

Quiet-Time Equatorial Plasma Fountain Observed by ICON

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Abstract

This study's main aim is to increase our understanding of how ICON could observe the signatures of forward fountain and reverse fountain at lower sunspot numbers within ICON's observational capability and operational limitation. Multi-instrument and multi-point observations demonstrate the Equatorial Ionization Anomaly (EIA) and the EIA's breaking down, and the signatures of underlying forward fountain and reverse fountain seen in the radial and meridional ICON drift measurements. Driver mechanisms investigated include the 1) equatorial electrodynamic field-perpendicular ($\perp$) upward/downward ($E \times B$) $_{\perp}$ drift driving fountain-related vertical plasma flows over the dip equator where the angle of inclination (I) is zero and 2) mechanical total field-aligned ($\parallel$) upward/downward ($V_{\text{mecha}} \sin I$) $_{\parallel}$ drift driving field-aligned plasma diffusions near the dip equator. Jicamarca radar measurements taken over the dip equator and ΔH values computed for the Asian sector validated the ($E \times B$) $_{\perp}$ drift's daily variation and the evening PRE. Total electron content maps verified the EIA's spatial variation at ~ 350 km altitude. Results show that shortly before/after the PRE, the EIA appeared under stronger/weaker solar conditions as a two-peak/single-peak structure. Their underlying forward fountain signatures are demonstrated with the enhanced upward ($E \times B$) $_{\perp}$ drift measured within $\pm 1.25^{\circ}$ (dip) latitudes and with the decreased total downward ($V_{\text{mecha}} \sin I$) $_{\parallel}$ drift's vertical and meridional drift components. Reverse fountain related signatures were demonstrated with the enhanced downward ($E \times B$) $_{\perp}$ drift measured within $\pm 1.25^{\circ}$ and with the total upward ($V_{\text{mecha}} \sin I$) $_{\parallel}$ drift's vertical and meridional drift components. From these observational results we conclude that a $\pm 1.25^{\circ}$ (dip) latitude restriction should be applied to the ICON drift data to appropriately monitor the vertical ($E \times B$) $_{\perp}$ drift over the dip equator and to properly define the PRE.

Keywords

EIA, Field-Perpendicular Electrodynamic $E \times B$ Drift, Field-Aligned

1. Introduction

Over the dip equator's larger region ($\sim \pm 30^\circ$; dip), the quiet-time F-region (150 - 500 km; altitude) plasma fountain and related phenomena have been studied for decades for their scientific significance [1]-[5] and detrimental impact on space-based technology [6]. Overall, the plasma fountain circulates in a forward or reverse manner. This vertical fountain circulation is driven by the equatorial field-perpendicular ($\perp$) electromagnetic $E \times B$ drift ($(V_{E \times B})_\perp$; E = zonal electric field and B = northward magnetic field) over the dip equator, where the angle of inclination is zero ($I = 0$), and by the off-equatorial ($I \neq 0$) field-aligned ($\parallel$) mechanical drift ($(V_{mecha} \sin I)_\parallel$) [4] [5] [7]. As a function of $\sin I$, the $(V_{mecha} \sin I)_\parallel$ drift is driven by gravitational (g) and pressure (p) gradient forces ($(V_{g,p} \sin I)_\parallel$) and by meridional neutral winds $(U \sin I)_\parallel$ causing the plasma's asymmetric distribution with respect to the dip equator [8]-[13]. During forward fountain circulation, the overall combined effects of equatorial upward $(V_{E \times B})_\perp$ drift and off-equatorial downward $(V_{mecha} \sin I)_\parallel$ drift give rise to the development of Equatorial Ionization Anomaly (EIA) or Appleton Anomaly [14]. At F-region heights, the EIA appears as a two-peak feature characterized by a plasma trough over the dip equator and two conjugate plasma crests at $\pm 15^\circ$ magnetic latitudes with a crest-to-trough ratio of ~ 1.5 at daytime [14]-[22]. However, as the forward plasma fountain can extend to higher altitudes, the two peaks develop closer to the dip equator with increasing altitude and the two crests finally merge at higher altitudes. Consequently, the EIA appears as a single peak feature in the topside ionosphere [12] [23]. During reverse fountain circulation [10] [24], the combined effects of equatorial downward $(V_{E \times B})_\perp$ drift and off-equatorial upward $(V_{mecha} \sin I)_\parallel$ drift break down the two-peak EIA [4] [5] [10]. Both forward and reverse fountain circulations were first modelled by the first-principles Sheffield University Plasmasphere Ionosphere Model (SUPIM) covering the altitude range of 200 - 1600 km [1]-[3] [10] [11] [24]. SUPIM incorporates $(V_{E \times B})_\perp$ drift velocity measurements provided by the ground-based Incoherent Scatter Radar (ISR) at Jicamarca, located 2° north of the dip equator in Peru [25] and wind data simulated by the Horizontal Wind Model (HWM) [26].

