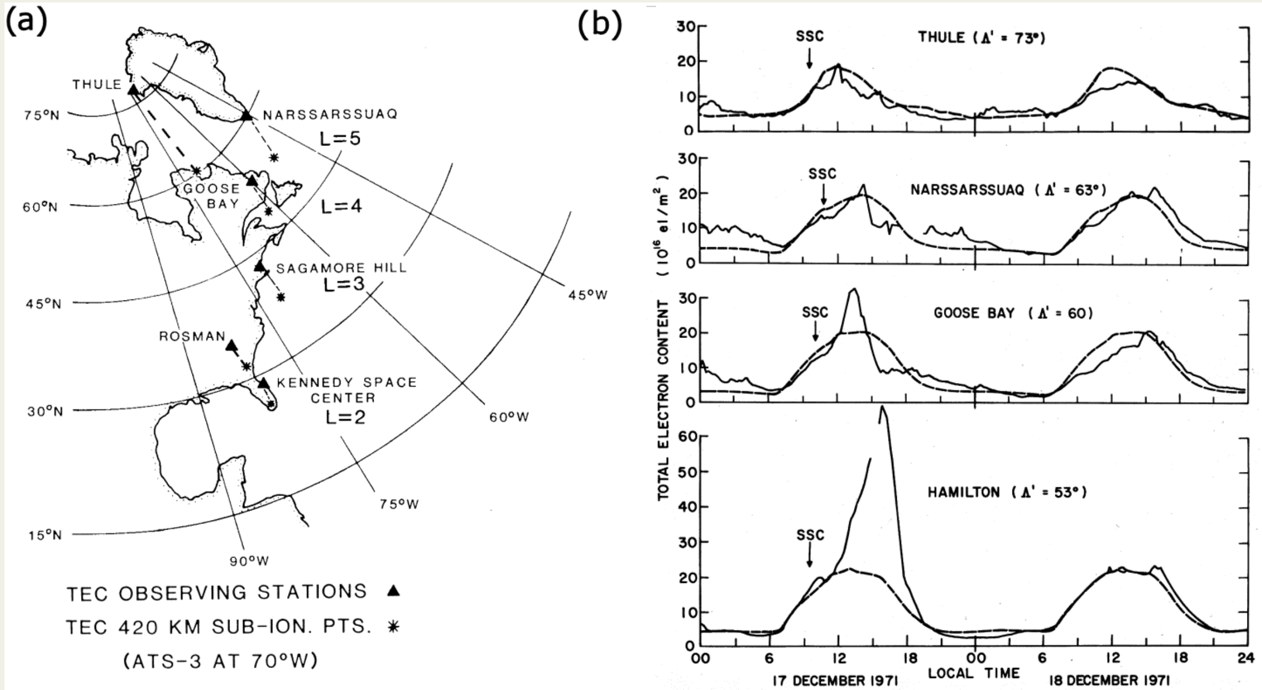
  --- How coherent are storm effects at Geophysically Equivalent Sites in each hemisphere?

- Imaging local disturbances at geomagnetic conjugate points?

  --- Do ambient seasonal patterns affect the observed perturbations?

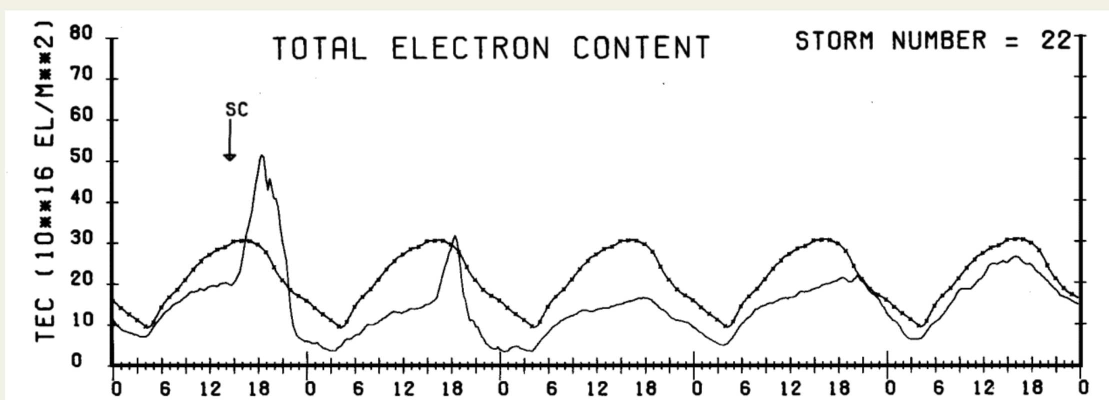
Characteristics of an Ionospheric Storm

—Brief (dramatic) Positive Phase—Long (boring?) Negative Phase.

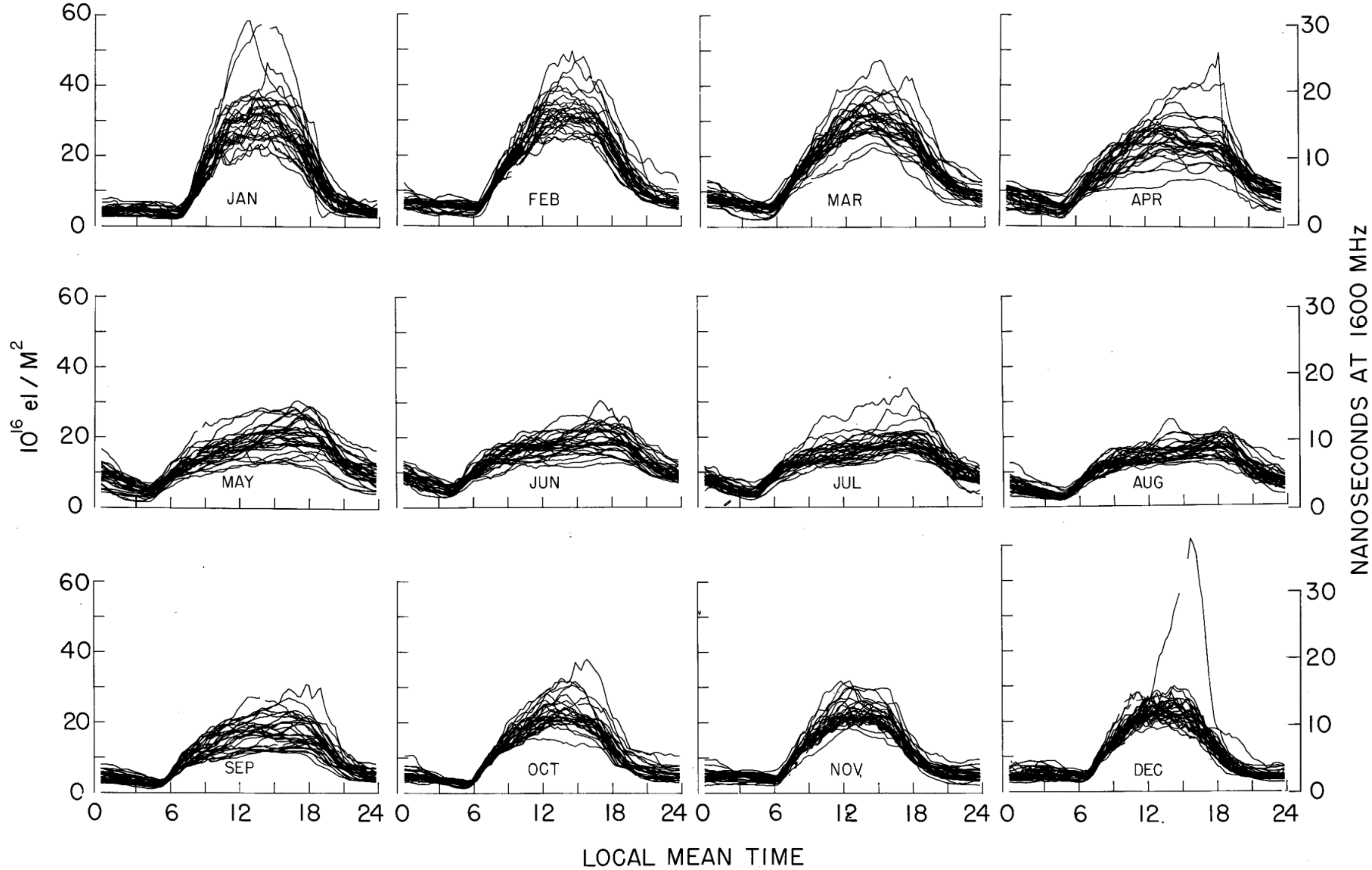


17-18
Dec
1971

14-18
May
1969



Day-to-day Variability — Seasonal Patterns —Storm Effects



1971

Sydney Chapman and The Anomalous Ionosphere

Production: $h\nu + \text{O} \rightarrow \text{O}^+ + e^-$ $[\text{P} = \text{I}_{sun}\, \sigma_{ion}\, n(o)]$

Loss: $\text{O}^+ + \text{N}_2 \xrightarrow{k} \text{NO}^+ + \text{N}$

$\text{NO}^+ + e^- \xrightarrow{\alpha} \text{N} + \text{O}$ $[\text{L} = k\, n(\text{N}_2)\, \text{N}_e]$

For PCE (P=L): $\text{N}_e = \text{I}_{sun} \frac{\sigma_{ion}}{k} \left(\frac{\text{O}}{\text{N}_2}\right)$

$cos(SZA)$ $const.$ $slowly\ varying$

Seasonal Anomaly: $\text{N}_e(winter) > \text{N}_e(summer)$

I_{sun} *weaker* $\therefore \left(\frac{\text{O}}{\text{N}_2}\right)$ *higher*

"Production dominated ionosphere"

I_{sun} *stronger* $\therefore \left(\frac{\text{O}}{\text{N}_2}\right)$ *lower*

"Loss dominated ionosphere"

[Confirmed by TIMED/GUVI, Strickland et al. (2004)]

---Storm effects mimic seasonal effects ---

Mechanism for Positive Phase

--- Upward plasma drift → reduced loss + production continues. [winds + $\vec{\mathbf{E}} \times \vec{\mathbf{B}}$ drift]

--- Westward + poleward plasma convection → LT vs. Lat. pattern. [Electrodyamics]

--- Plasmasphere-Ionospheric linked effects.

