Equatorial and low-latitude ionospheric TEC response to CIR-driven geomagnetic storms at different longitude sectors

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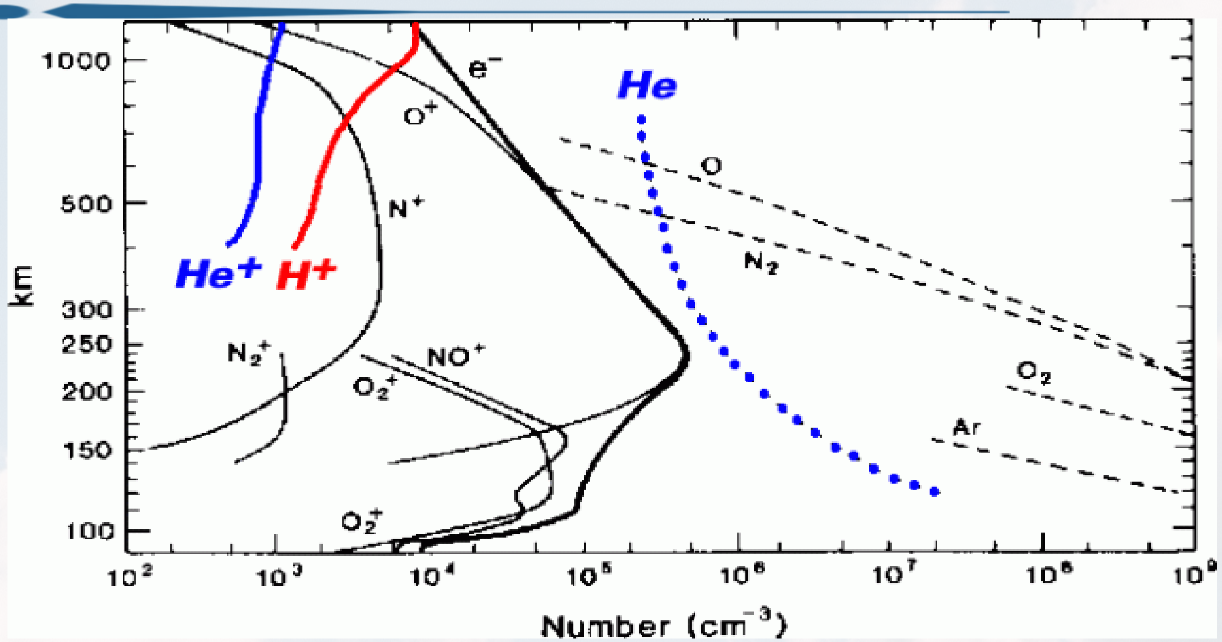
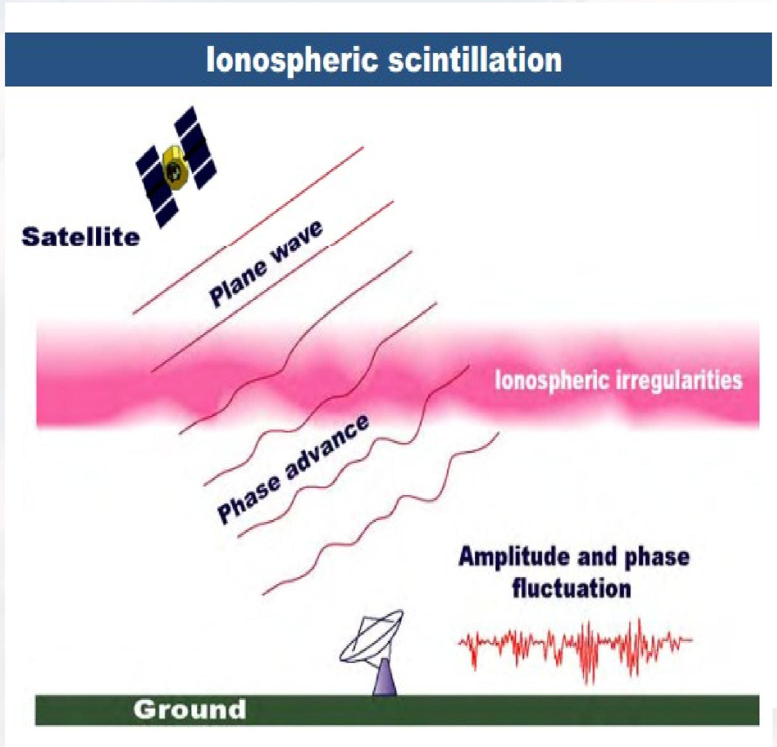
Outlines

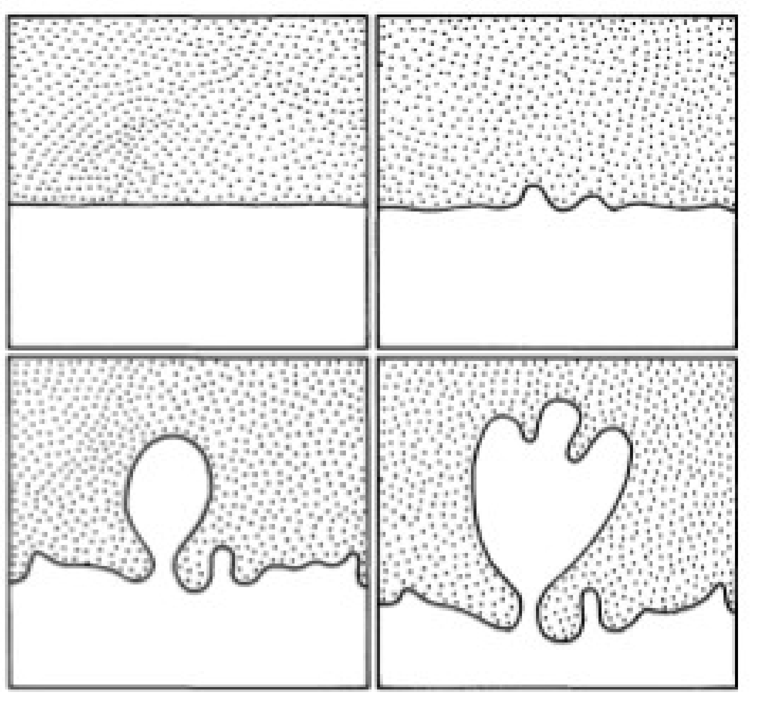
- Quick Overview
    - Ionosphere
    - Geomagnetic storms
- Motivation
- Data and Method of Analysis
- Results
    - Positive/negative ionospheric storm
    - Enhancement /inhibition of irregularities
- Summary

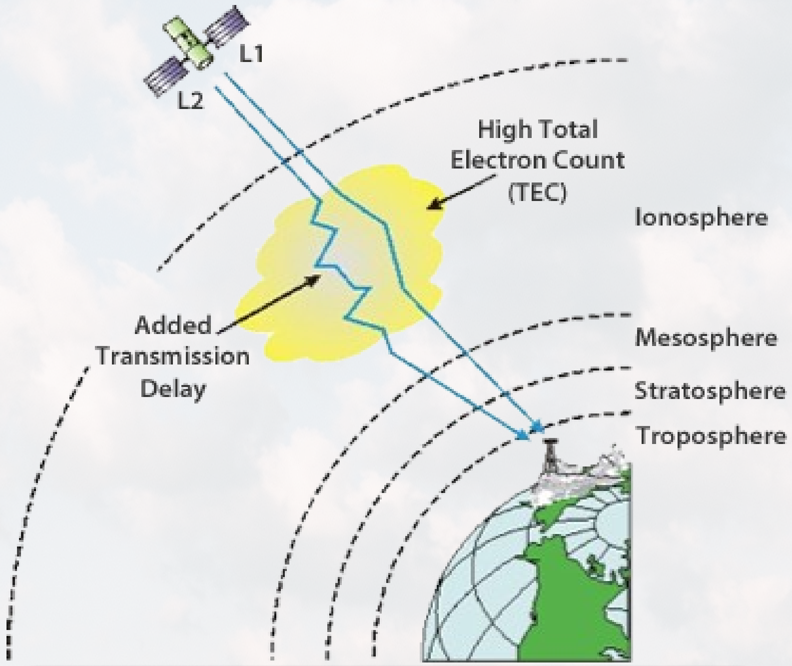
Overview

- Ionosphere is the ionized region of upper atmosphere.
- It is major source of positioning errors/scintillation.





