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DEPARTMENT OF PHYSICS

UNITED NATIONS
Office for Outer Space Affairs

Impact of St. Patrick's geomagnetic storm of 2015 on ionospheric total electron content using GPS over the Southeast Asian region

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Space and Atmospheric Research Group (SPAR)

- Our research deals with the study of space environment and the atmosphere using different space-based and ground-based systems.
- Currently, we focus on the use of global navigation satellite systems (GNSS) (e.g., GPS) to estimate ionospheric total electron content and study its response to geomagnetic and solar activities and its effects to radio wave propagation. We also estimate tropospheric precipitable water vapor content using GNSS and compare it with hydrological and meteorological phenomena.
- Earth observation using space and ground based remote sensing techniques is also being done in this group.

HEAD:

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Christian David Aquino (PHEC-5)
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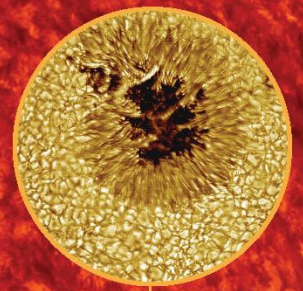
Space Weather

Space weather refers to the variable conditions on the Sun and in the space environment that can influence the performance and reliability of space-based and ground-based technological systems, as well as endanger life or health. Just like weather on Earth, space weather has its seasons, with solar activity rising and falling over an approximate 11 year cycle.

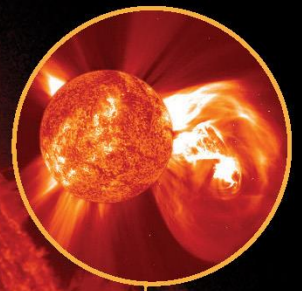
Sunspots

Sunspots are comparatively cool areas at up to 7,700° F and show the location of strong magnetic fields protruding through what we would see as the Sun's surface. Large, complex sunspot groups are generally the source of significant space weather.



Coronal Mass Ejections (CMEs)

Large portions of the corona, or outer atmosphere of the Sun, can be explosively blown into space, sending billions of tons of plasma, or superheated gas, Earth's direction. These CMEs have their own magnetic field and can slam into and interact with Earth's magnetic field, resulting in geomagnetic storms. The fastest of these CMEs can reach Earth in under a day, with the slowest taking 4 or 5 days to reach Earth.



Solar Wind

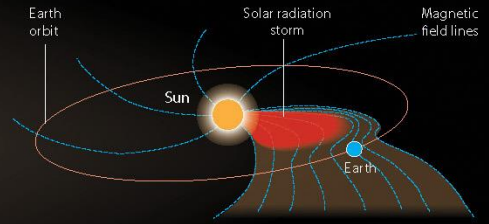
The solar wind is a constant outflow of electrons and protons from the Sun, always present and buffeting Earth's magnetic field. The background solar wind flows at approximately one million miles per hour!

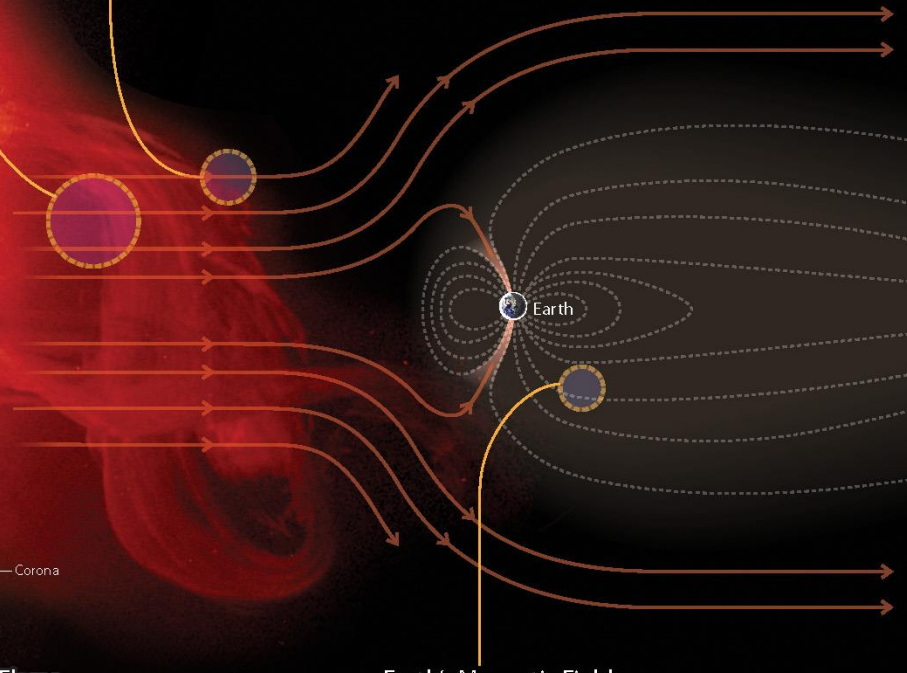
Sun's Magnetic Field

Strong and ever-changing magnetic fields drive the life of the Sun and underlie sunspots. These strong magnetic fields are the energy source for space weather and their twisting, shearing, and reconnection lead to solar flares.

Solar Radiation Storms

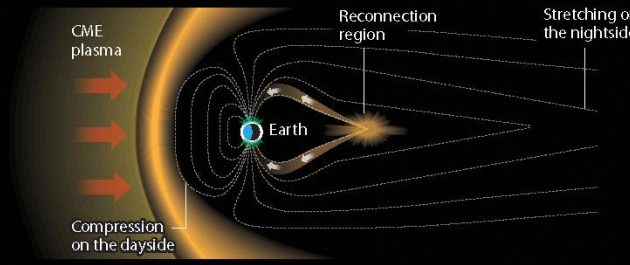
Charged particles, including electrons and protons, can be accelerated by coronal mass ejections and solar flares. These particles bounce and gyrate their way through space, roughly following the magnetic field lines and ultimately bombarding Earth from every direction. The fastest of these particles can affect Earth tens of minutes after a solar flare.





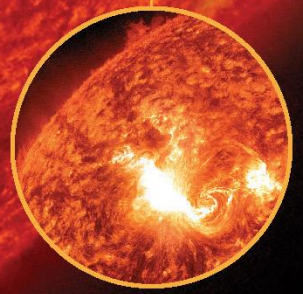
Geomagnetic Storms

A geomagnetic storm is a temporary disturbance of Earth's magnetic field typically associated with enhancements in the solar wind. These storms are created when the solar wind and its magnetic field interacts with Earth's magnetic field. The primary source of geomagnetic storms is CMEs which stretch the magnetosphere on the nightside causing it to release energy through magnetic reconnection. Disturbances in the ionosphere (a region of Earth's upper atmosphere) are usually associated with geomagnetic storms.



Solar Flares

Reconnection of the magnetic fields on the surface of the Sun drive the biggest explosions in our solar system. These solar flares release immense amounts of energy and result in electromagnetic emissions spanning the spectrum from gamma rays to radio waves. Traveling at the speed of light, these emissions make the 93 million mile trip to Earth in just 8 minutes.

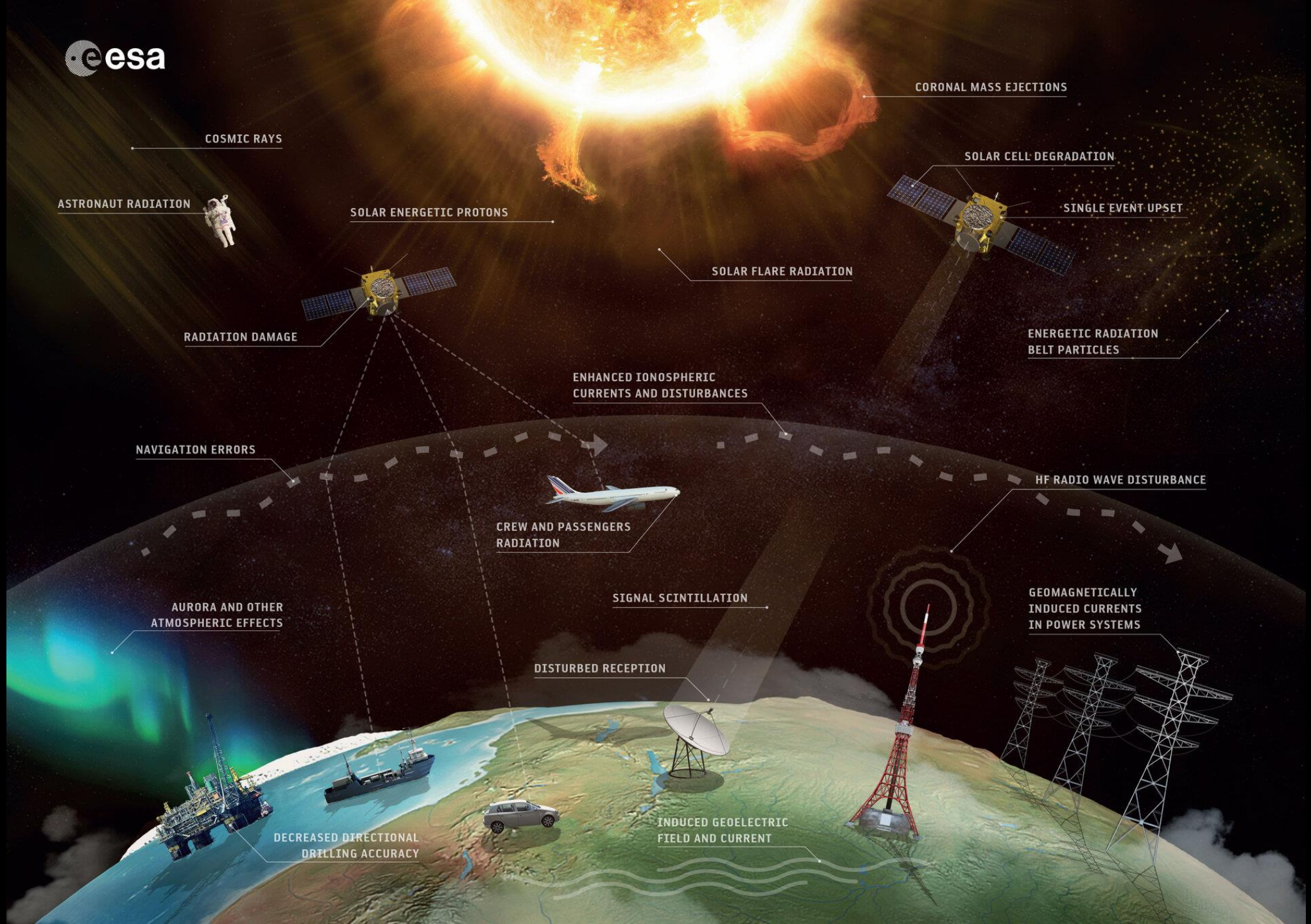


Earth's Magnetic Field

Earth's magnetic field, largely like that of a bar magnet, gives the Earth some protection from the effects of the Sun. Earth's magnetic field is constantly compressed on the day side and stretched on the night side by the ever-present solar wind. During geomagnetic storms, the disturbances to Earth's magnetic field can become extreme. In addition to some buffering by the atmosphere, this field also offers some shielding from the charged particles of a radiation storm.