*   *   *   *   *

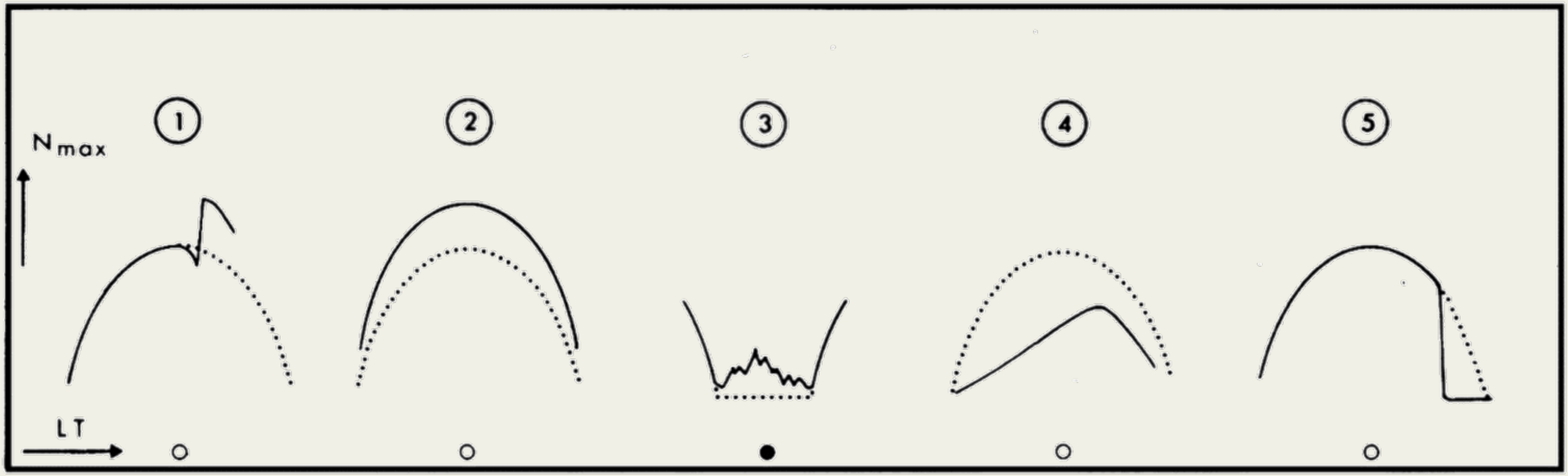
Mechanism for Negative Phase

--- Heating of thermosphere decreases $\frac{\mathrm{O}}{\mathrm{N_2}}$ ratio.

--- Enhanced loss rates → Storms make the ionosphere "summer-like".

Prölss (1995)

Ionospheric Storms at other Longitudes

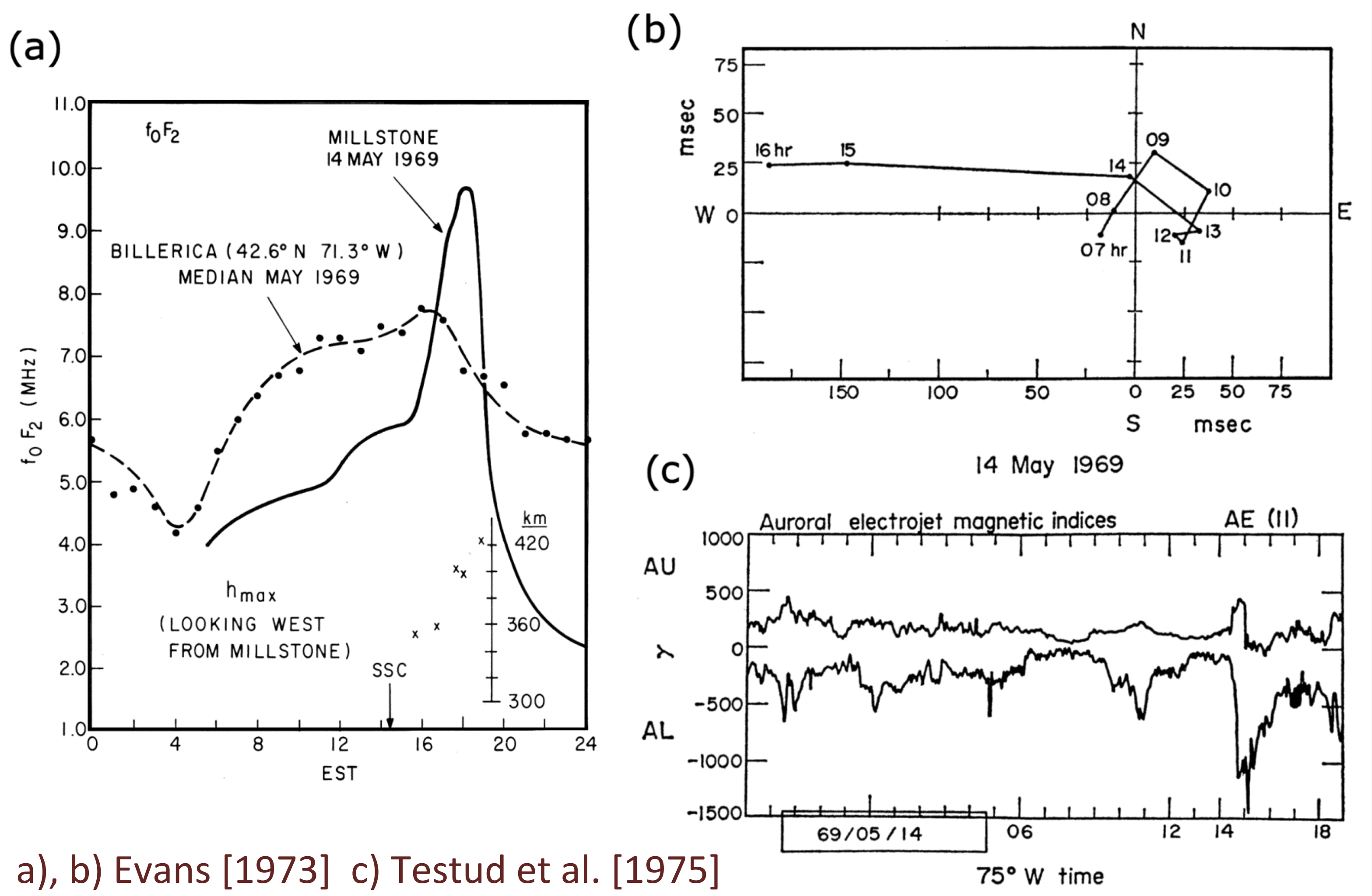


(1) (4) (5) North American → Electrodynamics dominant

(2) European + Asian → Equatorward Winds dominant

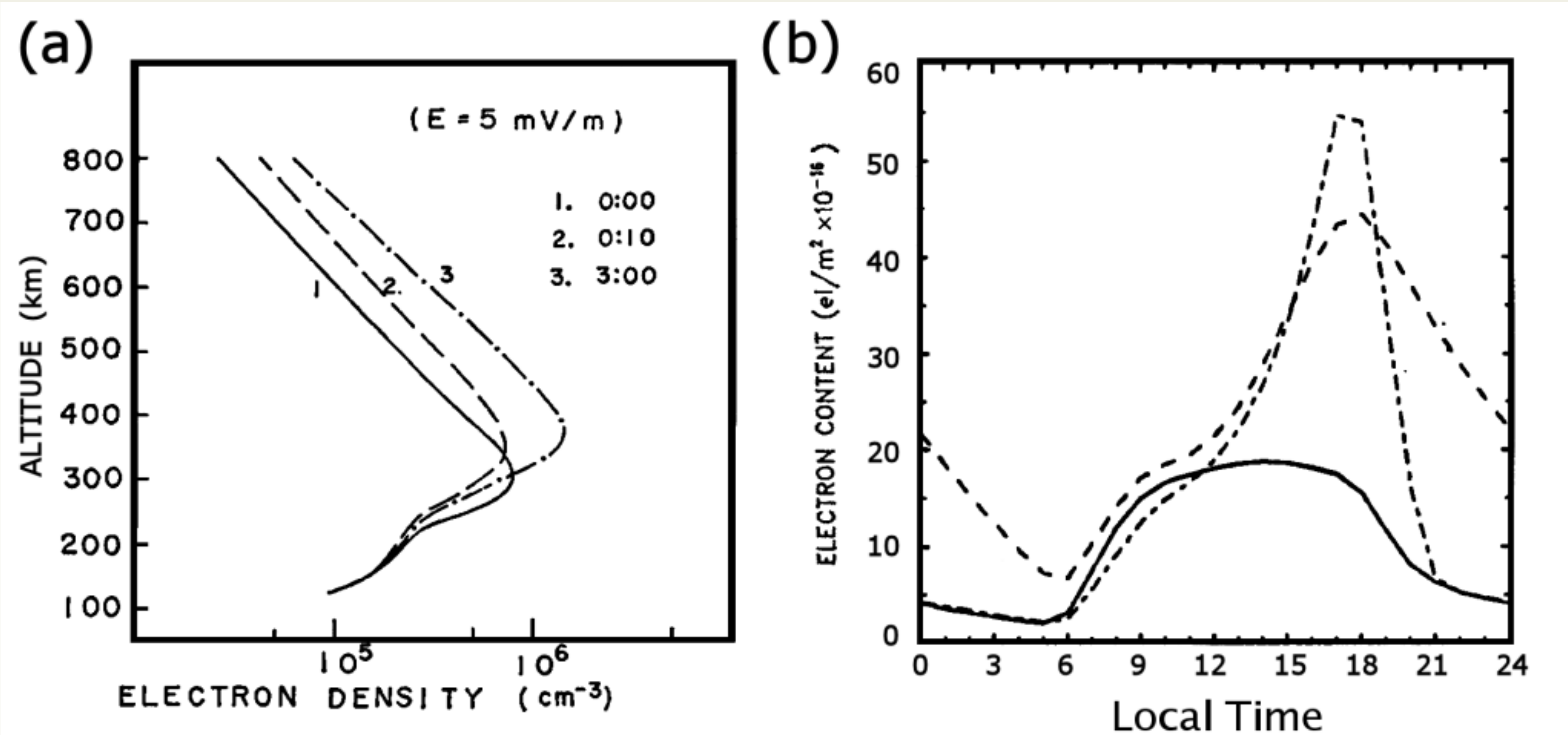
(3) (4) Negative phase and auroral enhancements at all longitudes