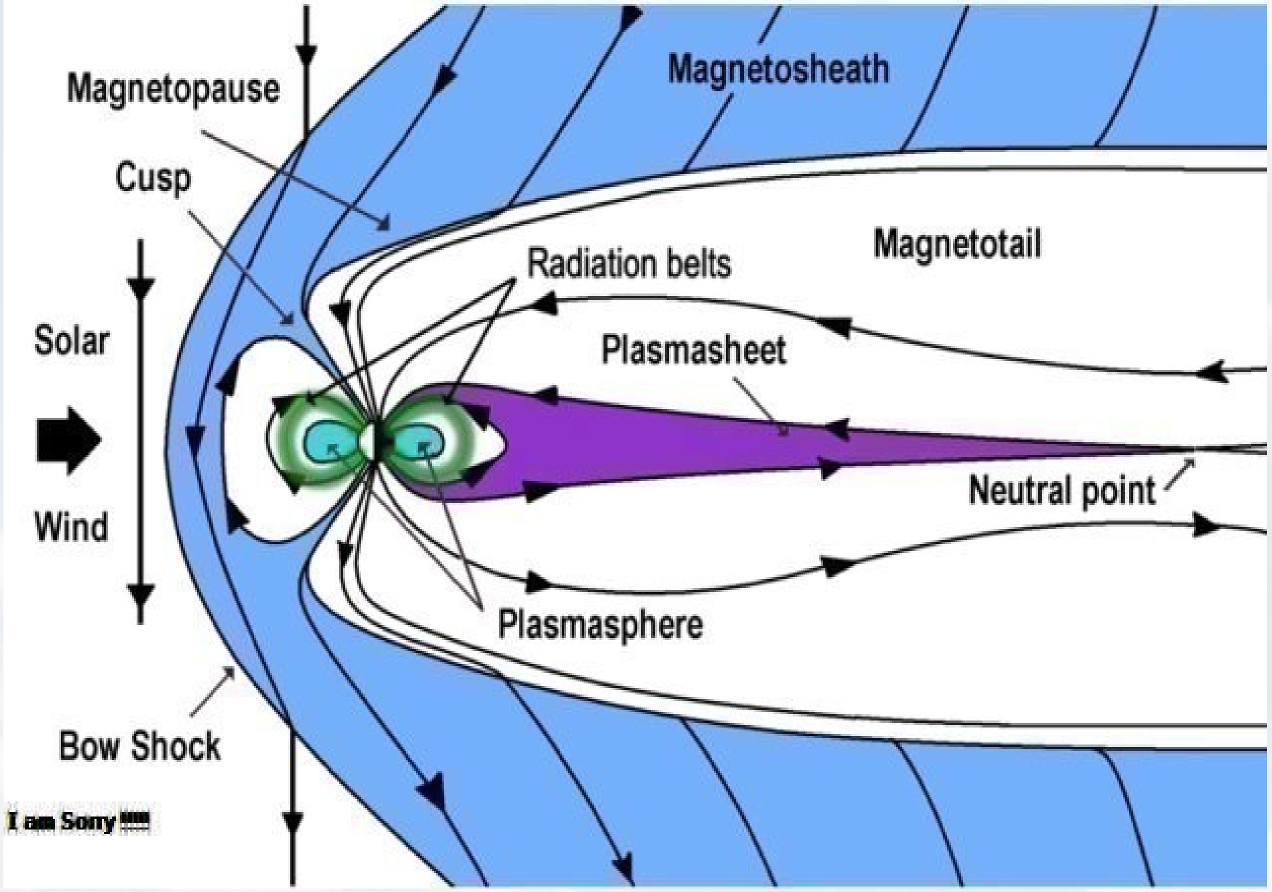




Effect of ionospheric refraction. The GPS signal are affected in different ways, depending on whether it is a question of codes or phases.

Geomagnetic storm drivers: CME and CIR

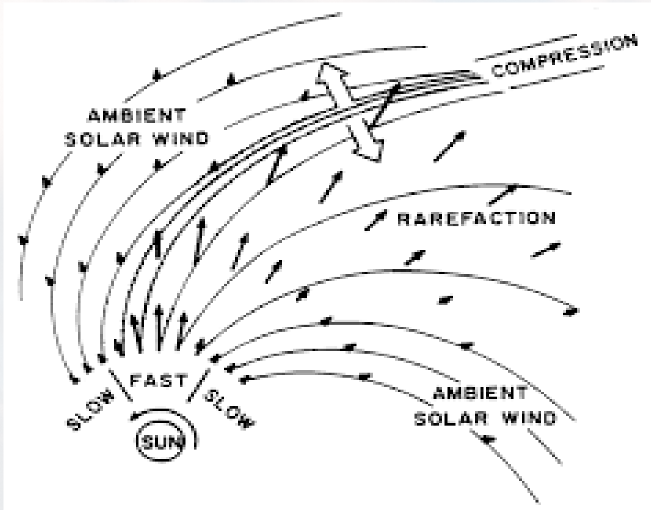
- The geomagnetic storms is a disturbance in Earth's B-field; developed when large quantities of disturbed solar wind plasma interact with Earth's B-field.
- Based on their driving sources, geomagnetic storms can be classified as due to
  - Coronal Mass Ejections (CMEs)
  - Corotating Interaction Regions (CIRs)

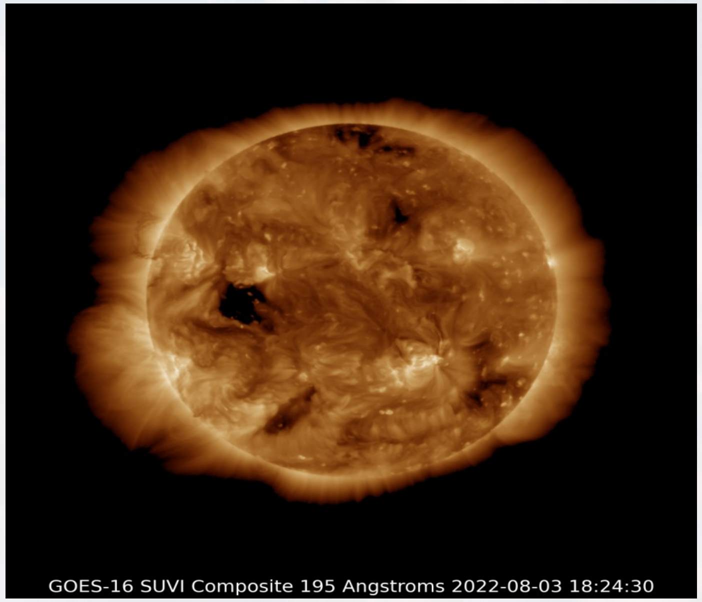


- Their geoeffectiveness depends primarily on a sustained southward orientation of the IMF Bz.

Geomagnetic storm drivers: CME and CIR

- The CME is a massive ejection of solar wind particles from the **active regions of Sun** (corona, sunspot groups, & often can be associated with solar flares).
- CMEs causes sporadic geomagnetic disturbances.
- The CIRs-driven storms are created when the high-speed wind streams from the CHs interact with the upstream slow speed streams.
- It causes a recurrent geomagnetic disturbances.