NOAA

Source images: NASA, NOAA.


esa
CORONAL MASS EJECTIONS
COSMIC RAYS
SOLAR CELL DEGRADATION
ASTRONAUT RADIATION
SOLAR ENERGETIC PROTONS
SINGLE EVENT UPSET
SOLAR FLARE RADIATION
RADIATION DAMAGE
ENERGETIC RADIATION
BELT PARTICLES
ENHANCED IONOSPHERIC
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NAVIGATION ERRORS
HF RADIO WAVE DISTURBANCE
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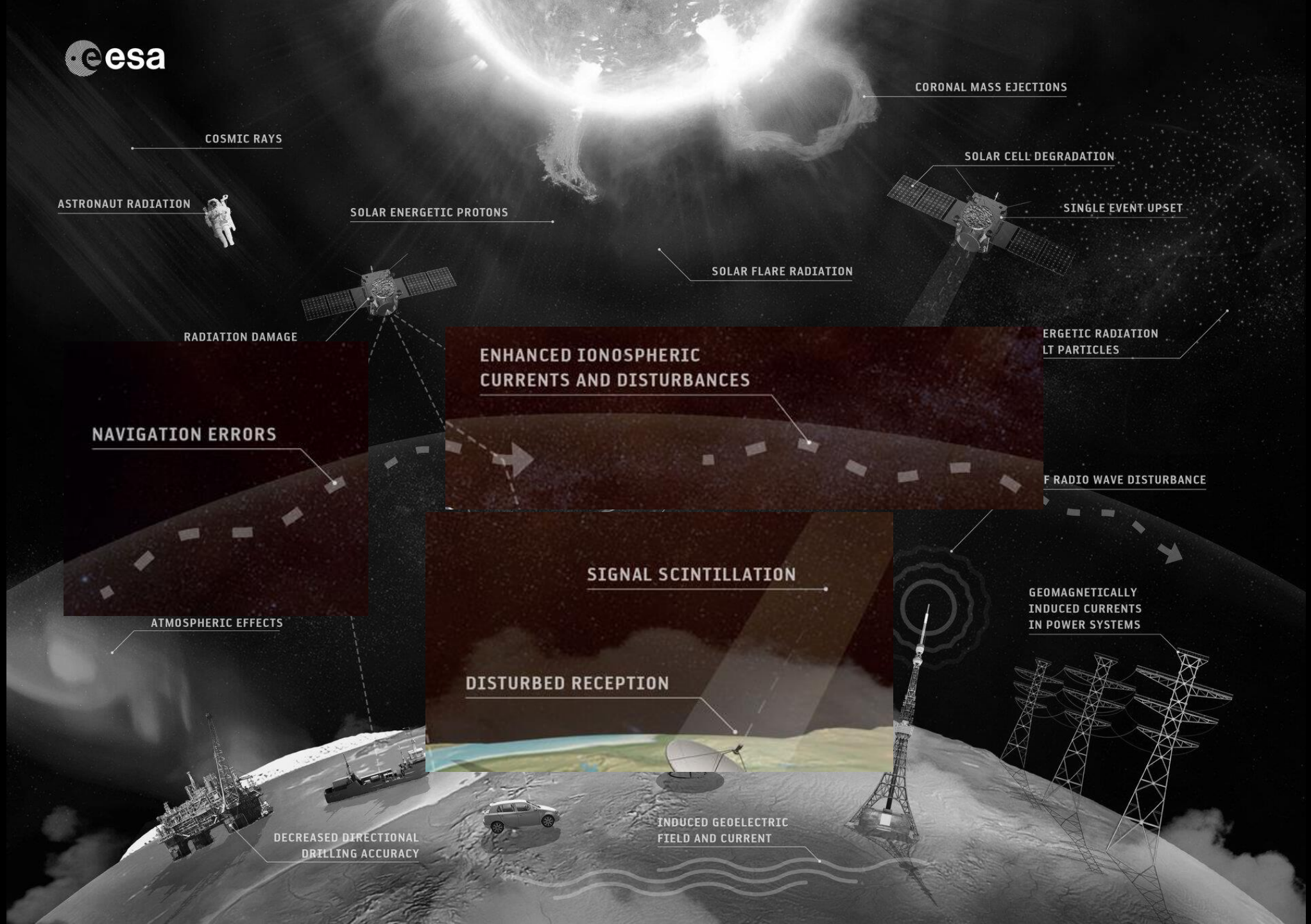
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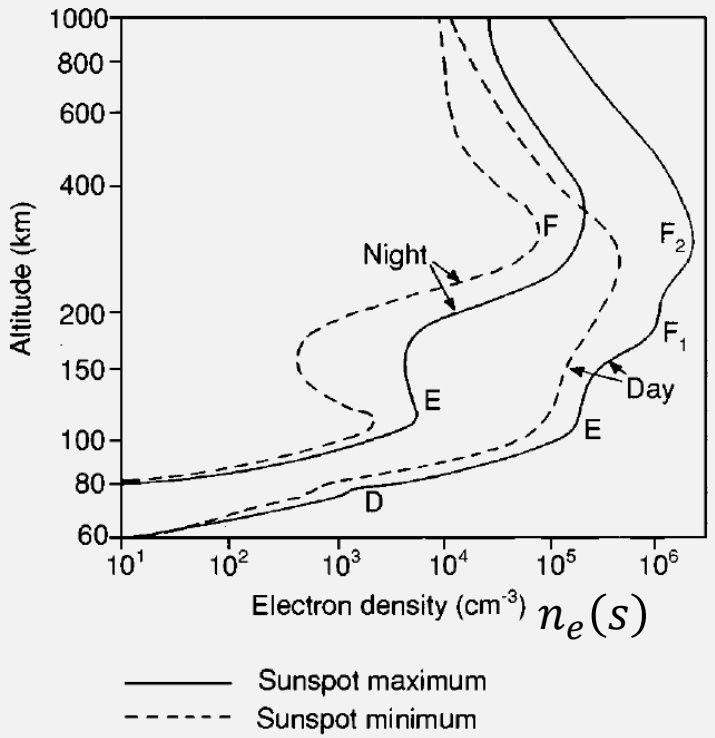
The Ionosphere



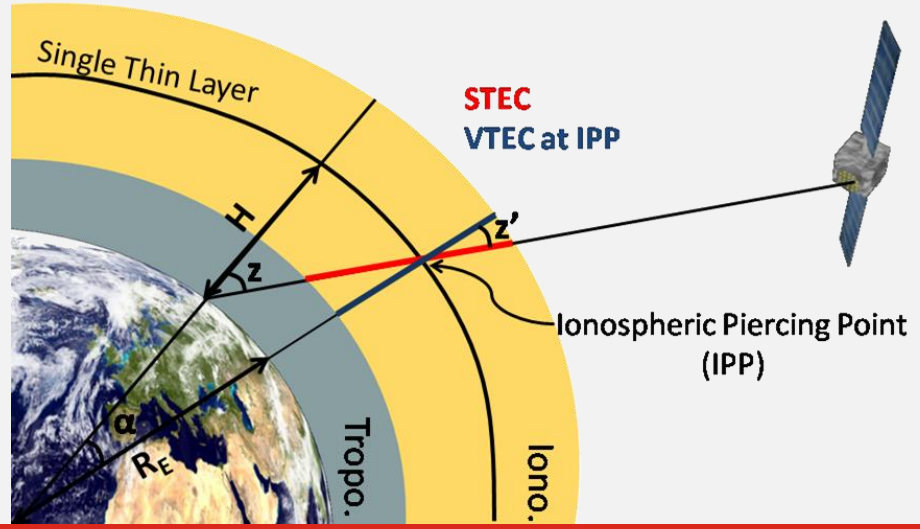
Hargreaves (1992)

TOTAL ELECTRON CONTENT (TEC)

Total number of electrons integrated between two points, along a tube of one meter squared cross section

$$TEC = \int n_e(s)ds$$ UNITS: 1 TEC unit =10^{16} el/m^2

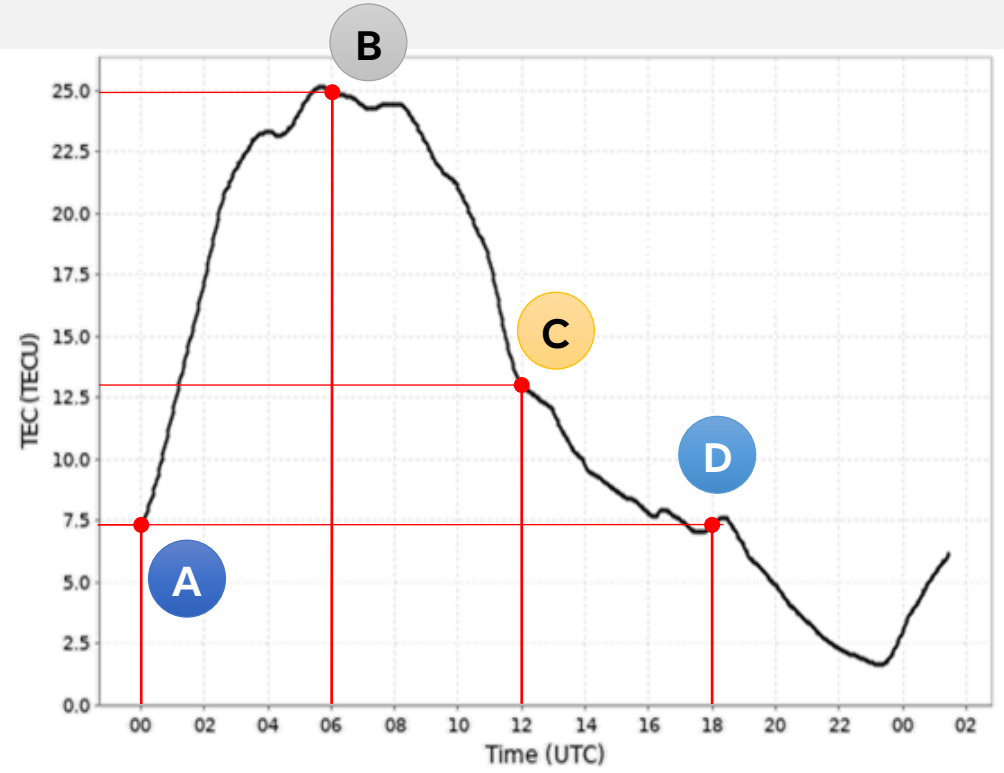
$$STEC = \frac{1}{40.3}\frac{{f_{L1}}^2 {f_{L2}}^2}{{f_{L1}}^2 - {f_{L2}}^2}(\rho_{L2} - \rho_{L1}) \qquad VTEC = \frac{STEC}{OF\,(z')}$$