Based on Jicamarca ISR observations, the equatorial $(V_{E \times B})_\perp$ drift's daily local time (LT) variation, development in the F region, and relation to the equatorial electrojet (EEJ) have been intensively investigated. According to Jicamarca ISR statistical studies, the equatorial $(V_{E \times B})_\perp$ drift is upward at daytime (8 - 17 LT), undergoes a pre-reversal enhancement (PRE; upward $(V_{E \times B})_\perp$ = maximum) during the evening (18 - 19 LT), turns downward (*i.e.* $(V_{E \times B})_\perp$ drift reversal) at ~ 20 LT and remains downward directed through local midnight until ~ 7 LT during equinoxes. Downward turning occurs ~ 1 hour earlier (at ~ 19 LT) in winter and

~1 hour later (at ~21 LT) in summer [10] [24]. During the PRE, the F-region eastward E field becomes suddenly increased by F-region dynamo effects [27]-[31]. Since the F-region eastward E field originates from the neutral-wind-generated E-region (90 - 120 km) dynamo eastward E field, via the Hall-current-related upward polarization E field, the equatorial upward $(V_{E \times B})_{\perp}$ drift is closely associated with the daytime eastward EEJ. This is a narrow ($\pm 3^{\circ}$; dip) band of enhanced E-region eastward current [32] [33]. Oppositely, the equatorial downward $(V_{E \times B})_{\perp}$ drift is closely associated with the daytime counter EEJ (CEJ) or nighttime westward EEJ [34]. Since the EEJ strength is a good proxy for the E-region zonal E field, the equatorial $(V_{E \times B})_{\perp}$ drift can be inferred by using H component observations obtained from a pair of ground-based magnetometers (located near and somewhat away from the dip equator) and by computing $\Delta H = \Delta H_{\text{equ}} - \Delta H_{\text{off-equ}}$ [35] [36].