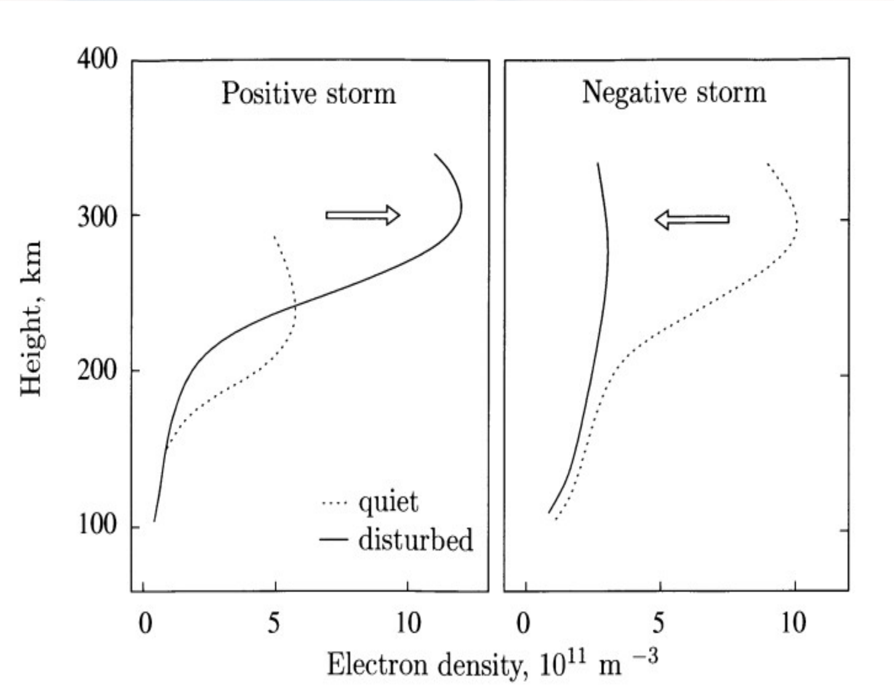




An image shared with Nexstar shows the coronal hole on the sun on Aug. 3, 2022. (Photo: GOES-16 via Space Weather Prediction Center, NOAA)

Ionospheric Storms

- Ionospheric storms: Perturbations in the ionosphere during geomagnetic storms; the ionospheric parameters significantly changes from its quiet time values.
- The major responses
  - Positive and
  - Negative ionospheric storm



- The response of the ionosphere to a specific geomagnetic storm depends on its
  - Onset time of the storm,
  - Season (equinox, solstice),
  - solar activity (high, low),
  - Drivers of the storm (CME, CIR)
  - Geographic/Geomagnetic location

Motivation

- Numerous studies have been done on the response of ionosphere to intense geomagnetic storms (especially during CME- events) over longitude sectors.
- Even though the CIR-induced storms are weak-to-moderate, studies indicate that they can also affect the ionosphere/atmosphere significantly.
- The CIR-driven storms were paid less attention in terms of its effect on occurrence of ionospheric irregularities.
- To study the ionospheric response to CIR-driven storms (during **19-24 January 2016** and **05-10 March 2016**) in the equatorial and low-latitude regions of American, African, Asian, and Pacific longitude sectors using **GPS-TEC data**, **in-situ electron density from Swarm-A** satellite data.

Data Sources and Method of analysis

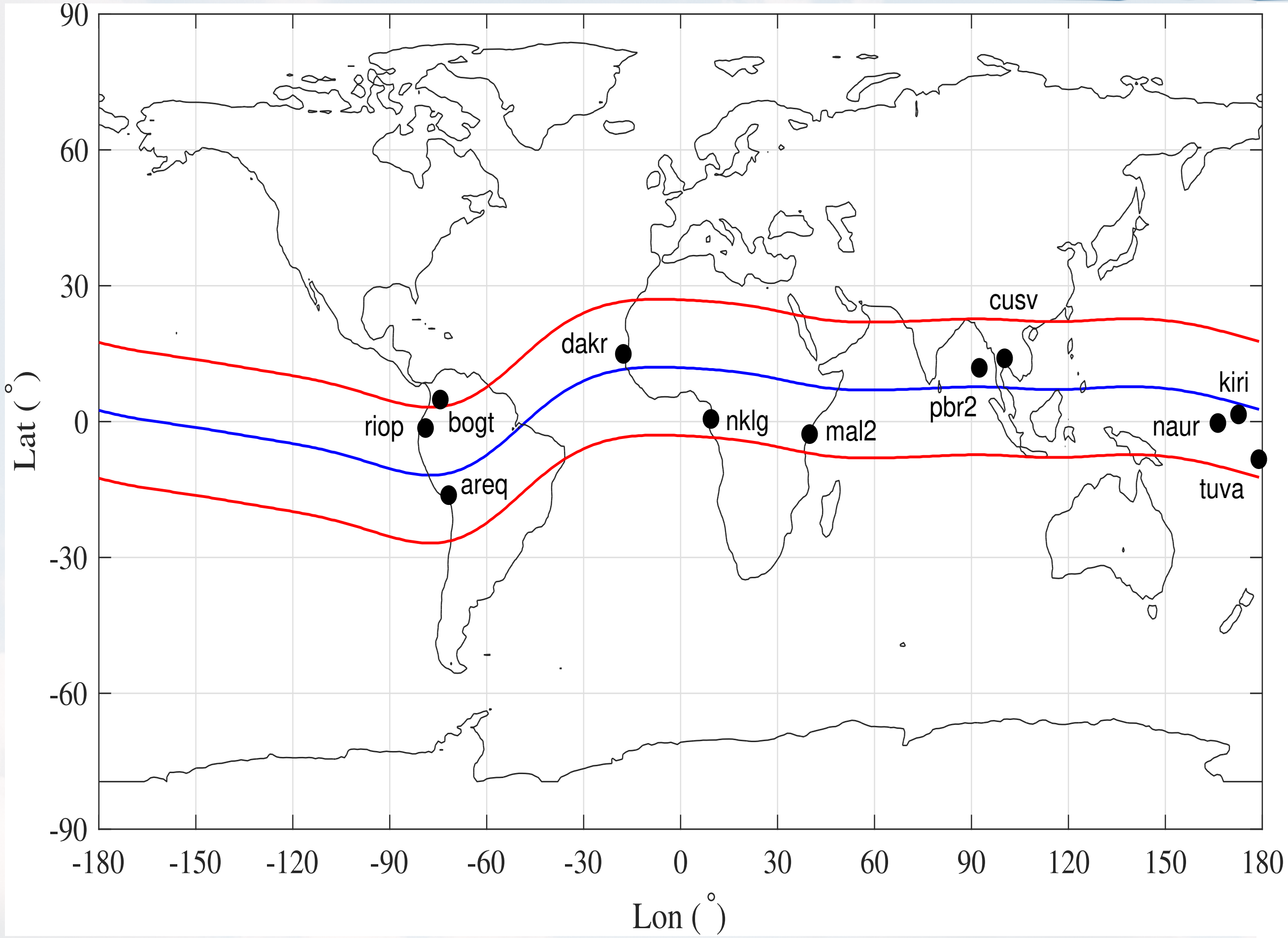


Fig. Map showing the locations of the GPS stations.

- Storm-time TEC response:

$$\Delta TEC = \frac{TEC_{obs} - TEC_{med}}{TEC_{med}} \times 100\%$$

- Ionospheric irregularity proxies:

$$ROT = \frac{\Delta TEC}{\Delta t}$$

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

- Relative plasma density perturbation (SWARM observation):

$$\delta N_e = N_e - \overline{N_e}, \Delta N_e = \sigma(\delta N_e)$$

$$r\Delta N_e = \frac{\Delta N_e}{N_e}$$

https://omniweb.gsfc.nasa.gov/
http://www.geodin.ro/varsiti/
http://www.unavco.org/data/gps-gnss/data/
http://wdc.kugi.kyoto-u.ac.jp/dstae/index.html
http://earth.esa.int/swarm