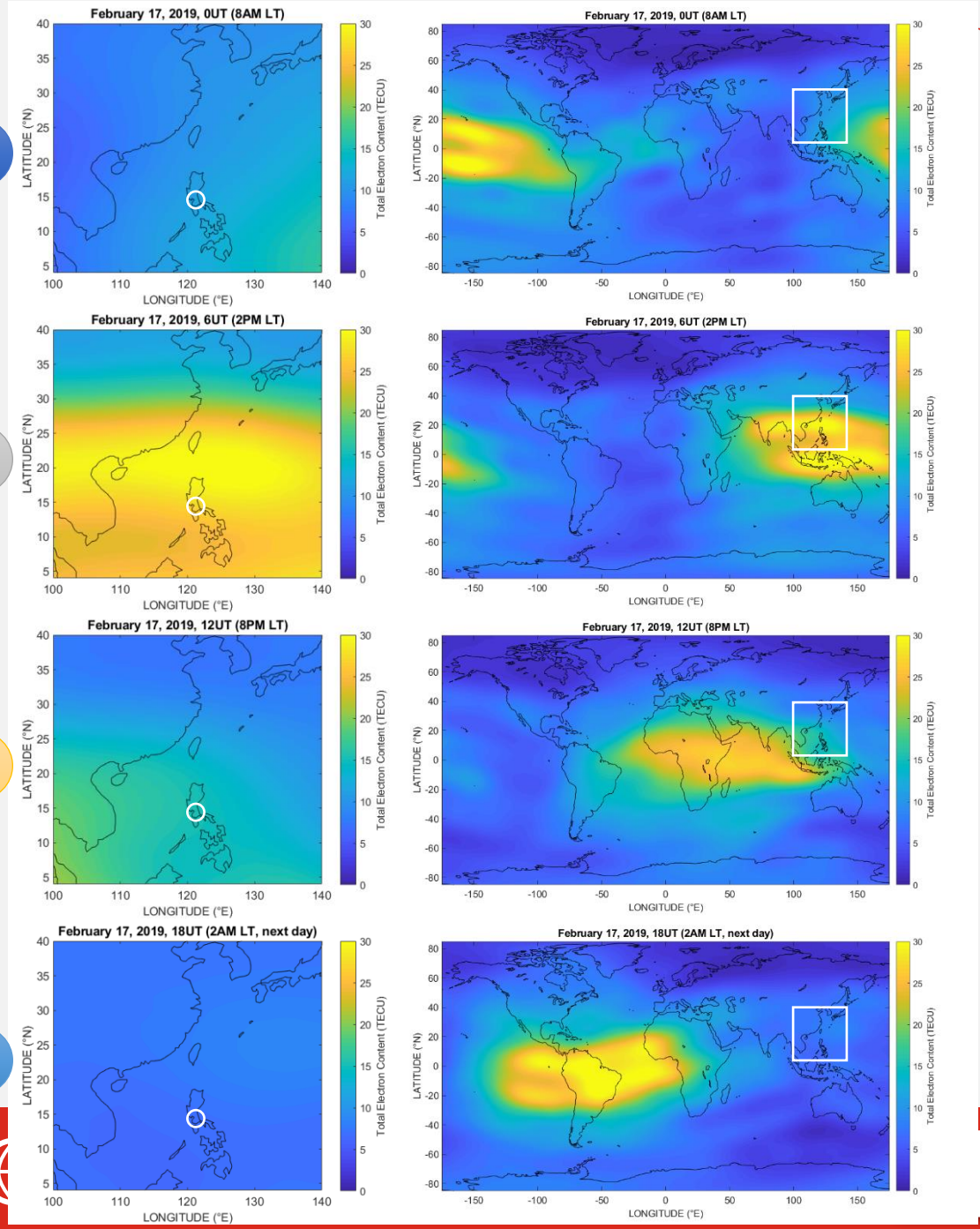


GNSS Bands
L1 (1575.42 MHz)
L2 (1227.60 MHz)

Total Electron Content

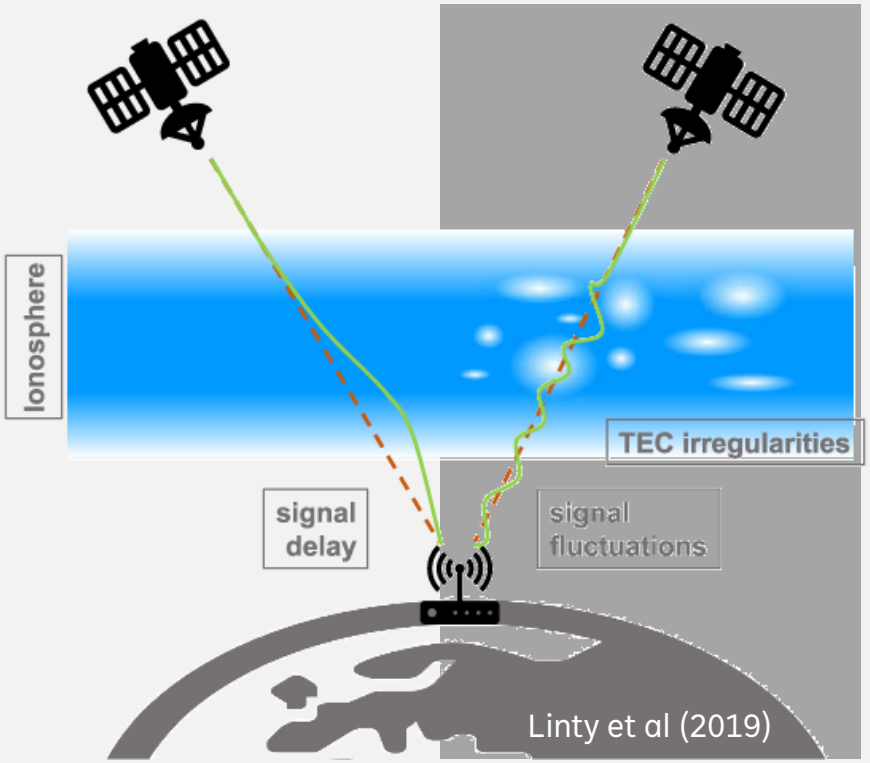
Quezon City, Philippines February 17, 2019

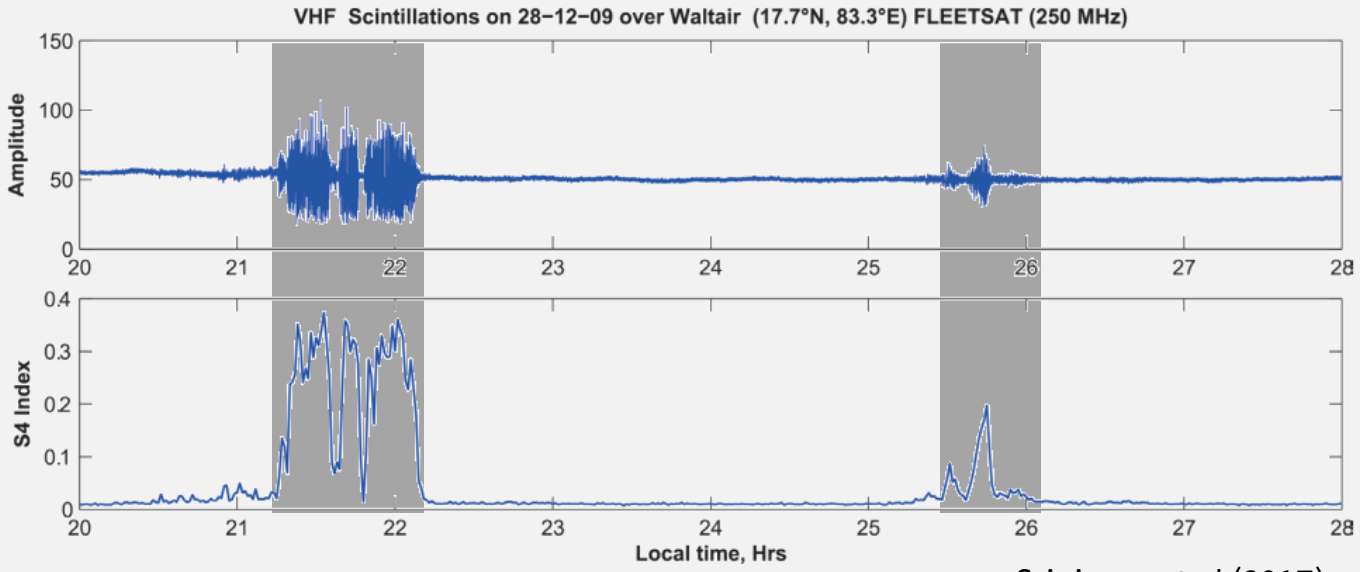




Ionospheric Plasma Irregularities

- Generates rapid fluctuations of amplitude, phase, polarization, and angle of arrival of a radio signal—**SCINTILLATION**. This phenomenon can cause a crucial disturbance for radio systems using satellites.





Srinivasu et al (2017)

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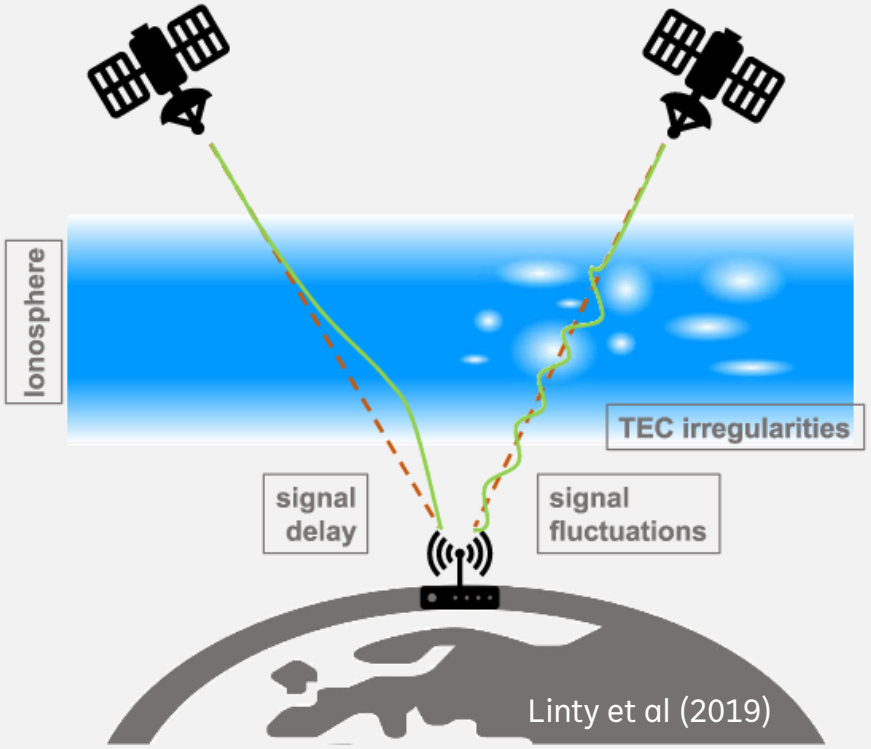
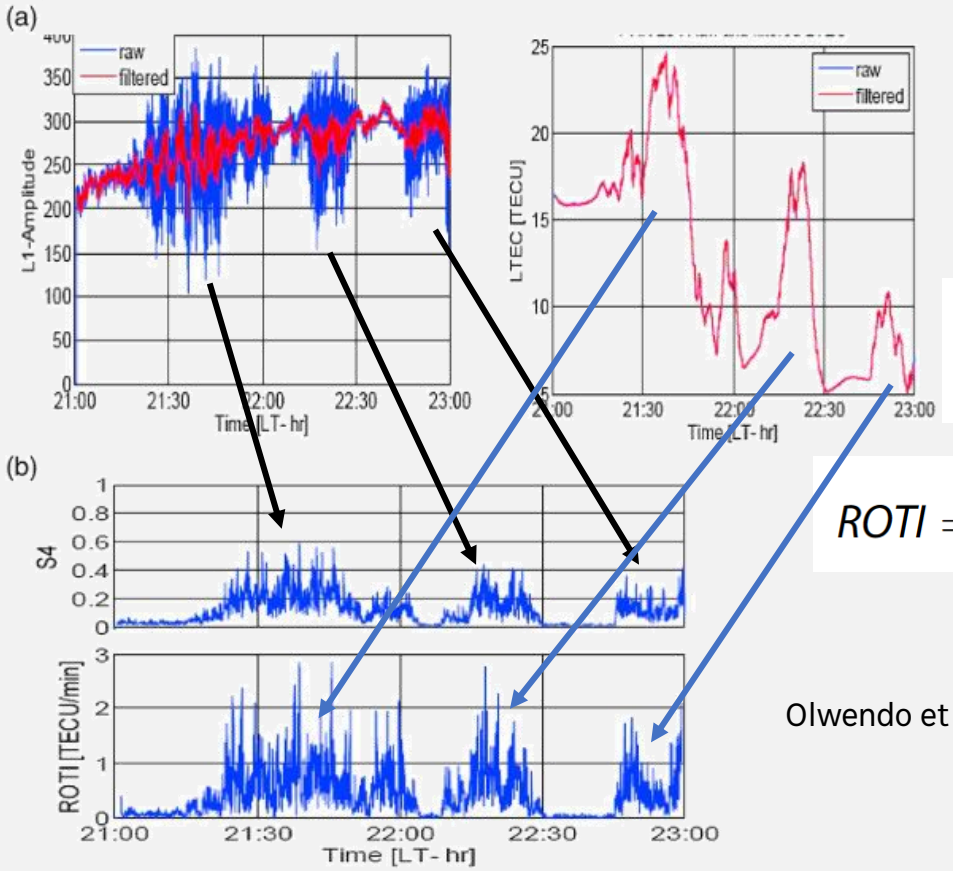