Based on satellite observations provided by the FORMOSAT-1 (ROCSAT-1) satellite, orbiting at ~600 km altitude, the first detailed analysis of quiet-time ($K_p \leq 3$) equatorial $(E \times B)_{\perp}$ drift's daily and longitudinal variations was carried out for high sunspot numbers [37]. By applying a strict latitudinal restriction to the ROCSAT-1 data, vertical drift measurements were considered from a narrow 10° (latitude) region of the dip equator or within $\pm 5^{\circ}$ (dip) latitudes, where $I \cong 0$. By using 45° longitudinal bins, covering 8 longitude sectors globally, the ROCSAT-1 results revealed the equatorial $(V_{E \times B})_{\perp}$ drift magnitude $(E \times B/B^2)$ [5] longitudinal variation governed by the varying strength of B field along the dip equator that is anomalously weak in the American longitude sector known as the South Atlantic Magnetic Anomaly. Meanwhile, the daily $(V_{E \times B})_{\perp}$ drift pattern was characterized by daytime upward and nighttime downward $(V_{E \times B})_{\perp}$ drifts and the PRE commonly occurring during 18 - 19 LT and thus showing little longitudinal variation in LT occurrence [37]. The PRE's longitude independent LT variation can be explained with the PRE's LT occurrence depending on the equatorial declination angle that varies little globally along the dip equator outside the Brazilian sector [38]. More recent studies, using drift data measured by the Communication and Navigation Outage Forecasting System (C/NOFS) satellite at ~600 km altitude at lower sunspot numbers and applying a latitude restriction of $\pm 4^{\circ}$ (dip), obtained accurate daily $(V_{E \times B})_{\perp}$ drift patterns [39] [40]. However, a significant deviation from the accurate daily $(V_{E \times B})_{\perp}$ drift pattern was observed when larger than $\pm 5^{\circ}$ (dip) latitude restrictions were used [41]-[44]. This implies a knowledge gap in the understanding of equatorial forward and reverse plasma fountain circulations and underlying equatorial $(V_{E \times B})_{\perp}$ drift and off-equatorial $(V_{\text{mecha}} \sin I)_{\parallel}$ drift variations.

This study's main objectives are to address this knowledge gap and to demonstrate with the events of 3 March 2022 in the Asian sector and 1 - 3 April 2022 over the Mid Pacific how the Ionospheric Connection Explorer (ICON) satellite observed at lower sunspot numbers the forward fountain (just before or after the PRE) and the reverse fountain, and also to find out the latitude restriction that

should be applied to the ICON data. As our overall approach, we used multi-point measurements and multi-instrument ICON data, including drift data measured in two different local coordinate systems and ion density data, to specify the EIA and underlying fountain circulation. Jicamarca ISR and ΔH magnetometer observations indicated when the PRE occurred in the events of interest. This study's specific novelty and principal contribution include the specific use of ICON V_{VER} and V_{MER} drift data at lower sunspot numbers and the proposed $\pm 1.25^\circ$ (dip) latitude restriction that should be applied to the ICON V_{VER} and V_{MER} drift data to scientifically correctly monitor the vertical $(\mathbf{E} \times \mathbf{B})_\perp$ drift over the dip equator and to accurately define the PRE.

2. Data and Methodology

ICON orbited the Earth during 11 October 2019–25 November 2022 and observed the topside ionosphere's lower region between 575 km perigee and 603 km apogee altitudes. ICON completed 15 or 16 orbits a day characterized by an inclination angle of 27° and orbit period of 97-min [45] [46]. We obtained 1-second Level-2 Version 08 ICON data from the Coordinated Data Analysis Web (CDAWeb) Data Explorer. Level-2 V08 data are processed data that are quality checked, corrected for long-term systematic offsets and refined with respect to the previous Version 07.

In order to process and handle the daily ICON data files, we created a software package, which can define and number the satellite passes in the ascending and descending directions and can create a separate data file for each of the ascending and descending passes, where the different variables selected are listed. For this study, we used multi-instrument data provided by the Ion Velocity Meter-A (IVM-A) [45] [46] suite such as *in situ* ion density (N_i ; cm^{-3}) measurements and orbit parameters including footprints in geographic coordinates, solar local time (LT; Hr), and magnetic local time (MLT; Hr). For each ICON line plot presented in this study, we specified when ICON crossed the dip equator in terms of universal time (UT; Hr), solar local time (LT) and magnetic local time (MLT). These dip-equator (DEQ) crossing times are indicated as DEQ(UT), DEQ(LT), and DEQ(MLT). Importantly, we used ion velocity (V_i ; m/s) values measured in two different local coordinate systems in order to demonstrate and explain similarities and differences (see details below).