Δ TEC >= 45%, +ve
Δ TEC <= -45%, -ve

ROTI >= 0.5 TECU/min

Ionospheric Response to **19-24 January 2016**

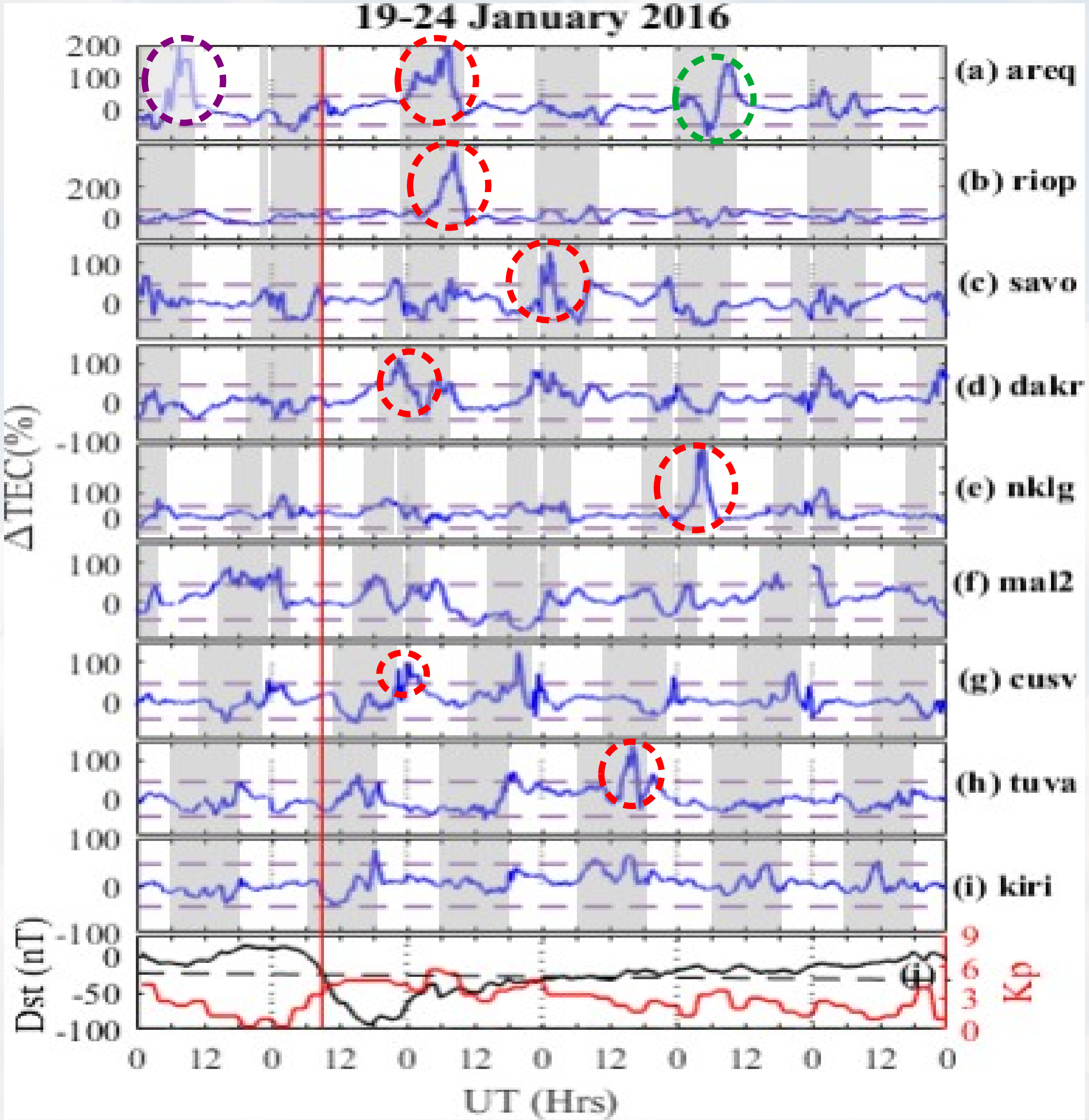


Fig. Diurnal variations of ΔTEC over (a-c) American, (d-f) African, (g) Asian, and (h-i-) Pacific longitude sectors in response to 19-24 January 2016, (j) shows the diurnal variation of geomagnetic indices during the storm event. The gray areas indicate local nighttime periods (18:00-06:00 LT). The vertical red solid line shows the SSC of the storm.

- Initial phase
  - Positive storm (areq)
- Main phase:
  - No significant effect
- Recovery phases:
  - Positive storm (America, Africa, Pacific)
  - Negative-Positive (America)

Ionospheric Response to 5-10 March 2016

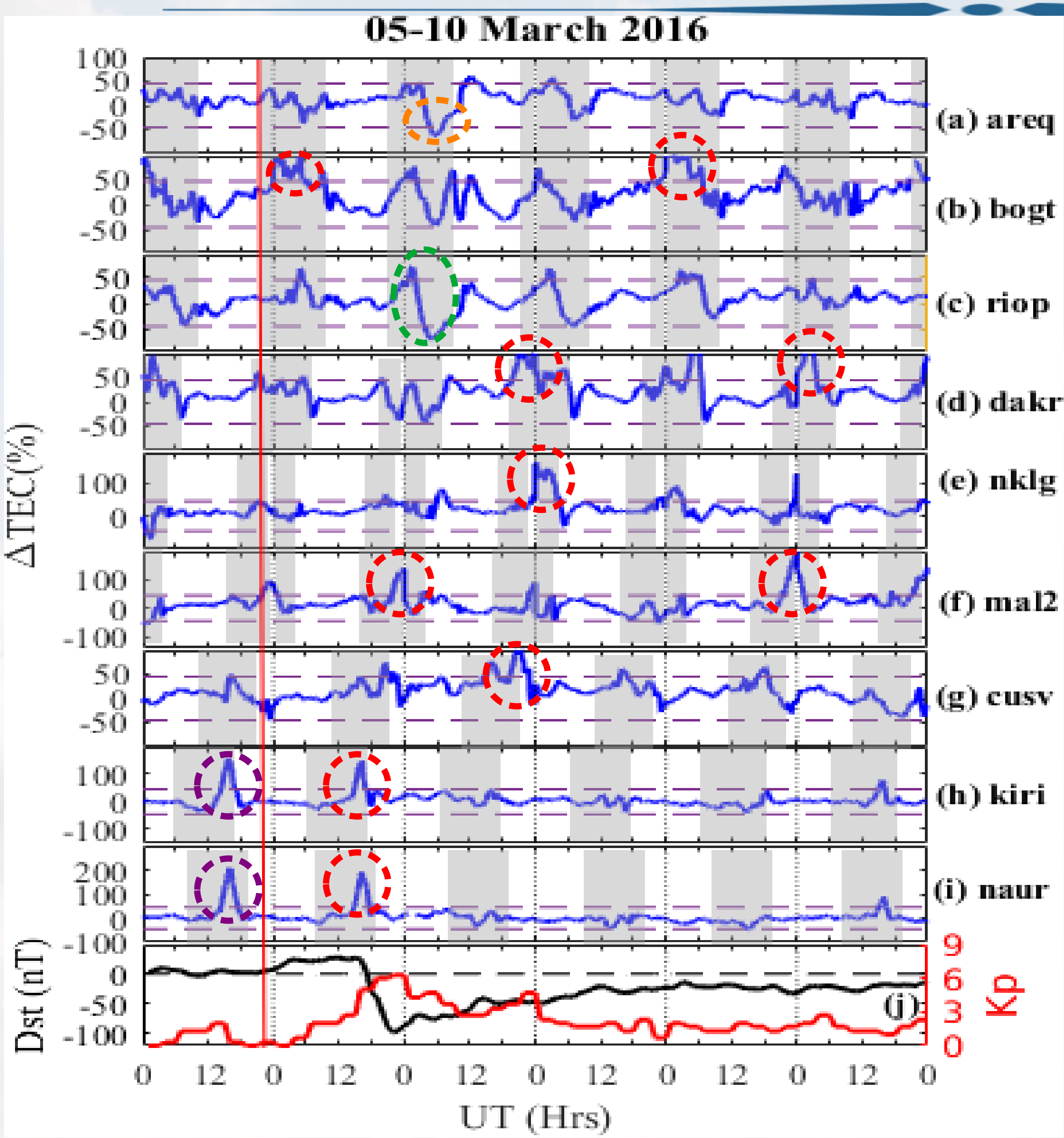


Fig. Diurnal variations of ΔTEC over (a-c) American, (d-f) African, (g) Asian, and (h-i) Pacific longitude sectors in response to 05-10 March 2016 storm events, (j) shows the diurnal variation of geomagnetic indices during the storm event. The gray areas indicate local nighttime periods (18:00-06:00 LT). The vertical red solid line shows the SSC of the storm.