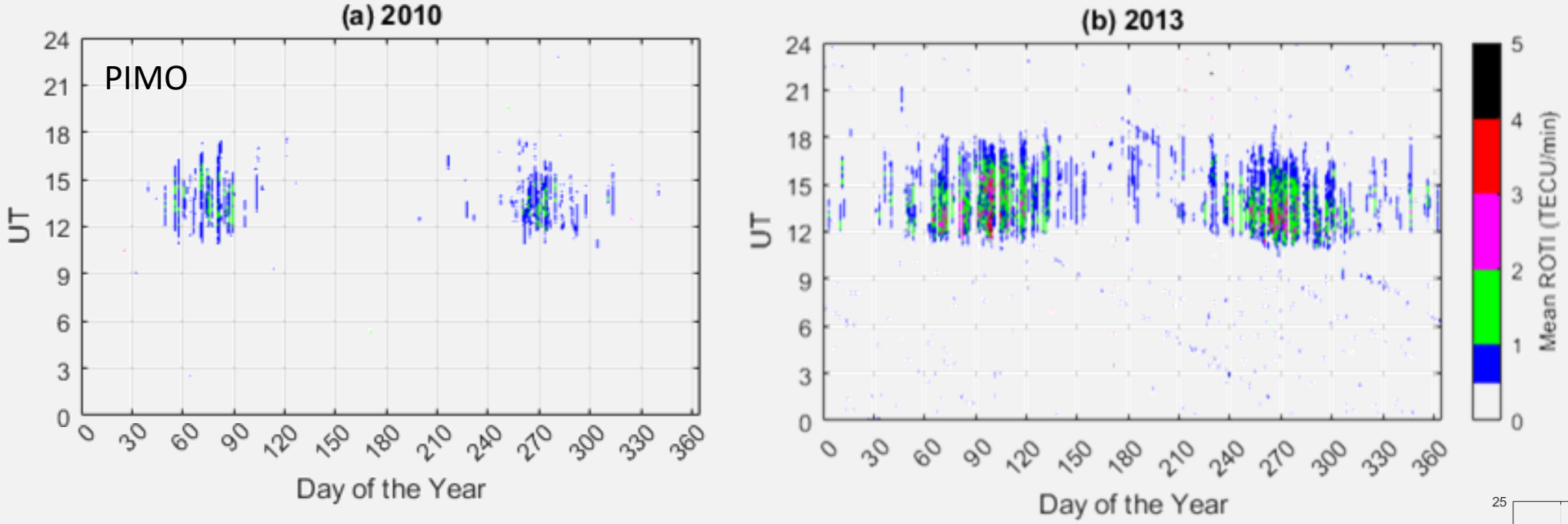


$$ROT = \frac{TEC_k^i - TEC_{k-1}^i}{t_k - t_{k-1}}$$

$$ROTI = \sqrt{\langle ROT^2 \rangle - \langle ROT \rangle^2}$$

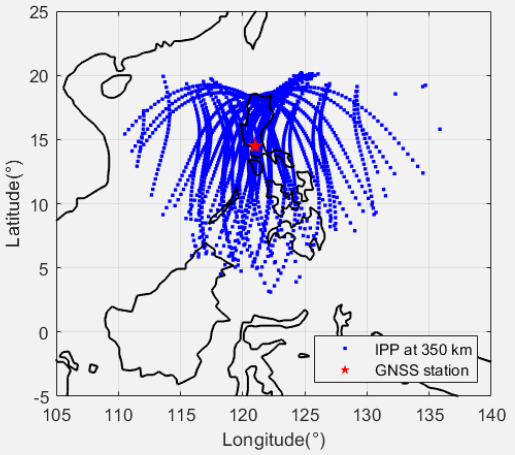
Olwendo et al (2018)

Scintillation Climatology



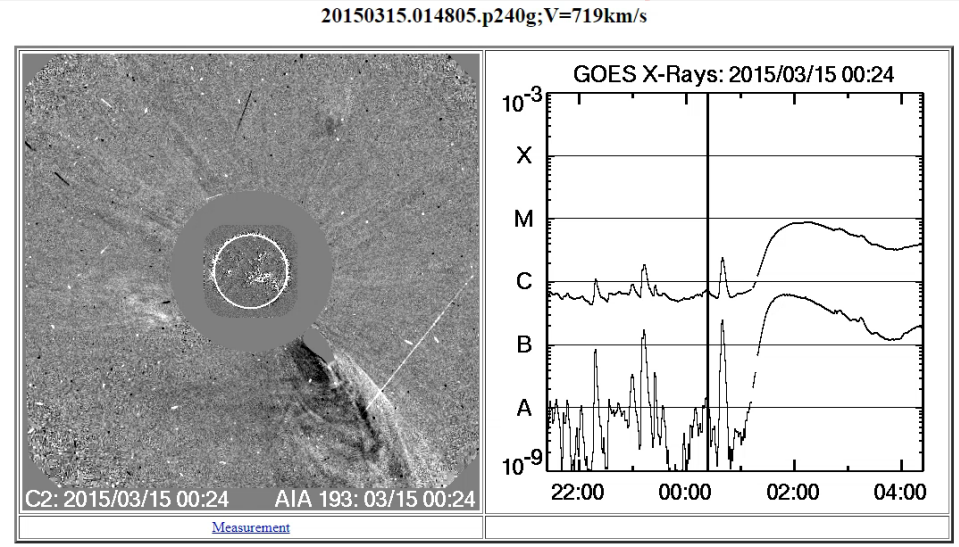
Daily 5-minute mean ROTI in (a) 2010 and (b) 2013.

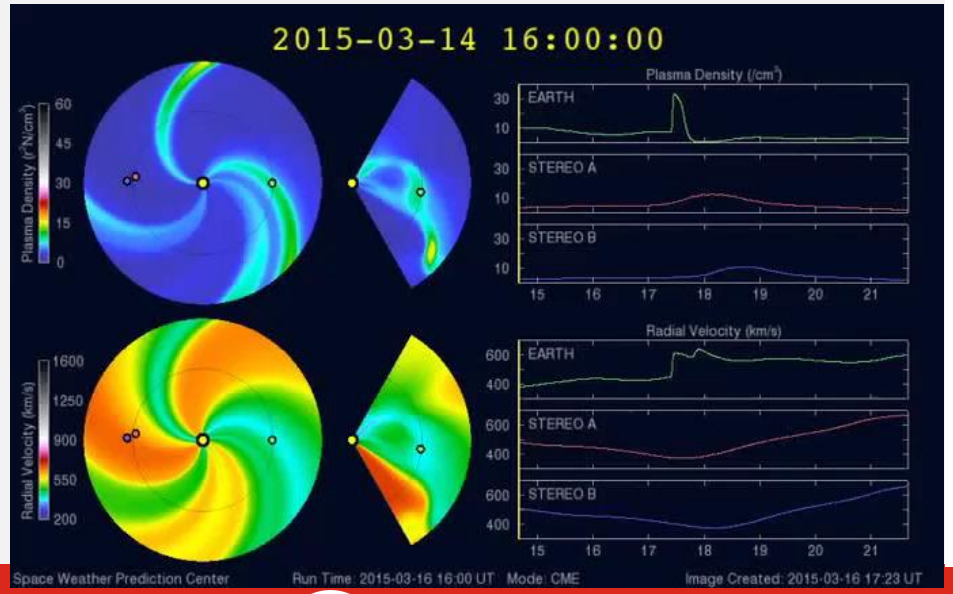
- Most of the ionospheric plasma irregularities occurred from **post-sunset** of about 2000LT (1200 UT) times up until **post-midnight** 0200LT (1800 UT).
- Increasing solar activity tends to lengthen the duration of occurrence.
- Observed mostly during the equinox independent of solar activity.