Evidence for Electrodynamical Cause of Positive Phase



a), b) Evans [1973] c) Testud et al. [1975]

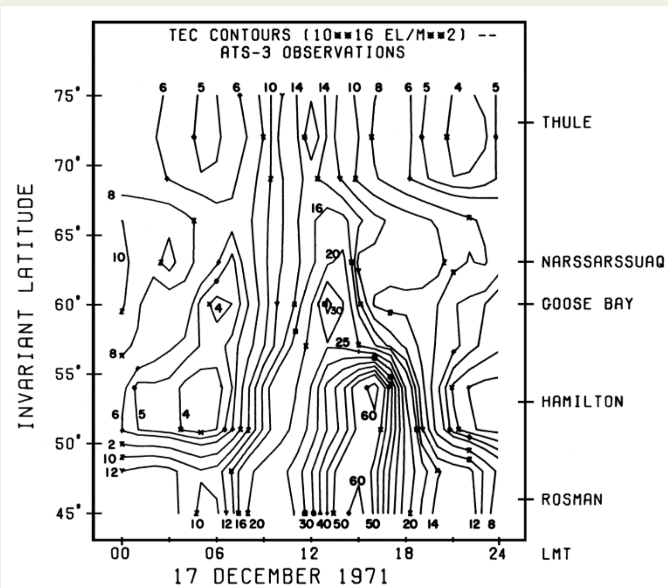
Modeling Positive Phase with Winds vs. E x B Drift



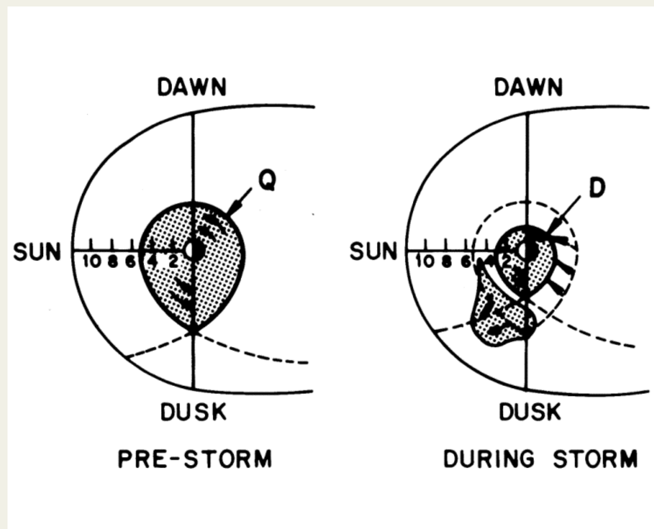
Anderson [1976]

Linked Plasmasphere-Ionosphere Electrodynamics

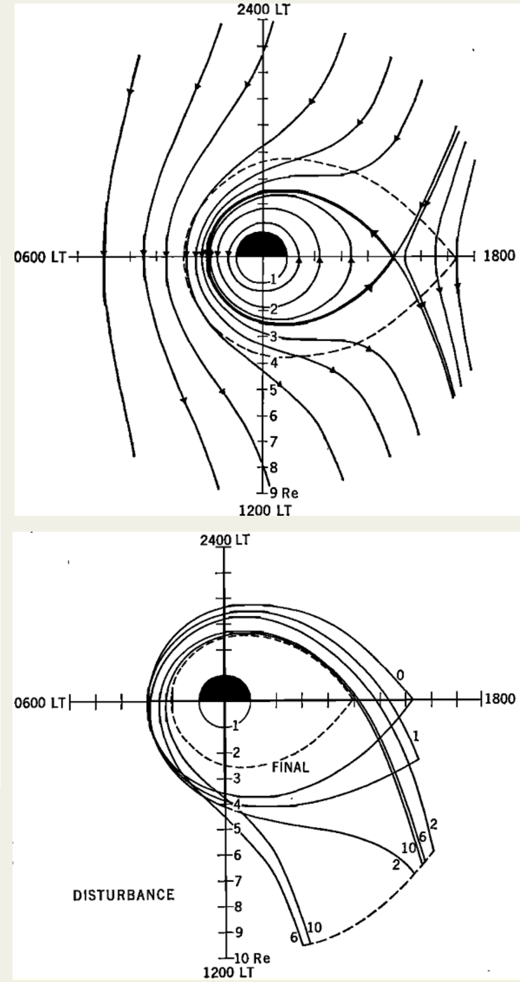
Lanzerotti et al. [1975]: Synthesis
"Dusk Effect" + "Plasmaspheric Tails"



Mendillo and Klobuchar [1975]

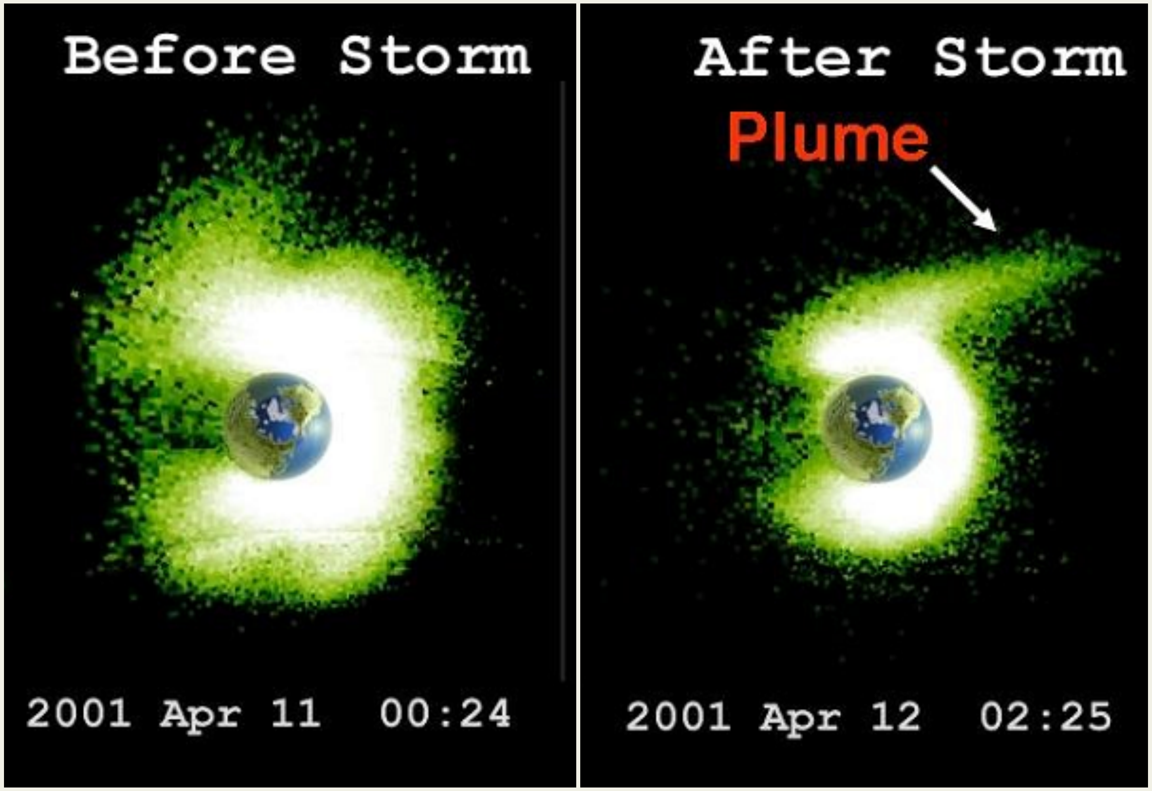


Chappell [1972]



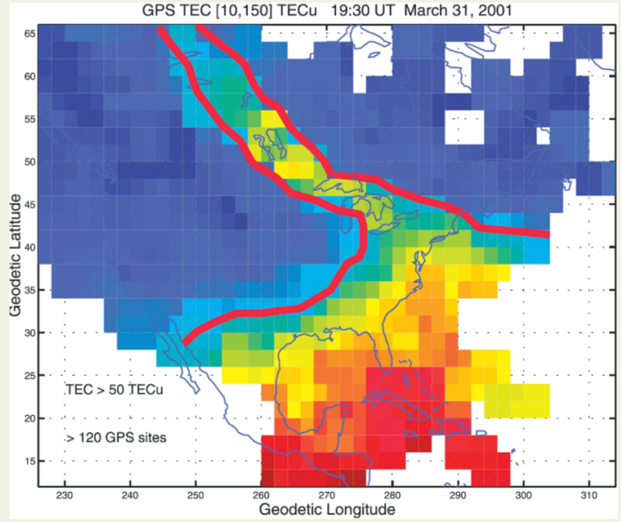
Grebowsky [1970]