- Initial phase:
  - Positive storm (Pacific, America)
- Main phase:
  - Positive (Africa)
- Recovery phase
  - Positive (Africa, Asia)
  - Positive-Negative (America)
  - Negative (America, areq)

Ionospheric Irregularities During 19-24 January 2016: GPS-ROTI

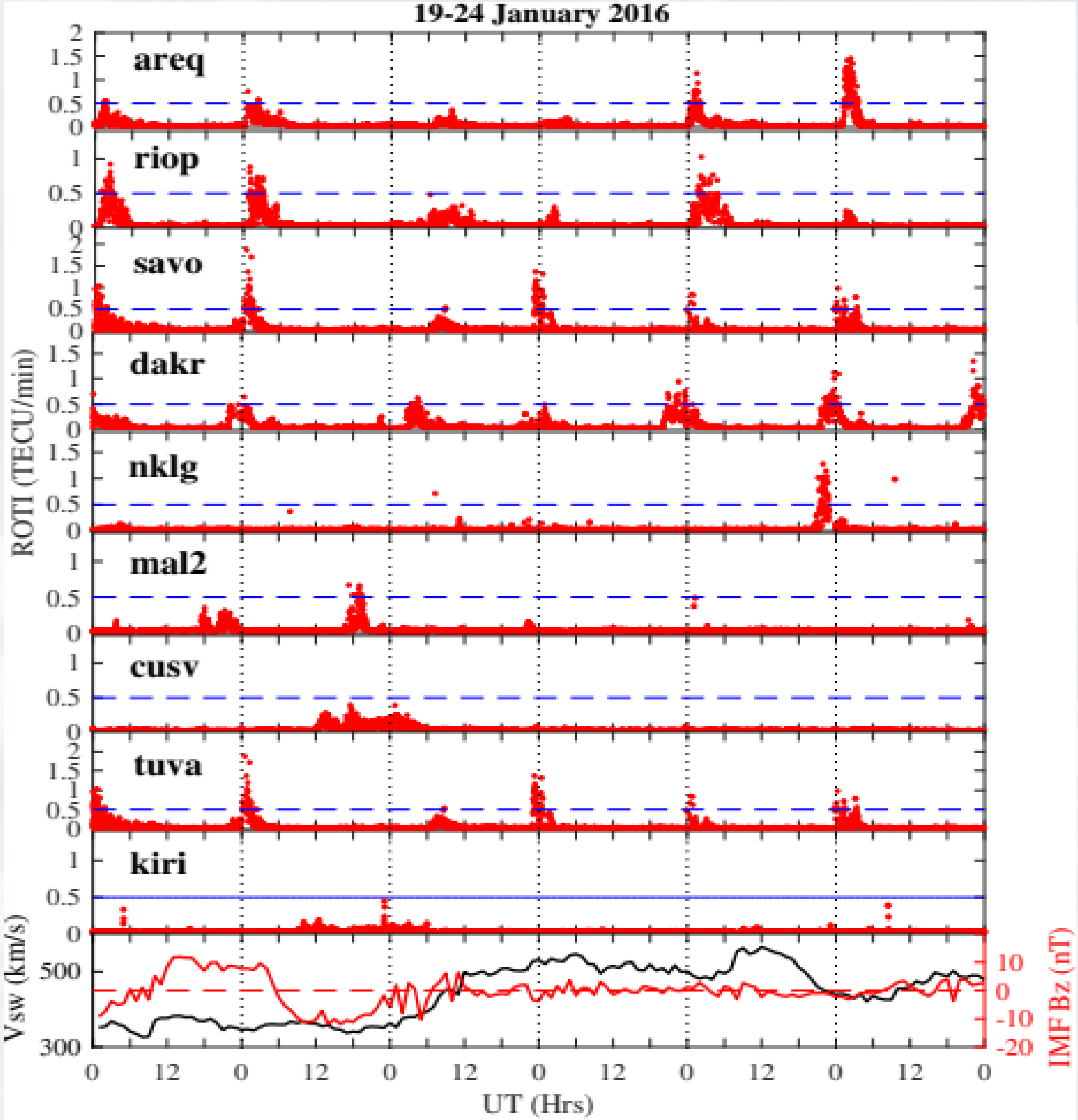


Fig. Variation in ROTI over American (areq, riop, savo), African (dakr, nklg, mal2), Asian (cusv), and Pacific (tuva, kiri) longitude sectors during 19-24 January 2016 storm events. The horizontal blue broken lines show the threshold of ROTI = 0.5 TECU/min.

Ionospheric Irregularities During 05-10 March 2016: GPS-ROTI

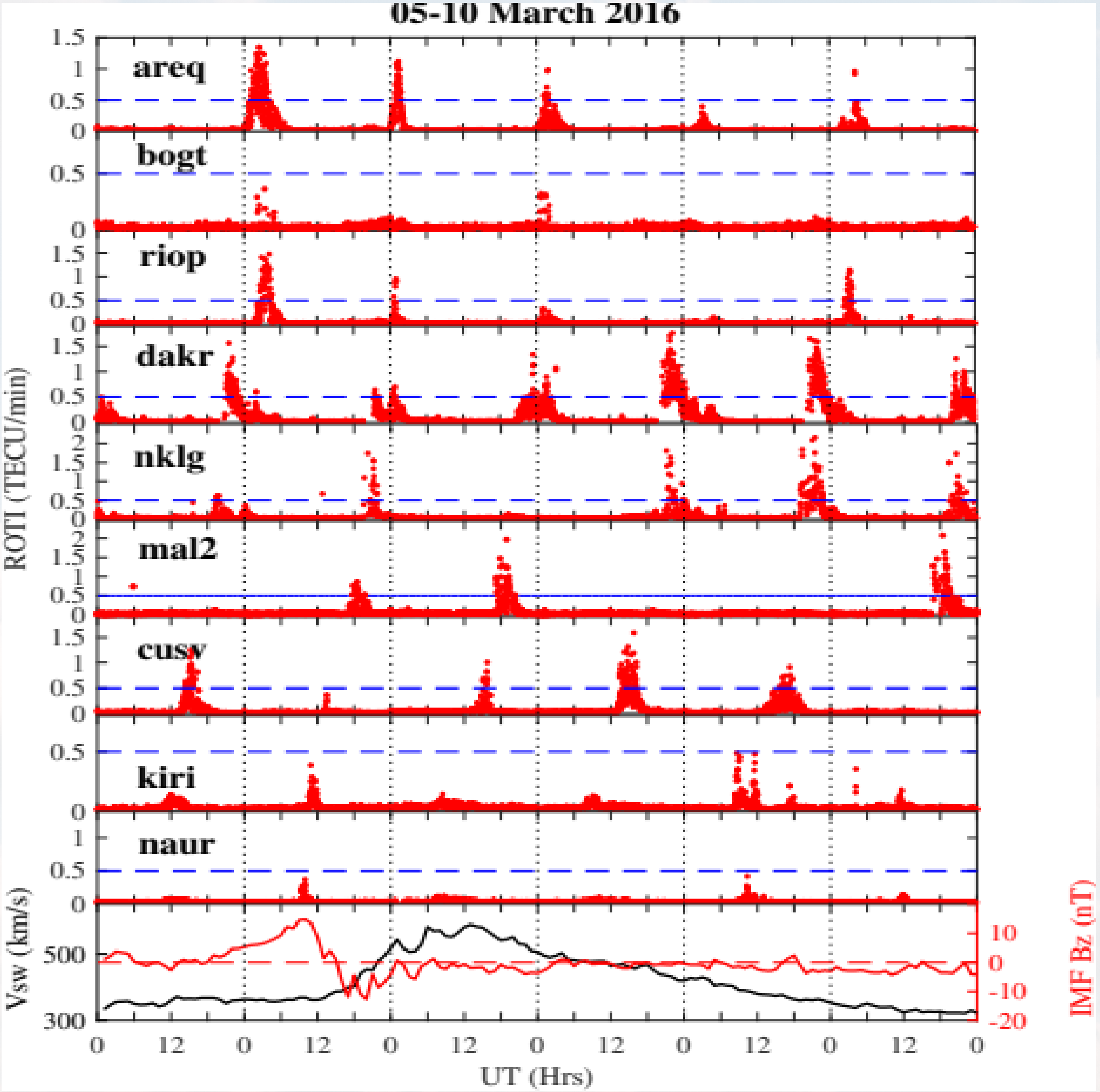


Fig. Variation in ROTI over American (areq, bogt, riop), African (dakr, nklg, mal2), Asian (cusv), and Pacific (kiri, naur) longitude sectors during 05-10 March 2016 storm events. The horizontal blue broken lines show the threshold of ROTI = 0.5 TECU/min.