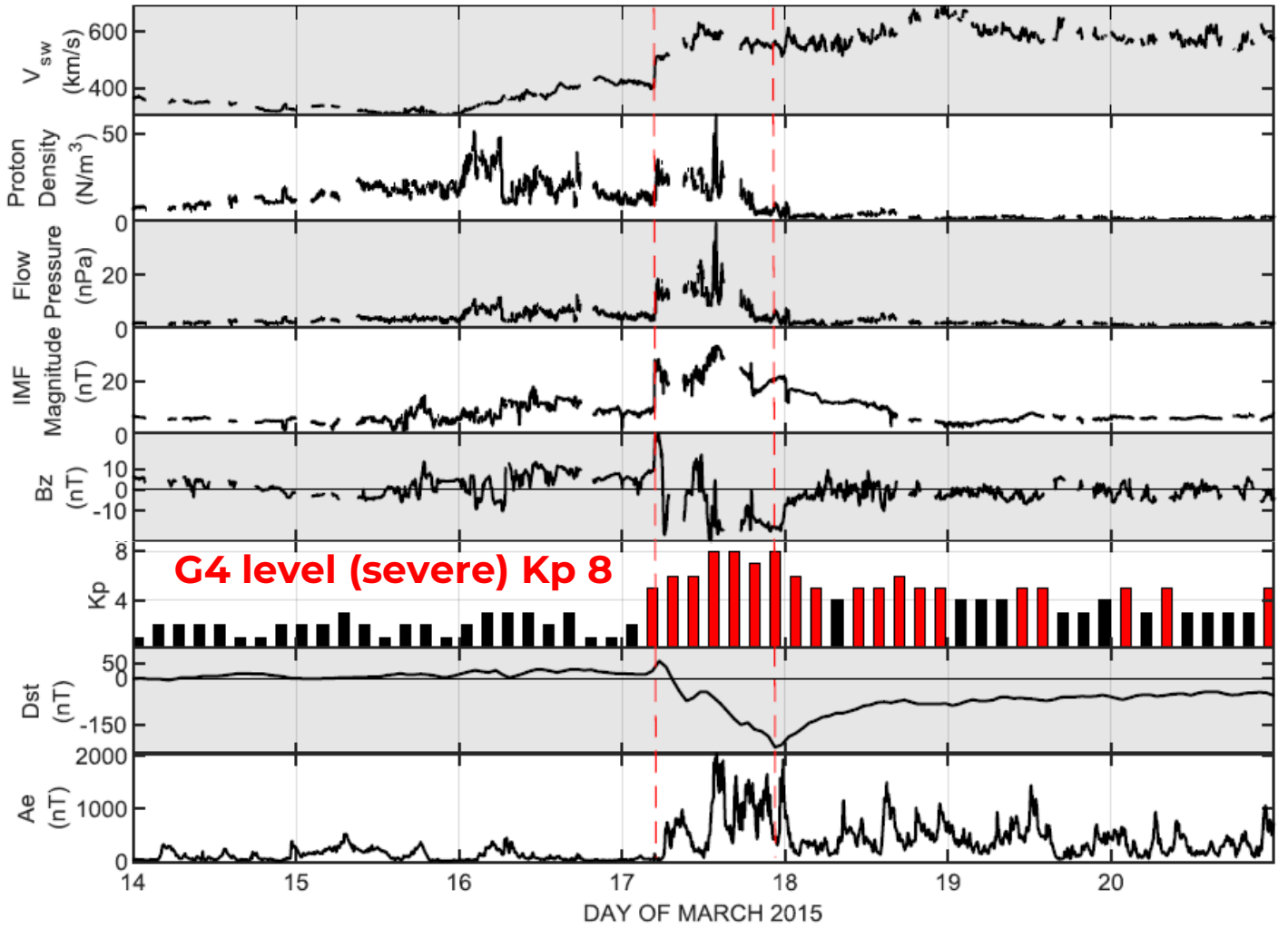


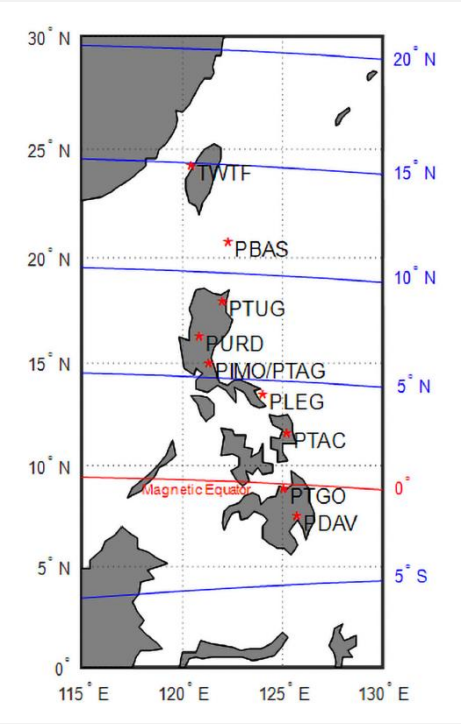
https://doi.org/10.1109/ICARES60489.2023.10329904

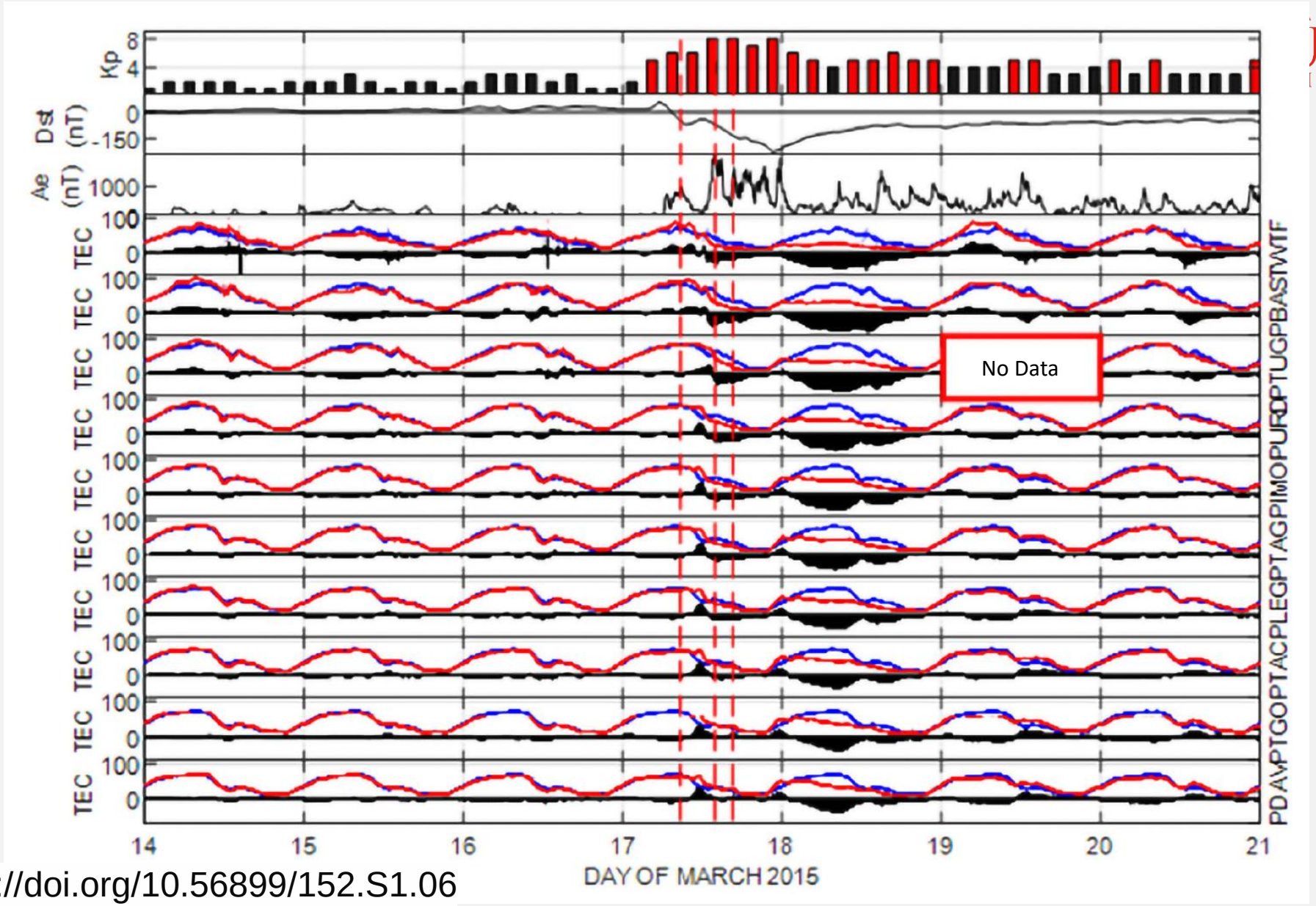
St. Patrick's Day Geomagnetic Storm of 2015











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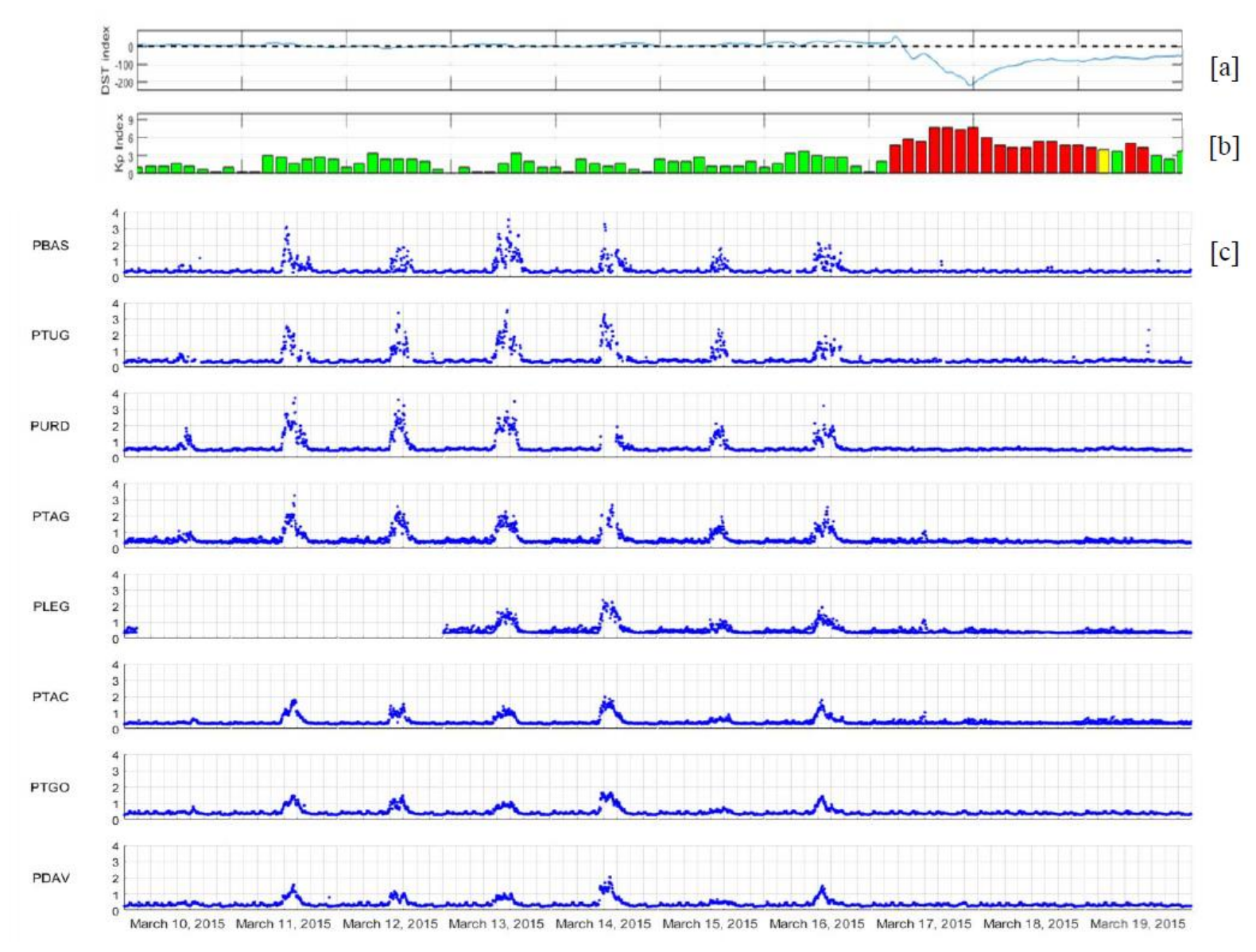
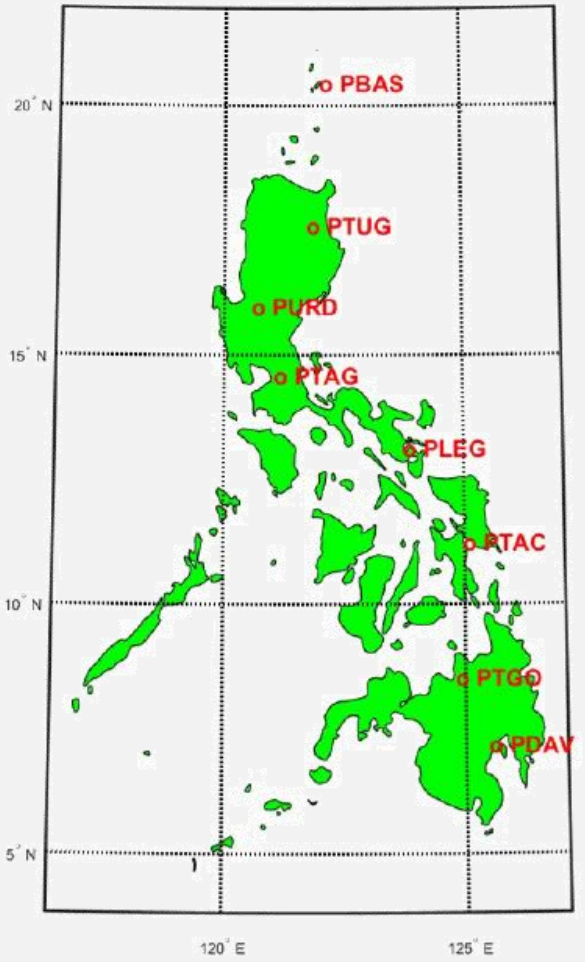