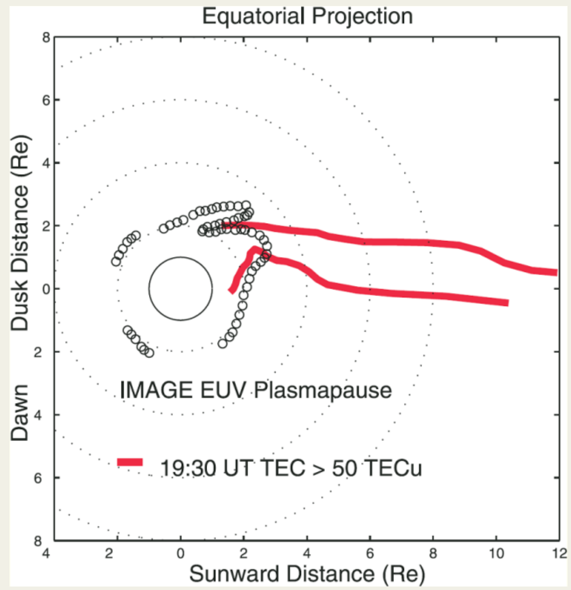
GPS and IMAGE Observations



Goldstein et al. [2003, 2004, 2005]

—New data, New names.



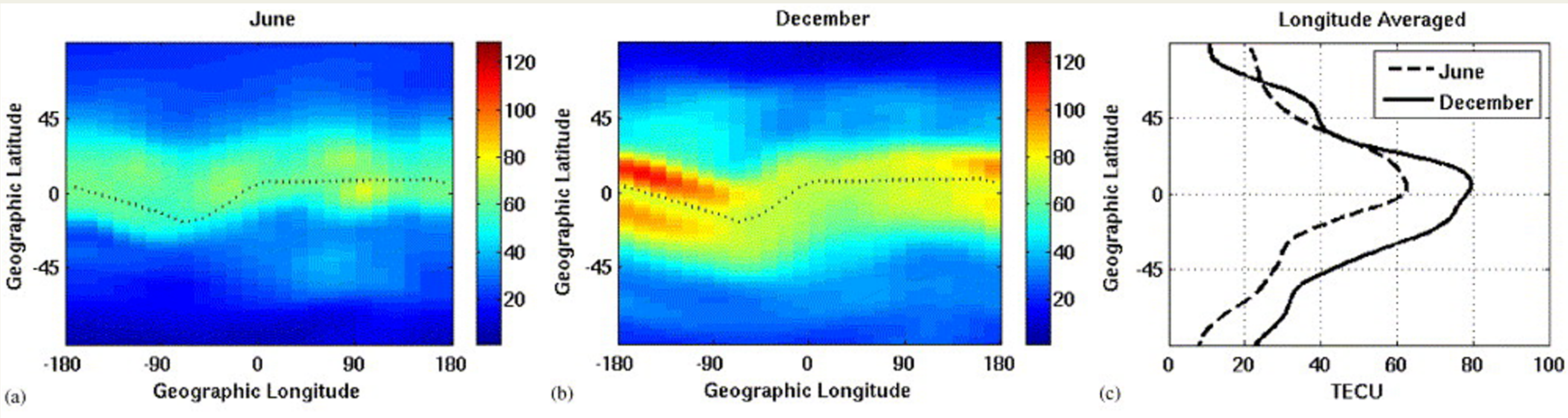


Foster et al. [2002]

Lessons Learned

Complication: Seasonal Anomaly is Hemisphere Dependent

--- GPS TEC Maps --- 2002



Summer TEC < Winter TEC (North)

Summer TEC > Winter TEC (South)

[Mechanism?]

Summary #1

- There is a daytime Seasonal Anomaly: Winter (N_{max}) > Summer (N_{max}) .
- The Seasonal Anomaly is hemisphere dependent.

 ---Stronger in the Northern Hemisphere.

- Ionospheric storms are exaggerated cases of ambient seasonal patterns.

 ---Positive Phase ΔN_{max}(winter) > ΔN_{max}(summer)

 ---Negative Phase ΔN_{max}(summer) > ΔN_{max} (winter)

- How do ionospheric storms appear in Southern Hemisphere?

Physical Drivers of Ionospheric Storms

Ambient Ionosphere = f(O/N_2)

Storm's Positive Phase due to uplift

- Electrodynamics → Maximizes in North America → Highest Λ geomagnetic for given Φ geographic
- Winds → Dominant in Europe and Asia

Storm's Negative Phase due to lower O/N_2 ratio → Heating changes composition globally

Highest Λ geomagnetic for given Φ geographic } Maximizes Magnetospheric Influence upon Solar Produced Ionosphere

$\Delta \equiv \Lambda$ geomag - Φ geog $\approx 12^{o}$

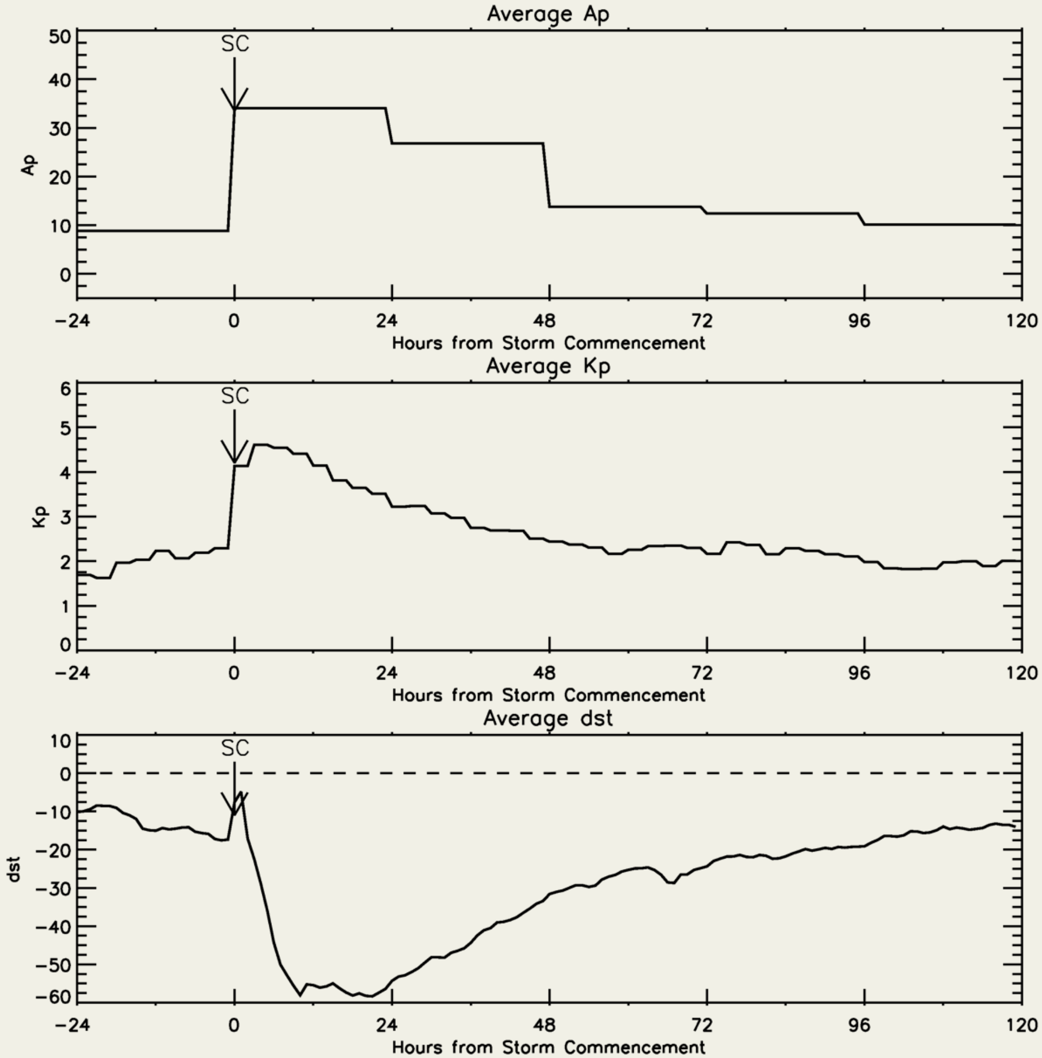
How to test concepts in the Southern Hemisphere

- Pairs of Stations → Geomagnetic Conjugate Points
- Pairs of Stations → Geophysical Equivalent Sites

Geophysical Equivalent Sites:

- Same Geographic Latitudes
- Same Geomagnetic Latitudes
- Same Geographic and Geomagnetic Latitudes