Ionospheric Irregularities During 19-22 January 2016: SWARM A-Ne

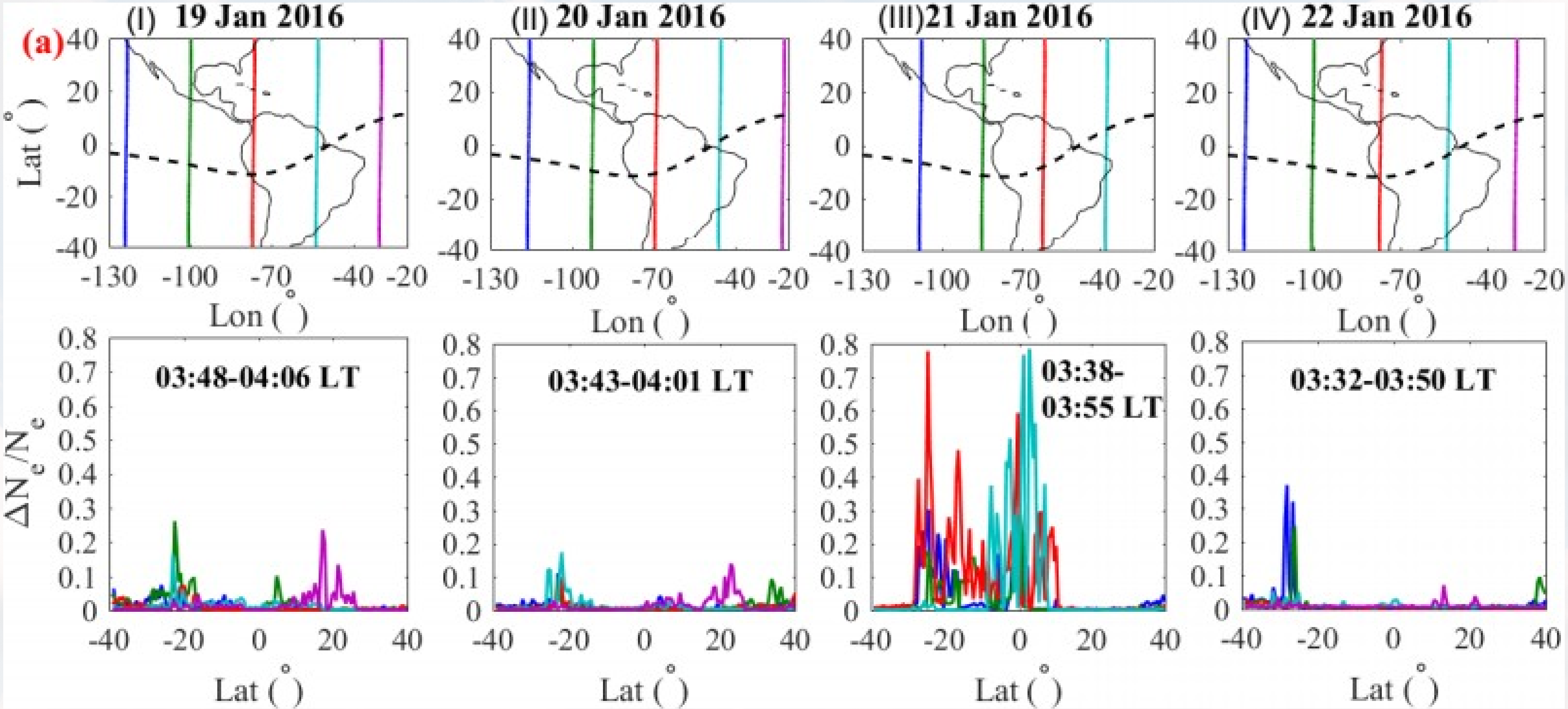


Fig: Depletion in electron density observed through in situ-satellite observation, Swarm-A satellite, during 19-22 January 2016 on (I, II, III) over equatorial and low-latitude region of (a) America within latitude range of ±40°. Relative ionospheric plasma density perturbation, ΔNe/Ne over different longitudes are indicated by different colors over different Ne sectors.

Ionospheric Irregularities During 19-22 January 2016: SWARM A-Ne

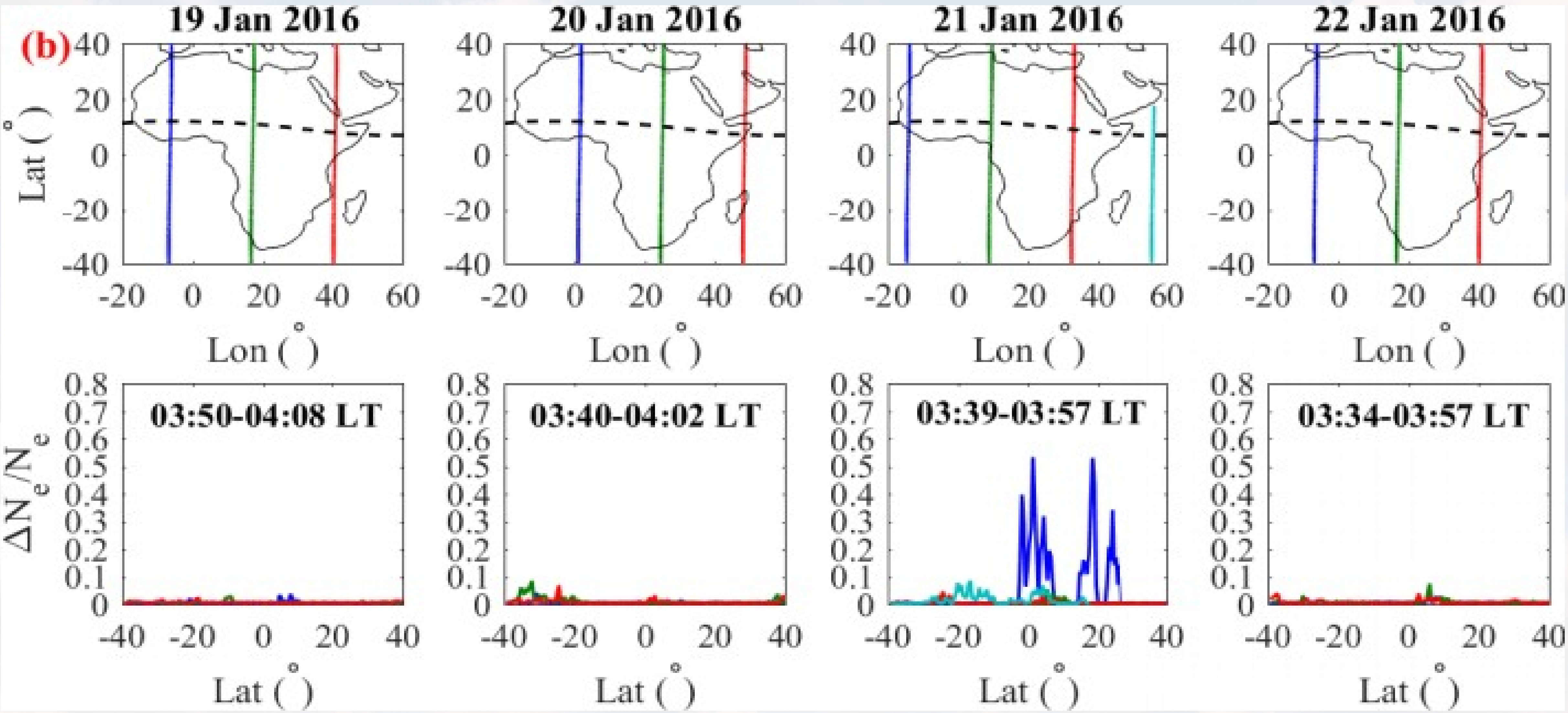


Fig: Depletion in electron density observed through in situ-satellite observation, Swarm-A satellite, during 19-22 January 2016 on (I, II, III) over equatorial and low-latitude region of (b) Africa within latitude range of ±40°. Relative ionospheric plasma density perturbation, ΔNe/Ne over different longitudes are indicated by different colors over different Ne sectors.