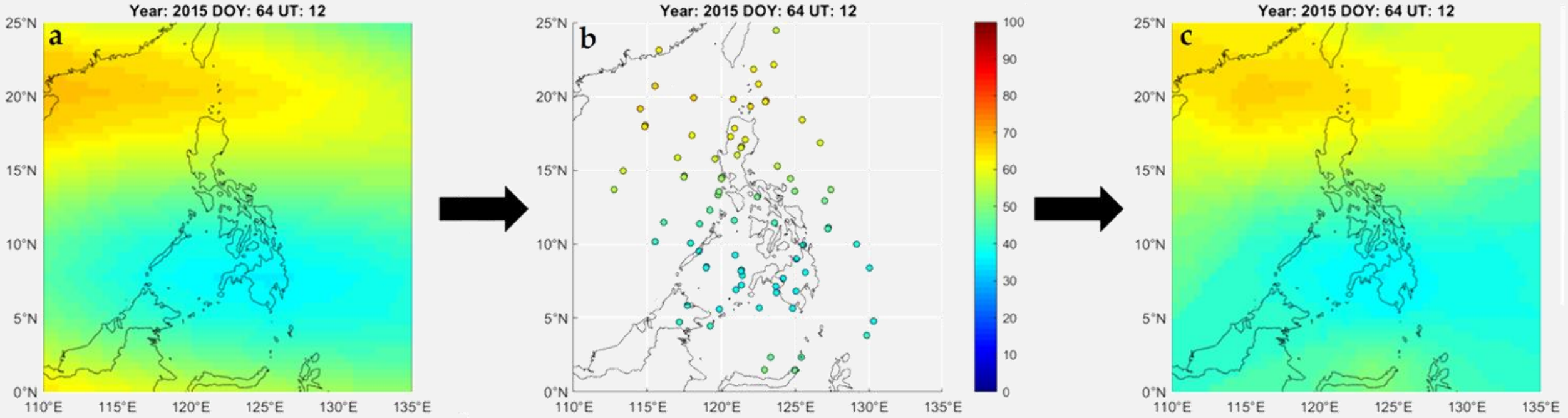


https://doi.org/10.1109/IconSpace.2019.8905976

Global Ionospheric Map (IGS)

Extract TEC from identified ionospheric pierce points (12 stations)

Reconstructed IGS Map using Kriging Interpolation



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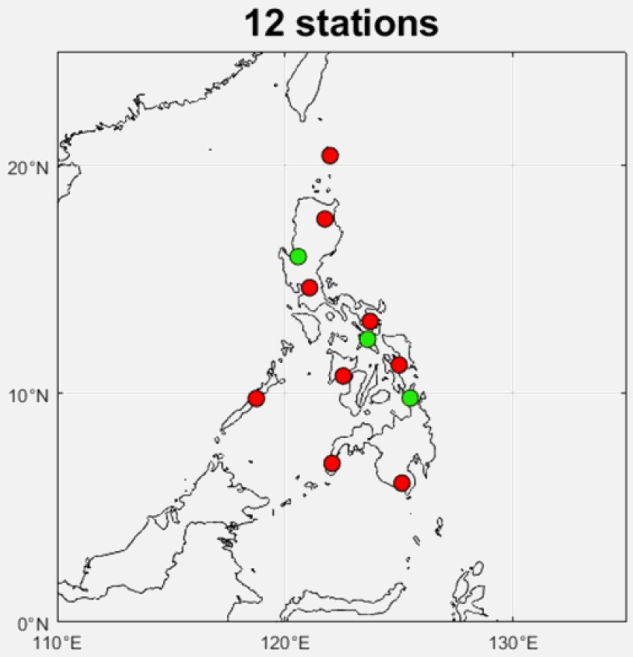

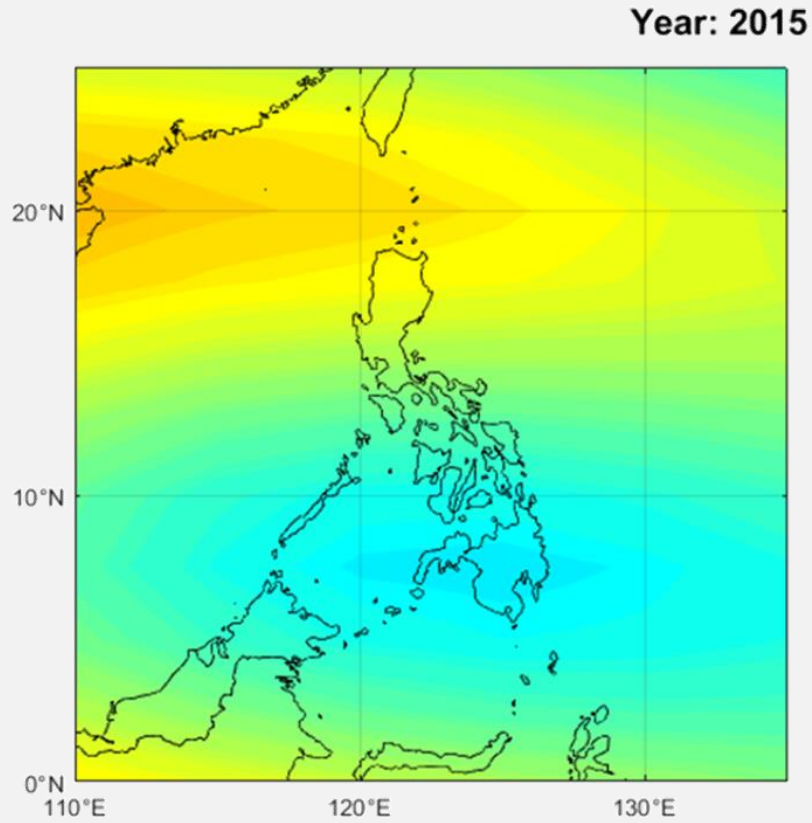

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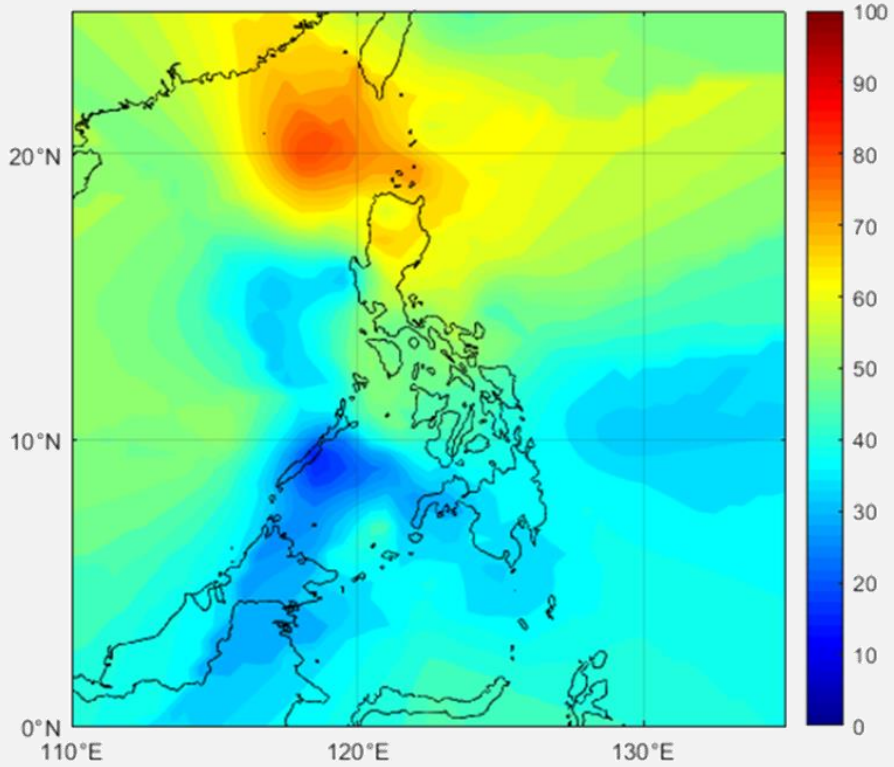
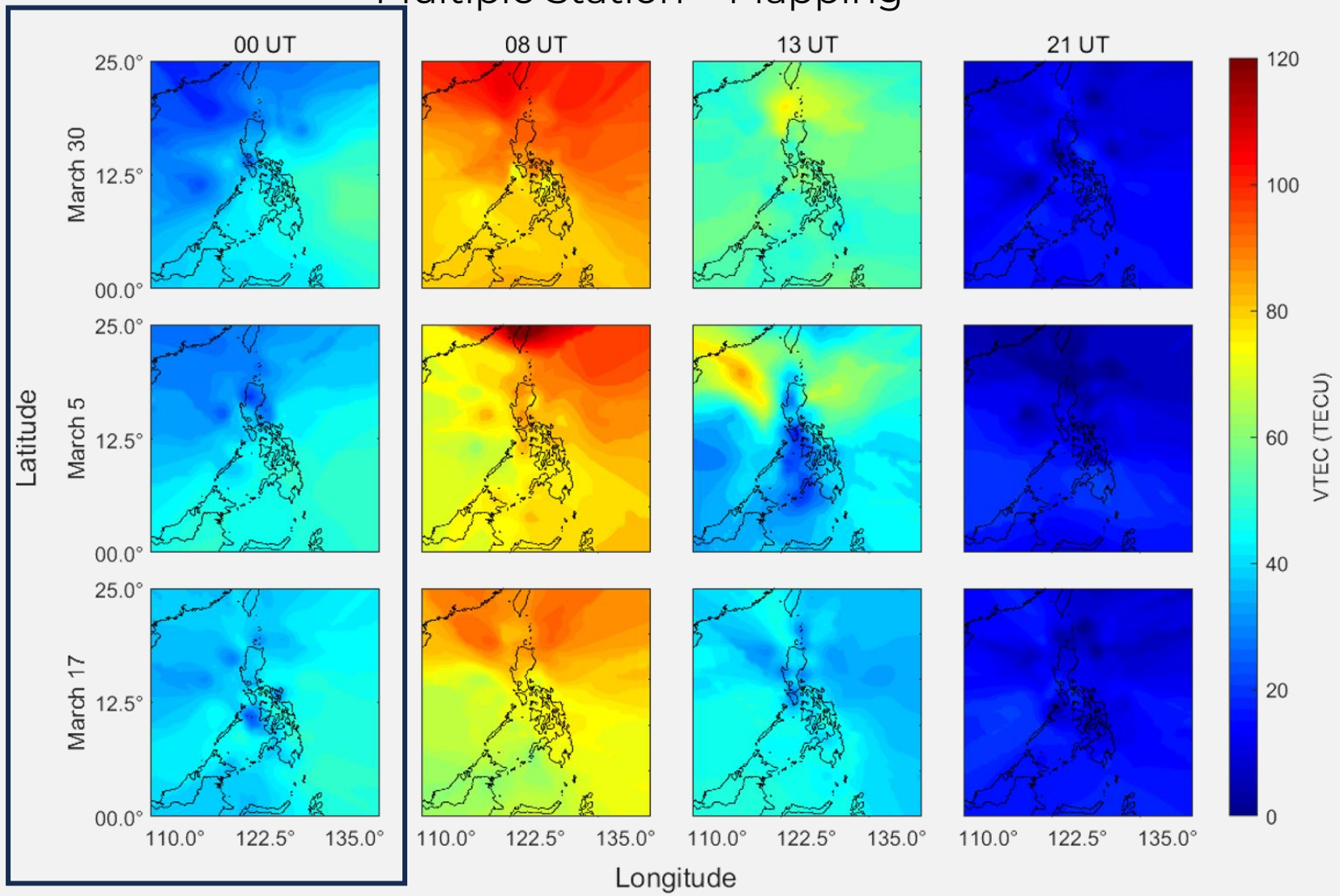
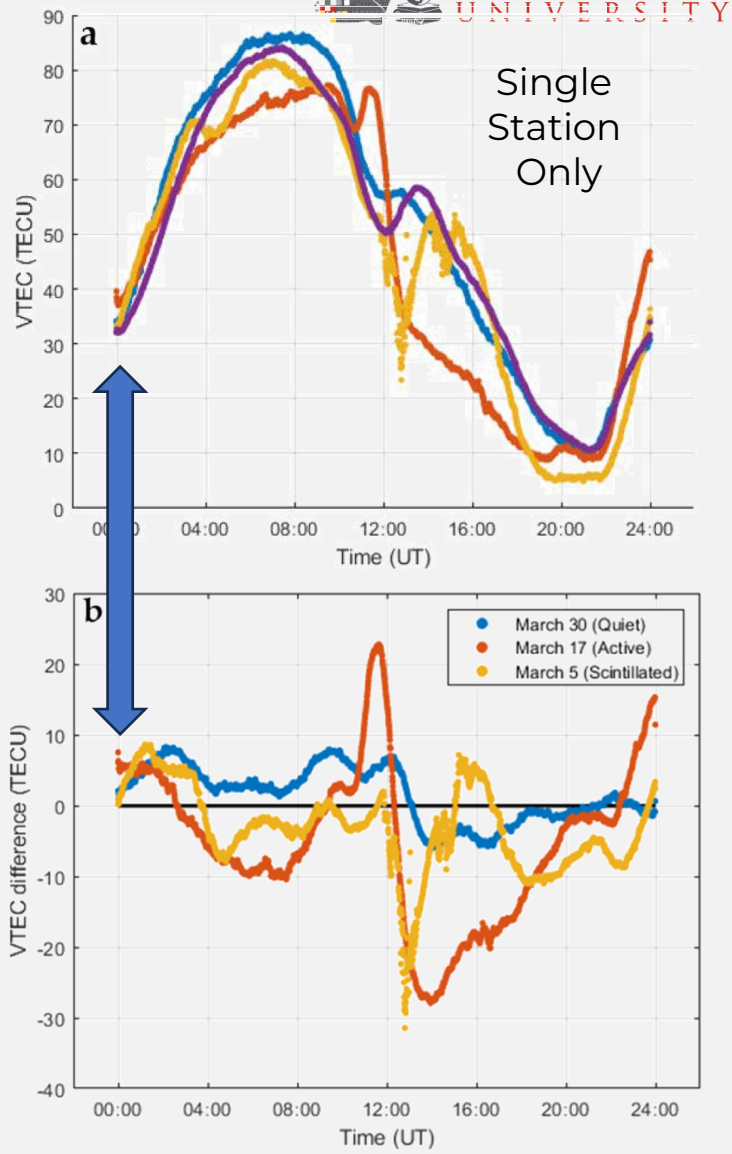