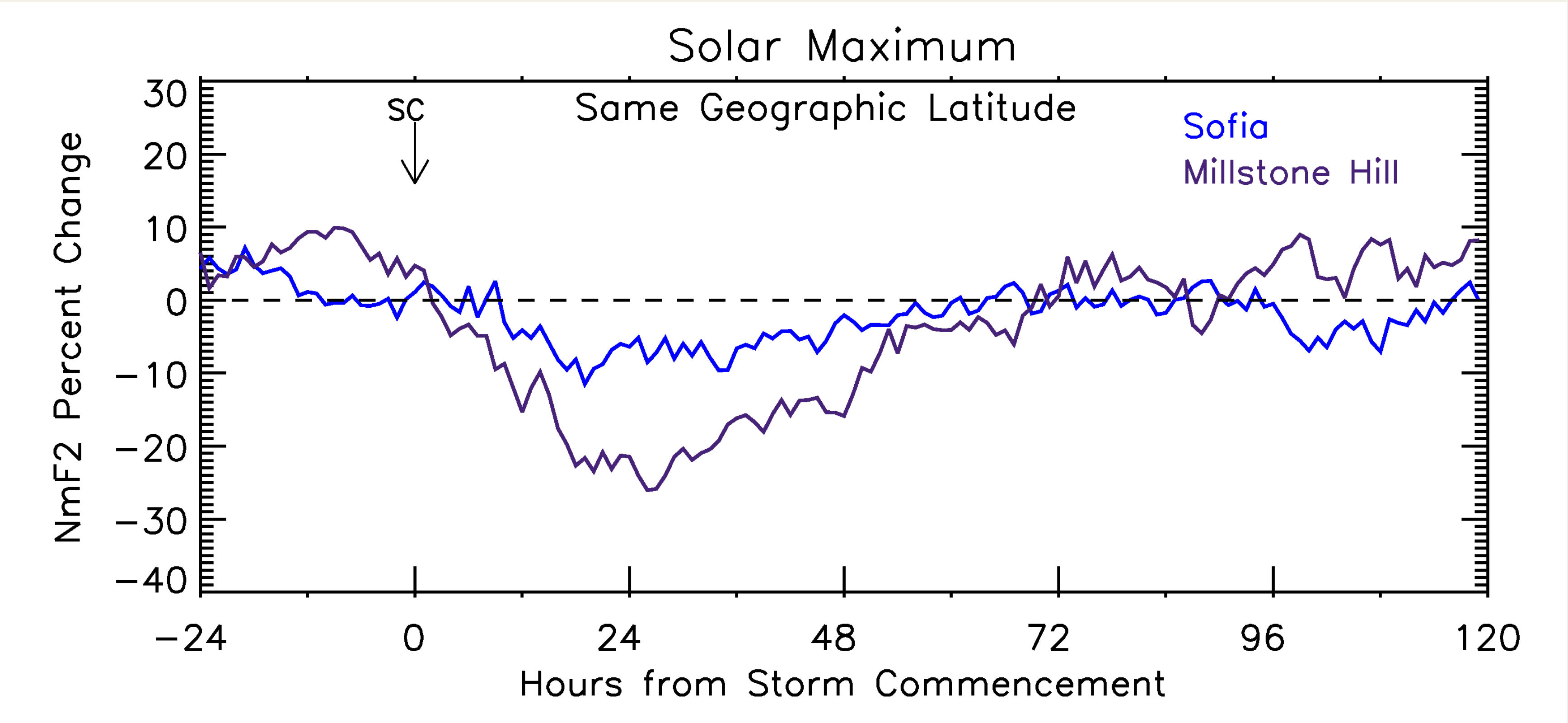
96 geomagnetic Storms: Solar Maximum (2000-2002)



96 geomagnetic Storms: Solar Maximum (2000-2002)

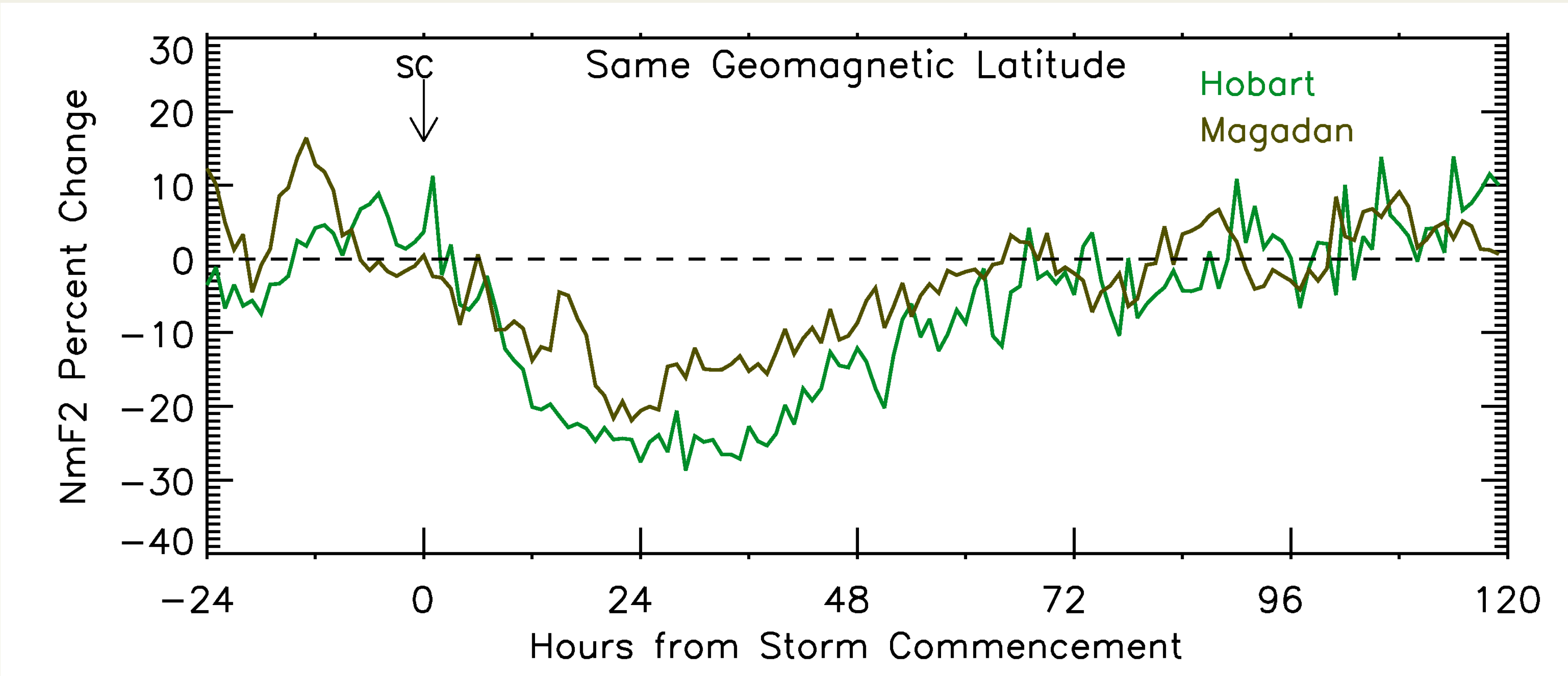
	Geographic		Geomagnetic		Geomagnetic - Geographic	Number of Storms
Station	Latitude	Longitude	Latitude	Longitude		
Hobart	42.9° S	147.3° E	54.0° S	133.3° E	11.1°	86
Millstone Hill	42.6° N	71.5° W	52.6° N	6.7° W	10.0°	80
Sofia	42.7° N	23.4° E	37.1° N	96.3° E	-5.6°	89
Magadan	60.0° N	151.0° E	53.8° N	140.5° E	-6.2°	93

Ionospheric Storms at Same Geographic Latitude as Millstone Hill (43°N)



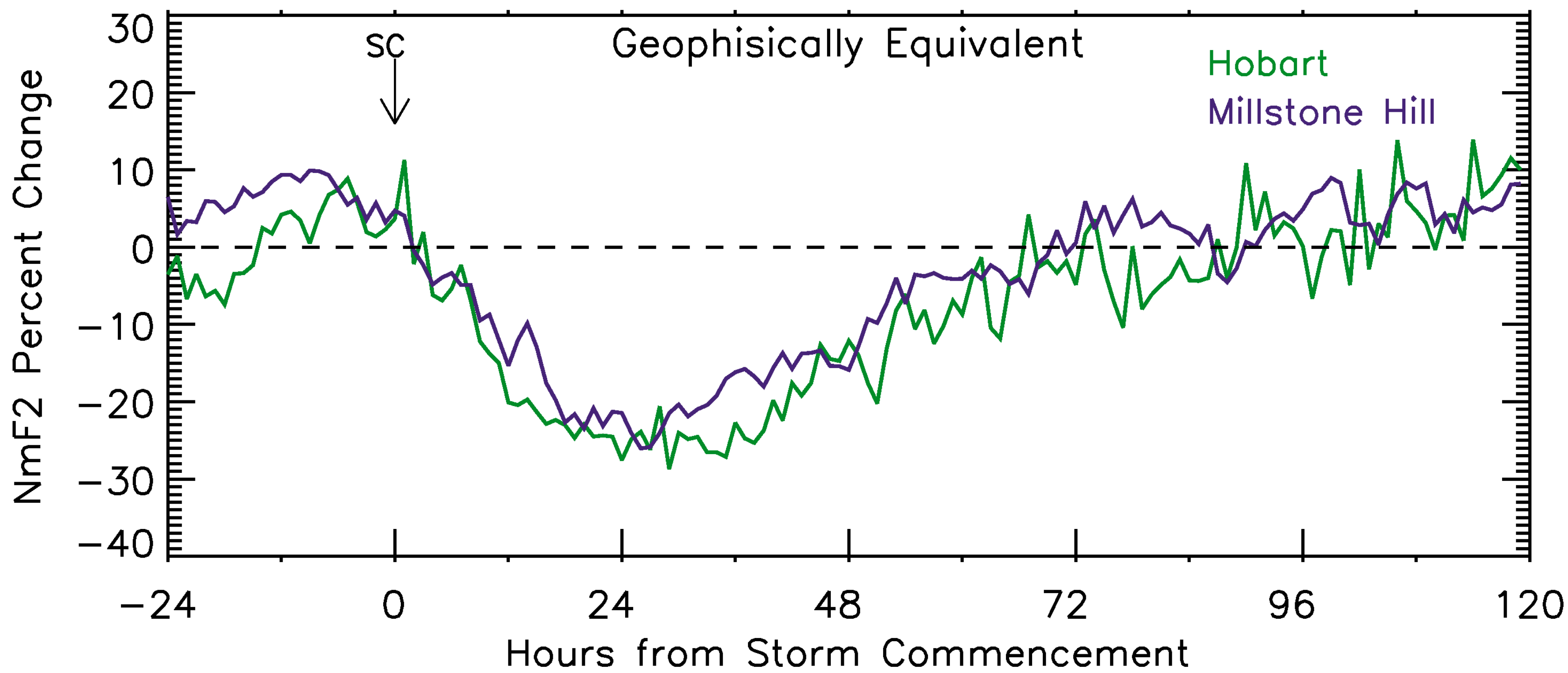
Different Geomagnetic Latitudes			
	Millstone Hill	53°N	80 storms
	Sofia	37°N	80 storms

Ionospheric Storms at Same Geomagnetic Latitude as Hobart (54° N,S)



Different Geographic Latitudes			
	Hobart	43°N	86 storms
	Magadan	60°N	93 storms

Ionospheric Storms at Geopysically-Equivalent Sites



Millstone Hill	43°N, 53°N	} Same Geomagnetic and Geographic Latitudes		80 storms
Hobart	43°S, 54°S			86 storms

Summary # 2

- Ionospheric Storms test our understanding of a highly-coupled global system.