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Ionospheric Irregularities During 19-22 January 2016: SWARM A-Ne

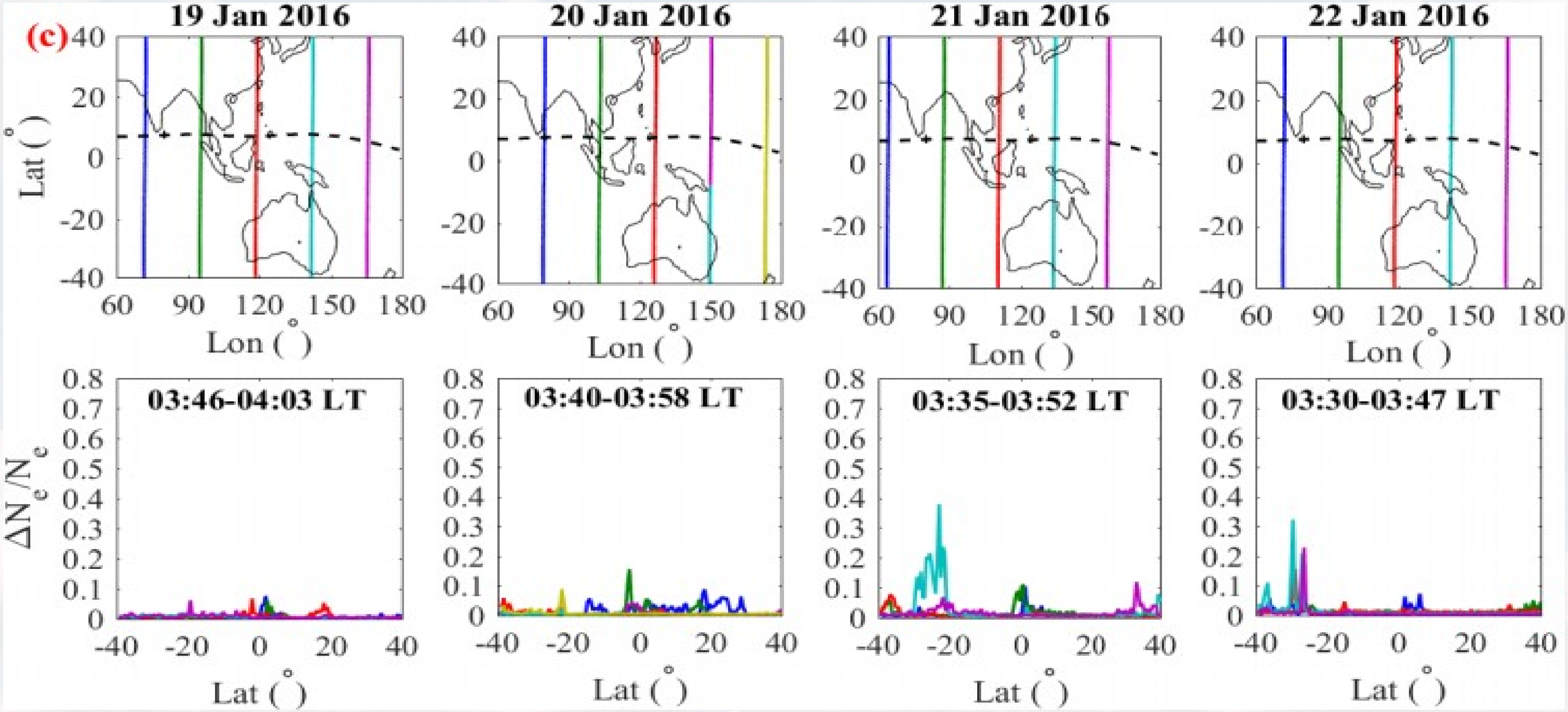

Fig: Depletion in electron density observed through in situ-satellite observation, Swarm-A satellite, during 19-22 January 2016 on (I, II, III) over equatorial and low-latitude region of (c) Asia within latitude range of ±40°. Relative ionospheric plasma density perturbation, ΔNe/Ne over different longitudes are indicated by different colors over different Ne sectors.

Ionospheric Irregularities During 5-8 March 2016: SWARM A-Ne

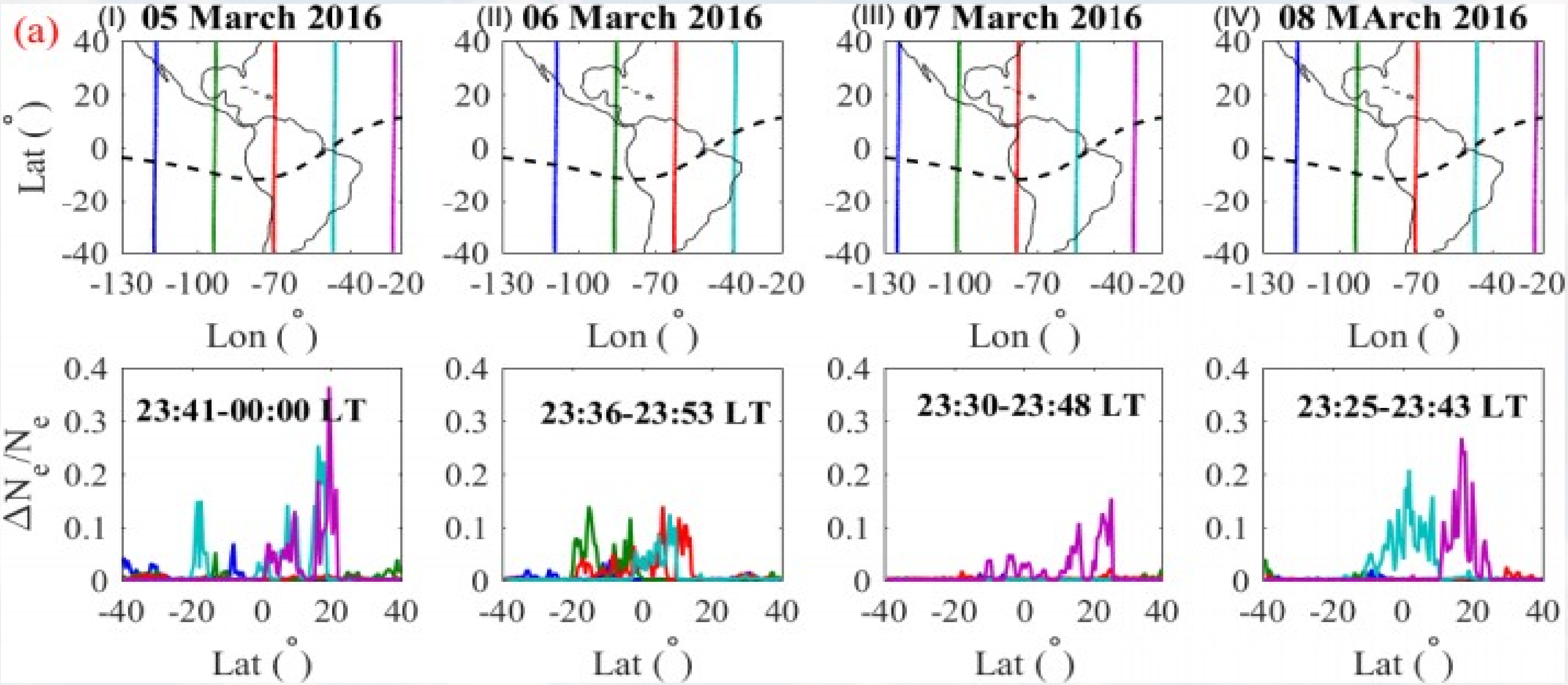

Fig: Depletion in electron density observed through in situ-satellite observation, Swarm-A satellite, during 05-08 March 2016 on (I, II, III) over equatorial and low-latitude region of (a) America within latitude range of ±40°. Relative ionospheric plasma density perturbation, ΔNe/Ne over different longitudes are indicated by different colors over different Ne sectors.