Reconstructed Ionospheric Map using actual TEC measurements

Multiple Station = Mapping





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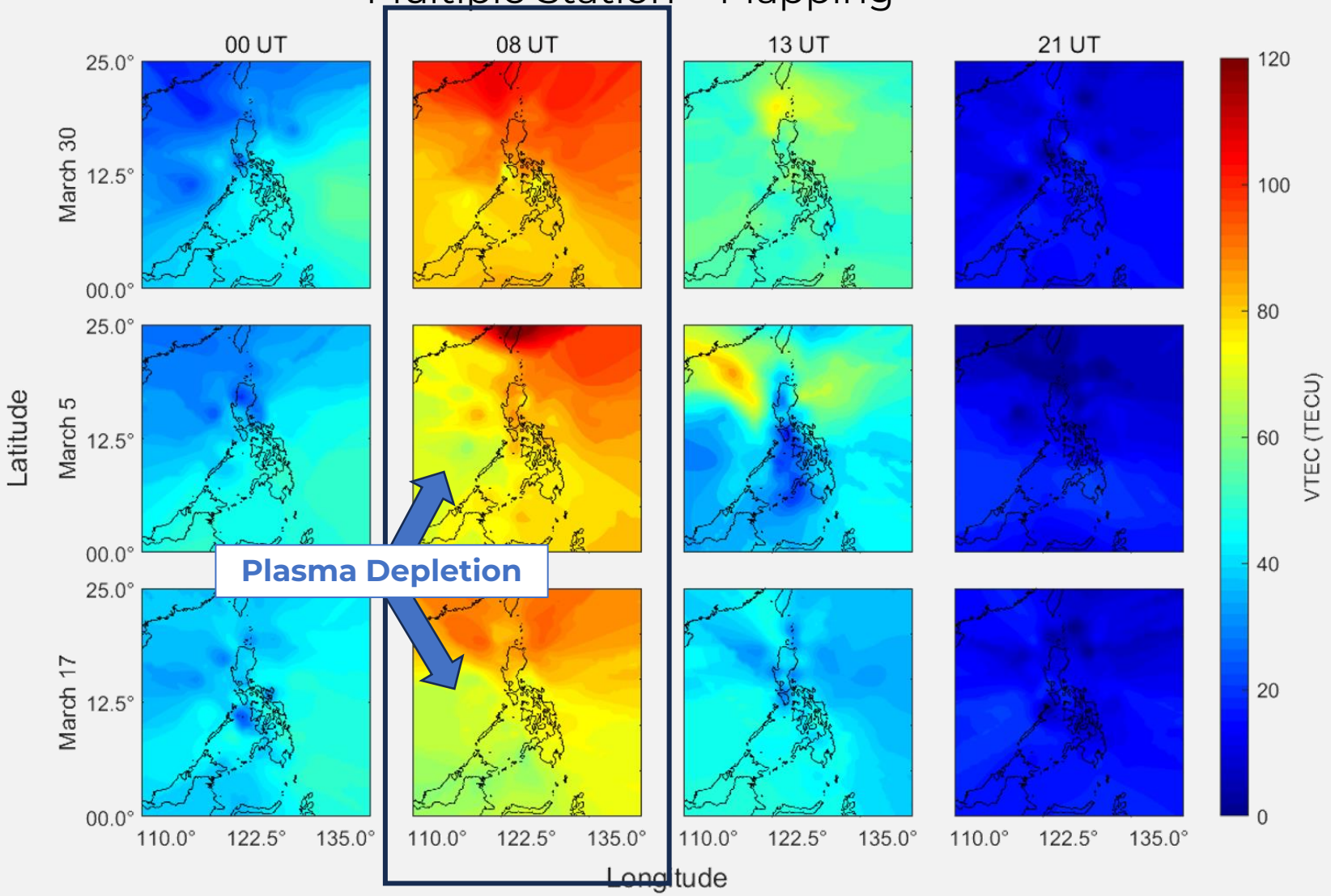

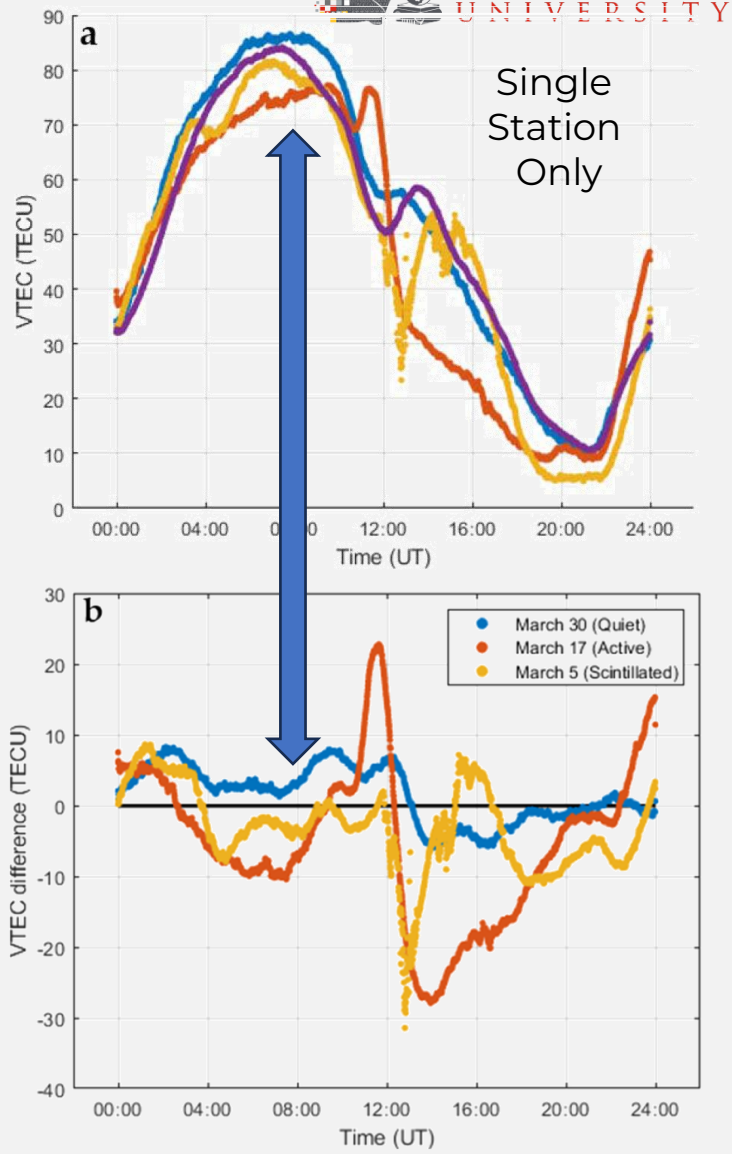

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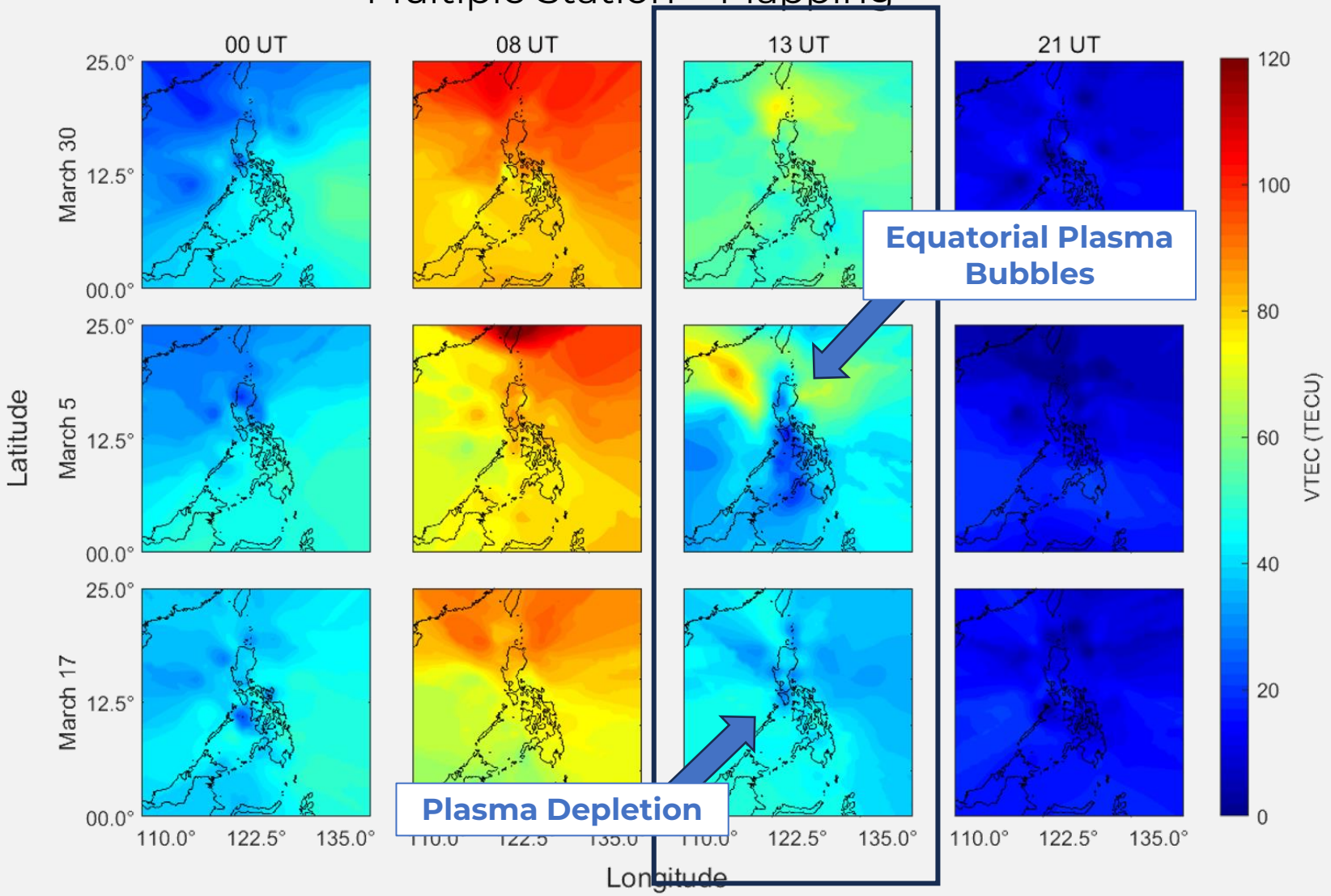