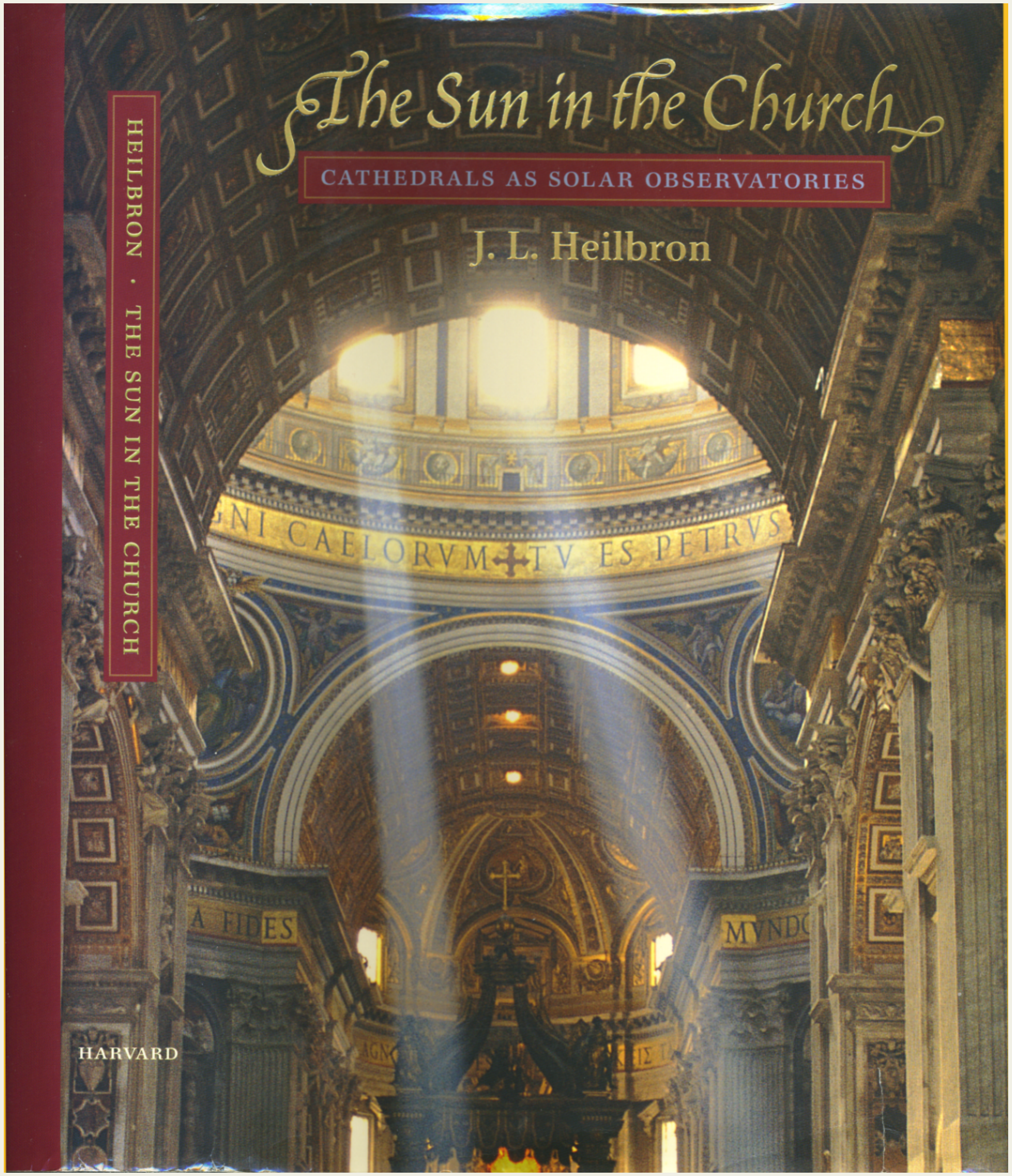
  Sun → Solar Wind → Magnetosphere → Ionosphere ←Troposphere
  Thermosphere

- Pre-event conditions ---Downward and Upward Coupling--- determine the characteristic patterns of perturbations induced by "Δ Downward Coupling."
- Pre-disturbance characteristics vary with hemisphere —In asymmetric ways— not a simple reversal of seasons.
- Yet at Geophysically Equivalent Sites ---Perturbations induced are statistically equal---Same System Response Functions.

The Power of Photons

From Light in a Cathedral to a Network of All-Sky-Imagers

"Seeing" Hemispheric Effects Upon the Ionosphere at Geomagnetic Conjugate Points


The Sun in the Church
CATHEDRALS AS SOLAR OBSERVATORIES
J. L. Heilbron
HEILBRON · THE SUN IN THE CHURCH
HARVARD

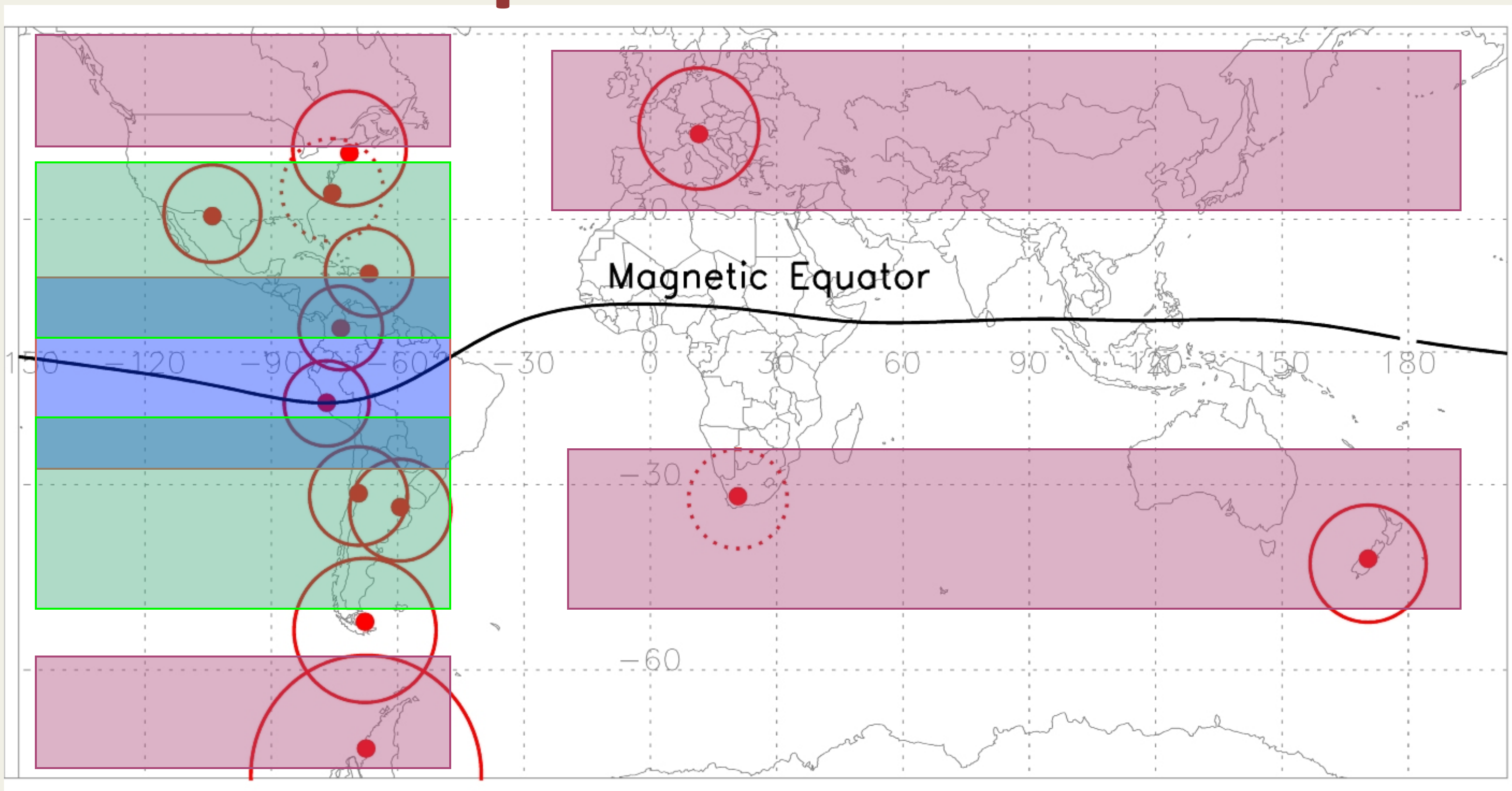
Bologna: San Petronio

N-S Meridian and Roof Hole for Sun

A Minutes Before Noon!