Ionospheric Irregularities During 5-8 March 2016: SWARM A-Ne

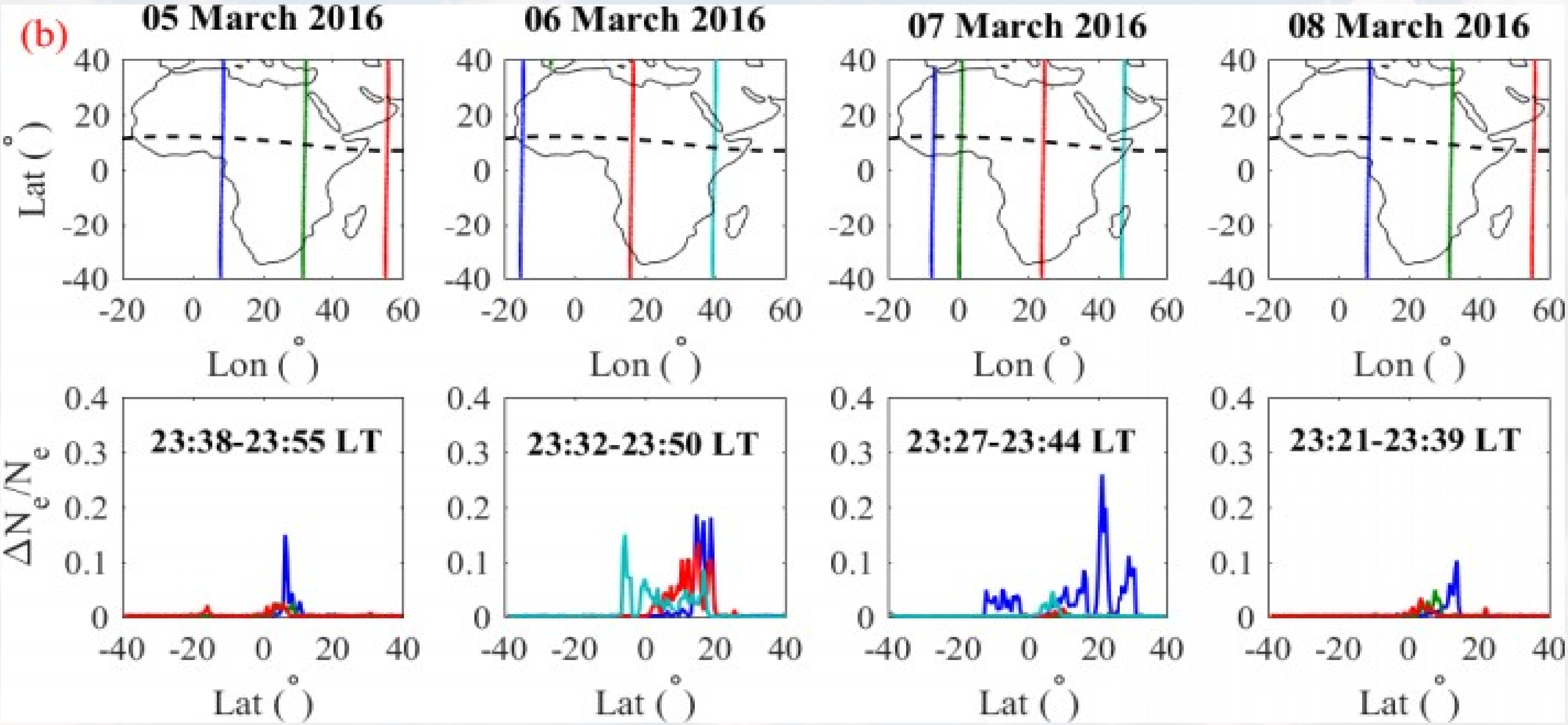

Fig: Depletion in electron density observed through in situ-satellite observation, Swarm-A satellite, during 05-08 March 2016 on (I, II, III) over equatorial and low-latitude region of (b) Africa within latitude range of ±40°. Relative ionospheric plasma density perturbation, ΔNe/Ne over different longitudes are indicated by different colors over different Ne sectors.

Ionospheric Irregularities During 5-8 March 2016: SWARM A-Ne

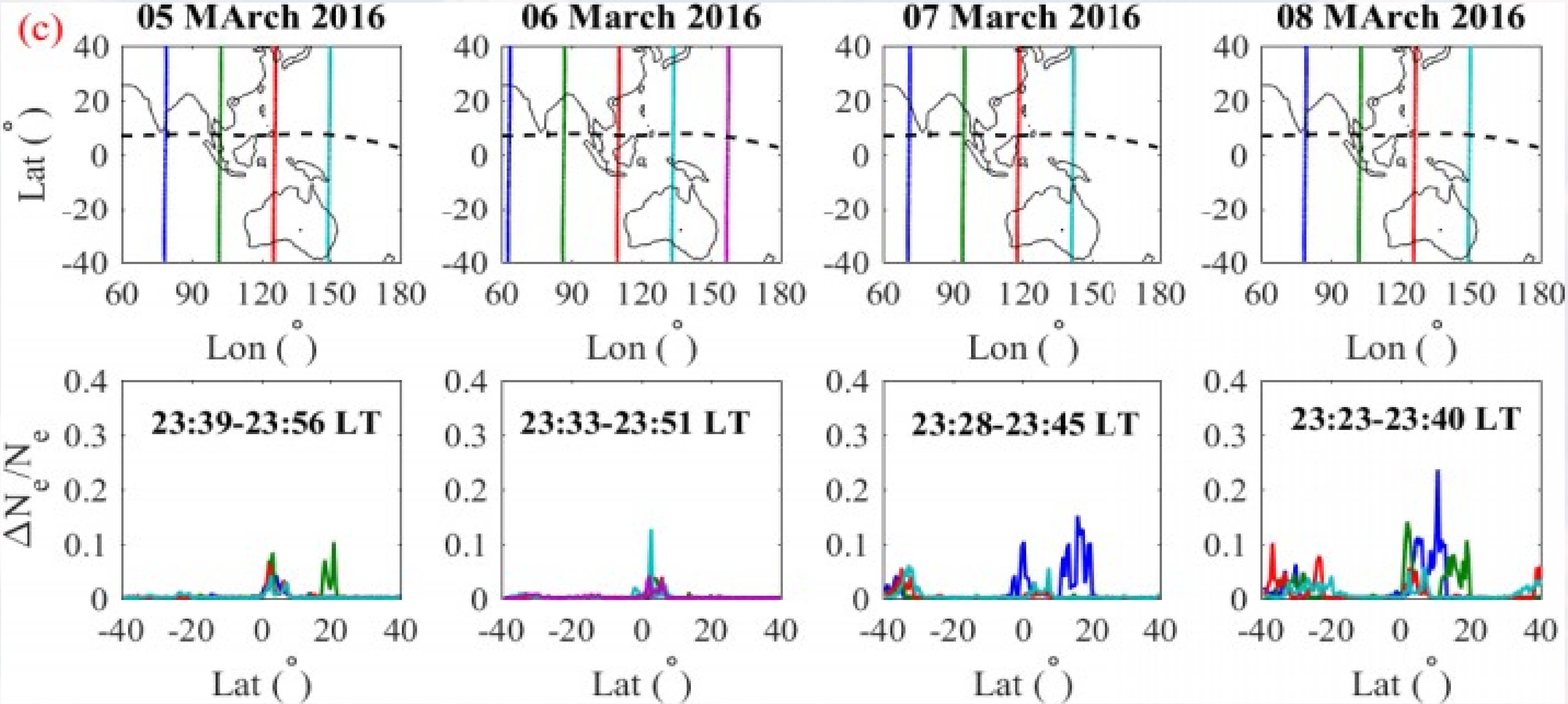

Fig: Depletion in electron density observed through in situ-satellite observation, Swarm-A satellite, during 05-08 March 2016 on (I, II, III) over equatorial and low-latitude region of (c) Asia within latitude range of ±40°. Relative ionospheric plasma density perturbation, ΔNe/Ne over different longitudes are indicated by different colors over different Ne sectors.

Summary

- Significant nighttime positive storm reaching about 115% (**dakr**), and 191% (**naur**) are observed during the storm main phase on 20 January 2016, and 06 March 2016, respectively, possibly associated with penetration of electric field and/or change in atmospheric composition.
- A comparison of the ionospheric responses between the American, African, Asian, and Pacific sectors shows that ionospheric response in the American and African sectors were stronger than that in the other two regions.
- Plasma density irregularities during the main phase of CIR-driven storms are observed mostly in the African and American sectors and are suppressed in the Asia and Pacific longitude sectors.
- The postsunset plasma density irregularities observed over different sectors using the in-situ measurement from Swarm satellite was consistent with ROTI (from GPS-TEC).

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