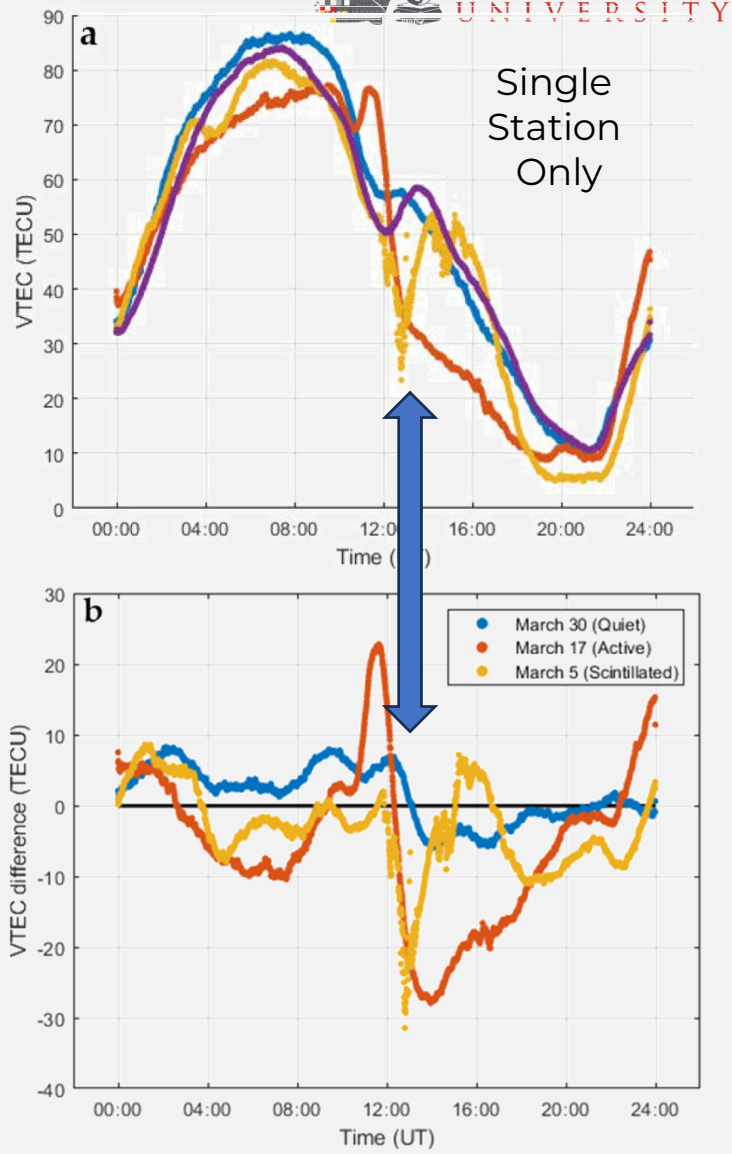

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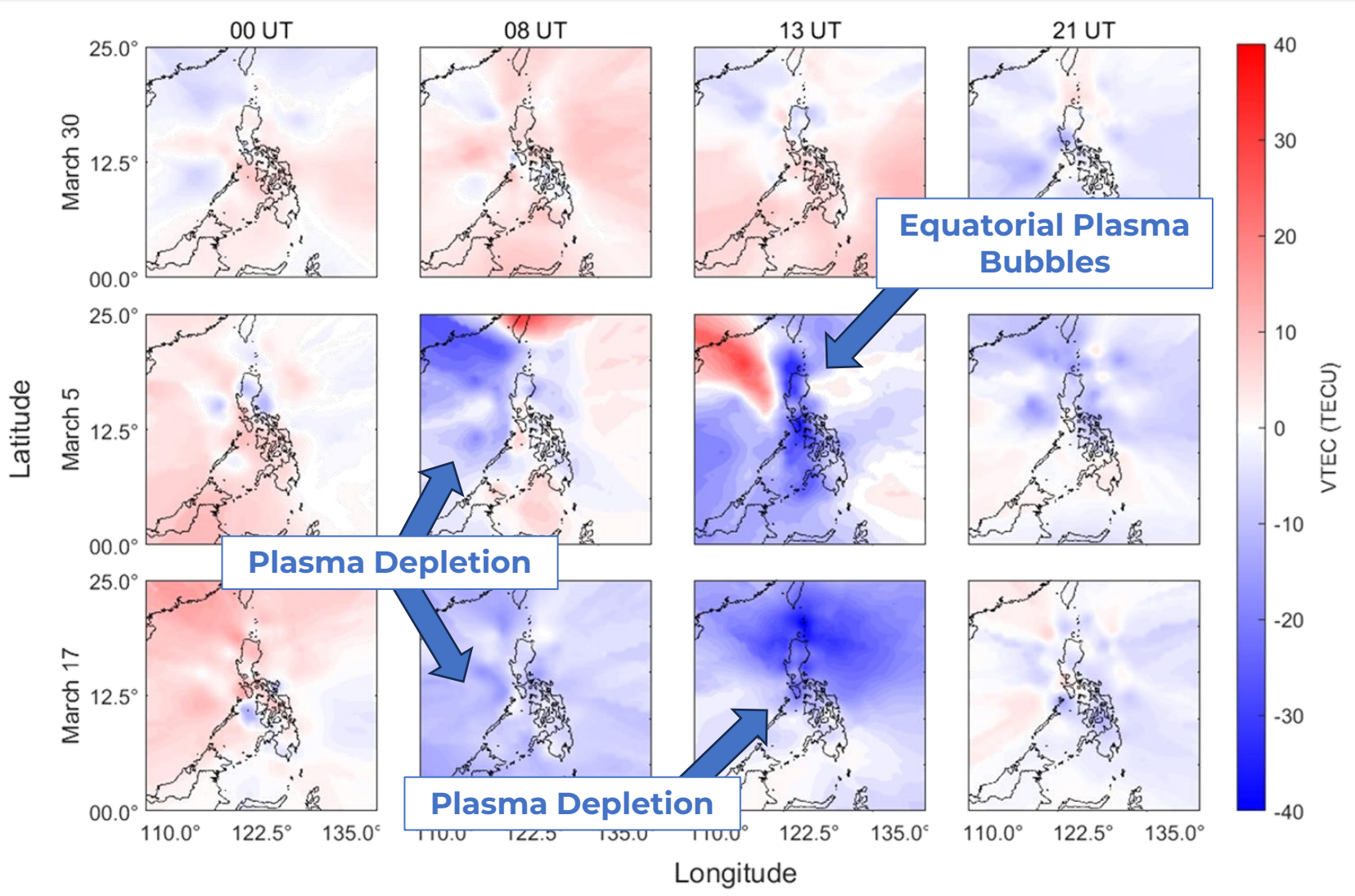

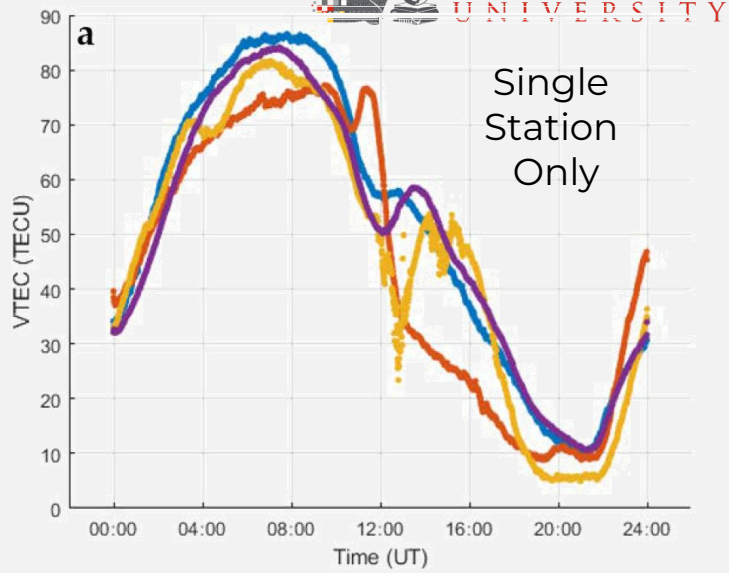

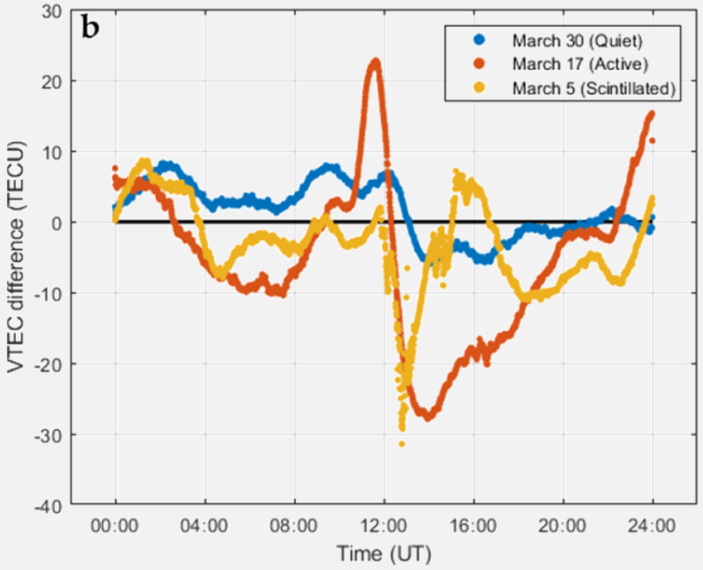

Summary

- St. Patrick Geomagnetic Storm is a G4 (severe) geomagnetic storm
  - March 17, 2015, | Onset ~ 14:00 UT (~10:00 Phil Standard Time) | Duration: ~ 18 hours
  - Cause: Coronal Mass Ejection ~2:00 UTC on March 15, 2015
- Impact over the Philippines
  - Ionospheric Density Depletion ~33 TECU @ PBAS = Observed across the Philippines.
  - The delay in TEC response in the Philippine-Taiwanese sector was caused by the local time and the arrival time of CME.
  - The depletion of TEC in the Philippine-Taiwanese region was caused by high amounts of neutral particle density in the equatorial region.
  - Plasma bubbles is observed before the storm = Typical occurrence during equinoctial months. = Ionospheric Scintillation
  - Scintillation is suppressed due to lack of background plasma in order for plasma bubbles to form → reduced pre-reversal enhancement electric field creating conditions unfavorable for ionospheric irregularities

Thank you for listening