BU Optical Network

existing
planned



1. Equatorial and low latitude Ionosphere (from magnetic equator to the crests of the Appleton Anomaly). *ESF and MSTIDs, effects on trans-ionospheric radio signals using GPS and optical diagnosis.*

2. Mid latitude Ionosphere (poleward from Anomaly crests to ~ ± 40 mag lat). *Nighttime MSTIDs, E and F region coupling.*

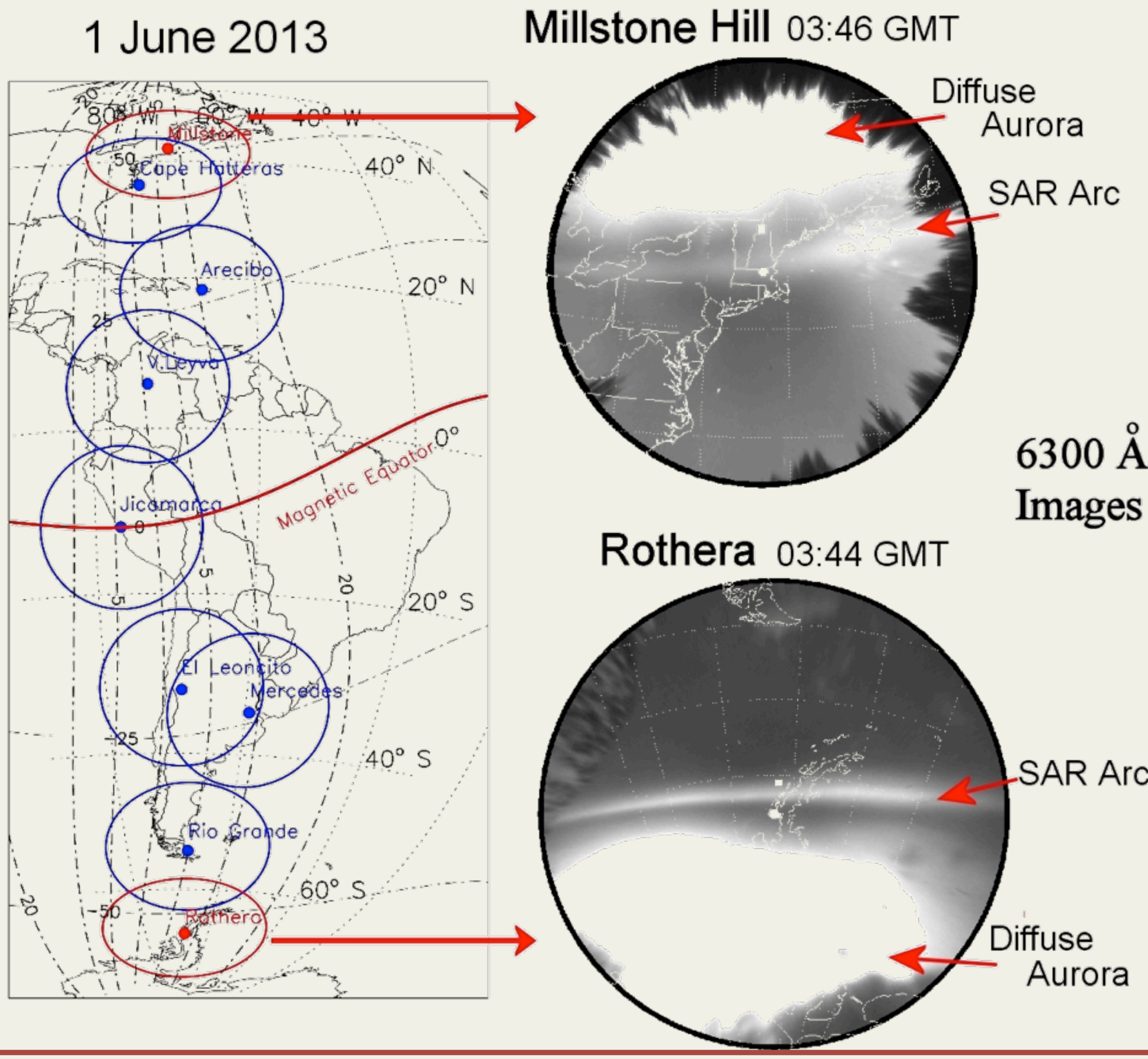
3. Sub-auroral Ionosphere (latitudes below auroral ovals). *Stable auroral red (SAR) arcs (magnetic activity effects that transfer magnetospheric ring current energy into the I-T system)*

Why Conjugate Point Science?

- Same electro-dynamical process acting upon different seasonal conditions simultaneously.

Boston University All-Sky-Imagers

Geomagnetic Conjugate Science Feature: Stable Auroral Red (SAR) Arcs



Similarities

- Both SAR Arcs at L= 2.74 R_e
- Same Separations from Diffuse Aurora

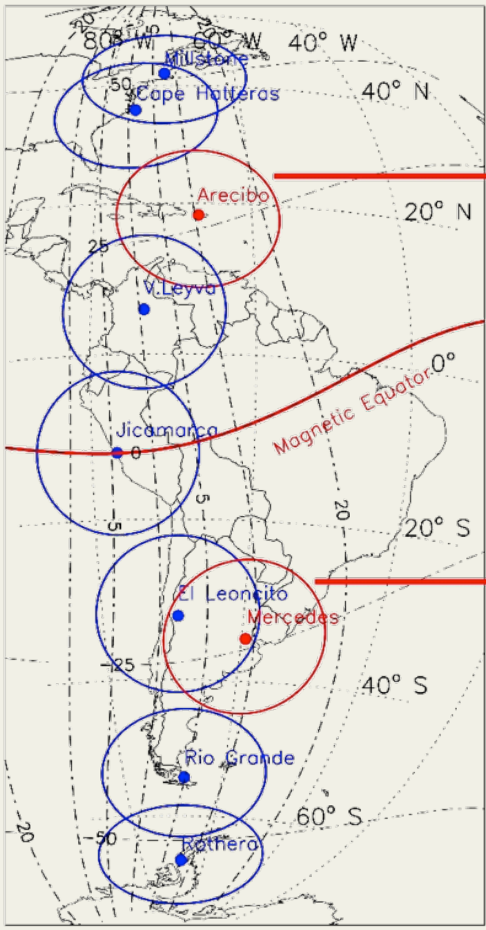
Differences

- Small scale structures along arcs
- Brighter in Southern Hemisphere
- Latitude gradients stronger in South

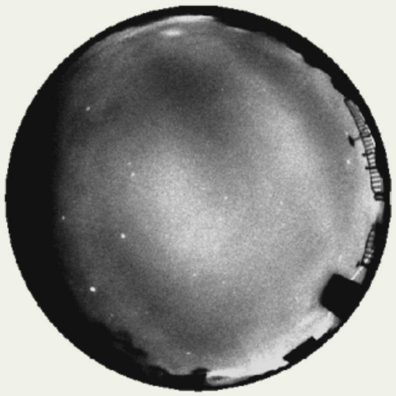
Boston University All-Sky-Imagers

Geomagnetic Conjugate Science Feature: Medium Scale Travelling Ionospheric Disturbances

9 Feb 2013

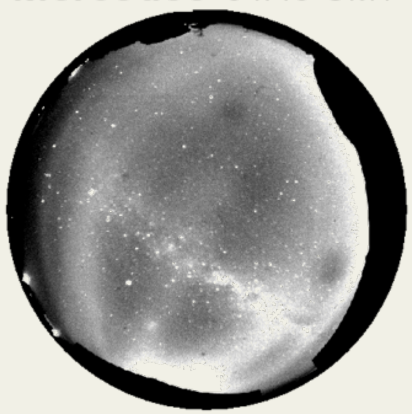


Arecibo 04:42 GMT



6300 Å Images

Mercedes 04:40 GMT



Similarities

- MSTIDs travel westward & equatorward in both hemispheres: SW in north, NW in south
- Wave Crests & Troughs linked by same field lines

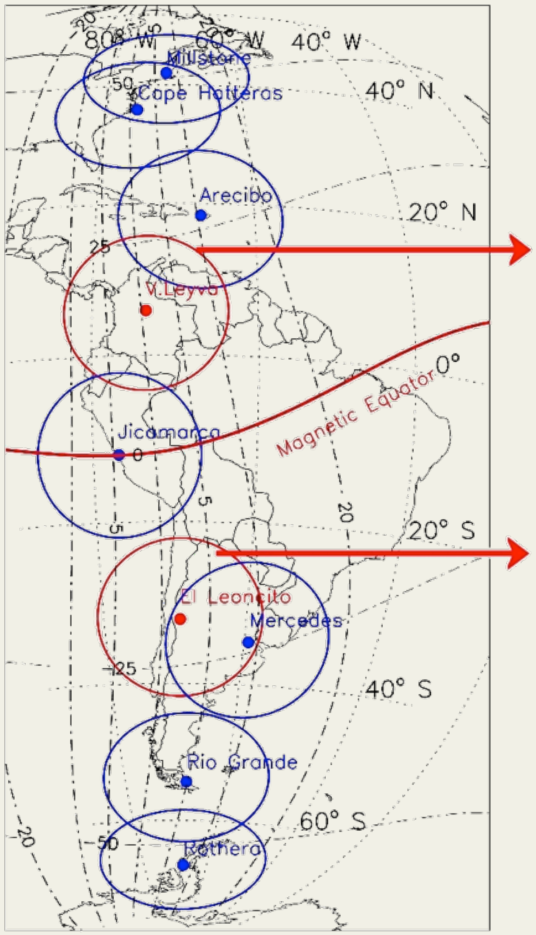
Differences

- Background airglow brighter in Summer (Southern) hemisphere
- Crest-to-trough brightness ratio higher in Winter (Northern) hemisphere
- Ionospheric radar data only available in Northern hemisphere

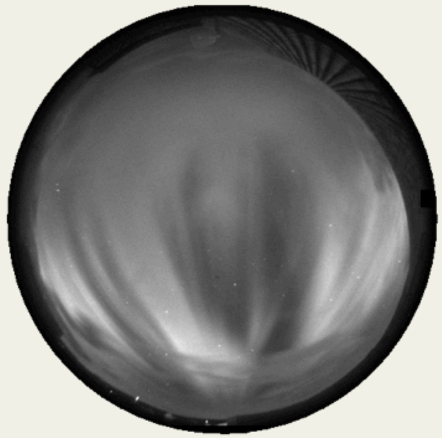
Boston University All-Sky-Imagers

Geomagnetic Conjugate Science Feature: Airglow Depletions showing trans-equatorial Plasma Instabilities

18 November 2014



Villa de Leyva 01:25 GMT



7774 Å Images

El Leoncito 01:25 GMT

Similarities

- Coherence of broad temporal & spacial occurrence patterns
- Broadly consistent zonal (E→W) drift patterns

Differences

- Fine structuring stronger in Southern hemisphere
- Bright-to-dark contrast greater in Winter (Northern) hemisphere
- Zonal drift patterns affected by South Atlantic magnetic field anomaly

Summary

- ***Solar-Terrestrial Physics*** provokes global effects

  --- Not just where most of the diagnostic instruments (and people) are located.

- ***Comparative Aeronomy*** can be done on Planet Earth

  --- with leadership roles for NSF sponsored ground-based radio and optical diagnostics.

- ***Opportunities for "enabled growth"*** in Africa and within existing southern hemisphere aeronomy communities.

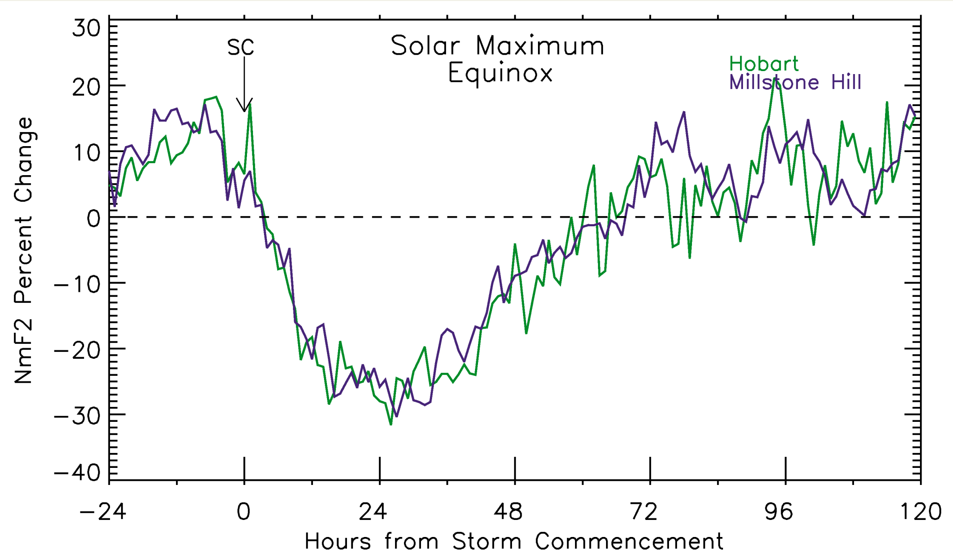
- With NASA's ***ICON and GOLD***

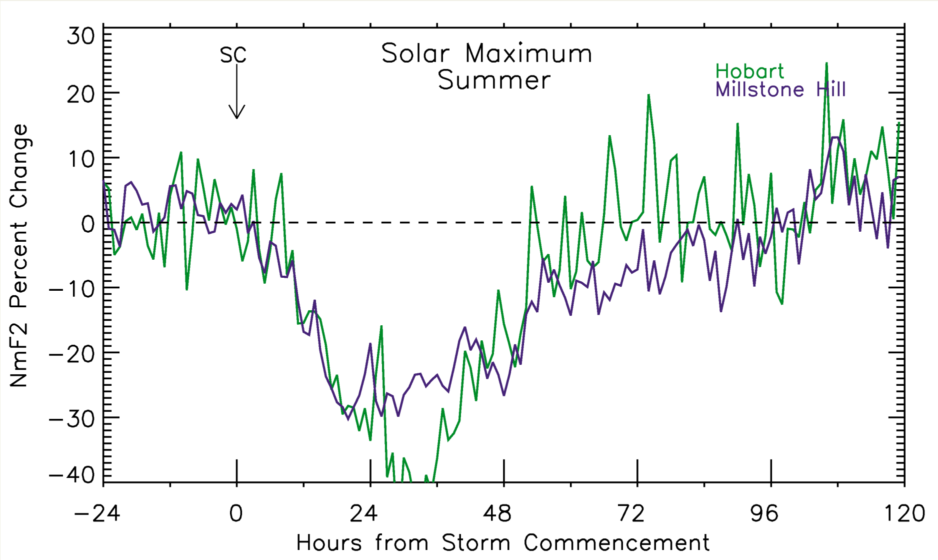
  --- a new era for global science of the Earth's coupled neutral-plasma environment.

- ***Global simulations*** and validation studies of Geophysically-Equivalent (and non-equivalent) sites.

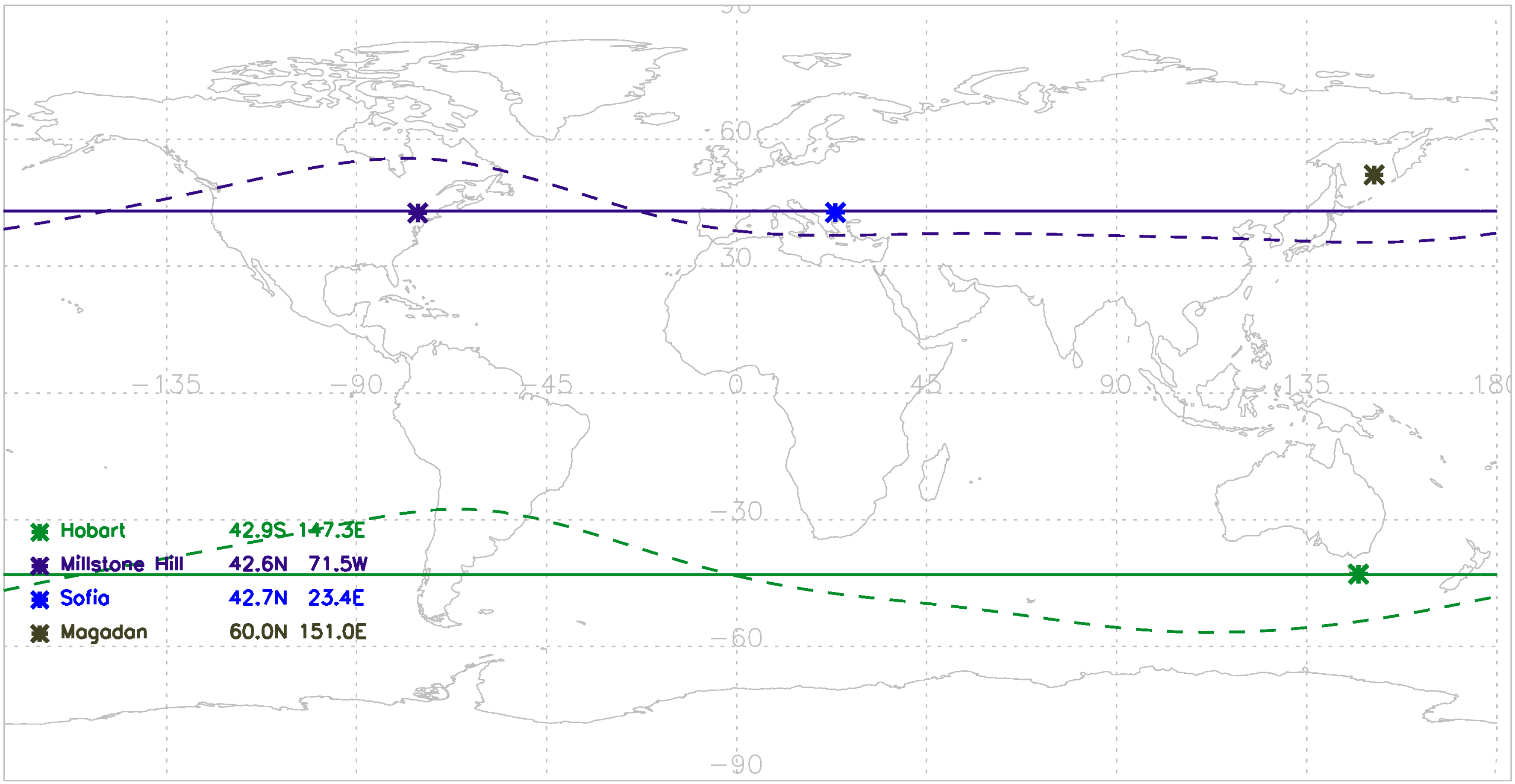
Back Up Slides

Ionospheric Storms at Geophysically-Equivalent Sites: ---Equinox, Summer





Stations



90
60
30
0
−30
−60
−90
−135
−90
−45
0
45
90
135
180
Hobart 42.9S 147.3E
Millstone Hill 42.6N 71.5W
Sofia 42.7N 23.4E
Magadan 60.0N 151.0E