From ICON IVM-A, we used the values of meridional ion velocity (V_{MER} ; m/s; positive upward over the dip equator and poleward away from the dip equator over the Northern Hemisphere). V_{MER} is measured in a B-field referenced coordinate system, within the local magnetic meridional plane along the local magnetic meridional direction. Thus, V_{MER} is perpendicular to the horizontal geomagnetic field over the dip equator, where the local meridional vector maps to the vertical direction. Therefore, over the dip equator, $V_{\text{MER}} > 0$ (or $V_{\text{MER}} < 0$) represents a vertical upward (or downward) ion drift, which is a field-perpendicular electrodynamic $\mathbf{E} \times \mathbf{B}$ drift (upward/downward $(\mathbf{V}_{\mathbf{E} \times \mathbf{B}})_\perp$) associated with the zonal east-

ward (or westward) E field [45]–[49].

From ICON IVM-A, we also used cross-track vertical ion velocity (V_{VER} ; m/s; positive upward) measurements taken in a spacecraft-centered coordinate system. Such V_{VER} measurements are taken in the radial direction, where the upward/downward direction points radially outward/inward and away/toward the Earth's centre [45]–[49]. We used the V_{VER} data to observe the equatorial upward/downward $(V_{\text{ExB}})_{\perp}$ drift measured over the dip equator and the off-equatorial upward/downward $(V_{\text{mecha}} \sin I)_{\perp}$ drift's vertical component measured away from the dip equator.

As a key concept of this study, our main aim was to demonstrate that even if V_{MER} and V_{VER} are measured in two different coordinate systems, they commonly represent the same upward/downward $(V_{\text{ExB}})_{\perp}$ drift over the dip equator. This idea is based on a previously established mathematical expression describing the variation of vertical drift (V_z) in terms of dip latitude (θ) as $V_z(\theta) = V_z^{\text{eq}} \delta$ where $\delta = \cos^3 \theta / (1 + 3 \sin^2 \theta)$ [38] [50]. This equation can be applied to the ICON V_{MER} and V_{VER} drift data providing the expression of $V_{\text{MER}}(\theta) = V_{\text{VER}}^{\text{eq}} [\cos^3 \theta / (1 + 3 \sin^2 \theta)]$. Thus, at $\theta = 0$, $V_{\text{MER}} \approx V_{\text{VER}} = (V_{\text{ExB}})_{\perp}$. Therefore, without V_{VER} , the basic verification of V_{MER} would be lost.

The Jicamarca ISR is located at 283.13°E; –11.95°N (geographic) and at 2° (dip) in Lima, Peru. Published by the Madrigal Database, we used averaged vertical drift values computed for 360 km altitude providing F region averages with a typical accuracy of ~2 m/s [25]. These are averaged drift values smoothed over the 218–577 km altitude range, where the actual vertical drift values do not change much with altitude, and are computed for the 360 km altitude. Thus, these published averaged drift values are upward/downward $(V_{\text{ExB}})_{\perp}$ drift velocities computed for 360 km altitude, are available only for a few days of a few months of the year and covered the 1–3 April 2022 events of interest, for which we considered the PRE's local time and compared the Jicamarca ISR data computed for 360 km altitude and TEC data computed for 350 km altitude (see details below).

To obtain an indication how the equatorial vertical $(V_{\text{ExB}})_{\perp}$ drift varied over the dip equator and when the PRE occurred in the Asian longitude sector on 3 March 2022, we used ground-based magnetometer data provided by SuperMAG [51]. We considered the dip-equator station of Dalat (DLT) at 108.48°E; 11.94°N (geographic) and 2.5°N (dip) and the off-dip-equator station of Kototabang (KTB) at 100.32°E; 0.20°N (geographic) and 9.5°S (dip). We computed the ΔH values for each station by subtracting the nighttime base level. Based on the equation of $\Delta H = \Delta H_{\text{equ}} - \Delta H_{\text{off-equ}}$ [36], the difference between the two stations was computed as $\Delta H = \Delta H_{\text{DLT}} - \Delta H_{\text{KTB}}$.

We also used vertical total electron content (TEC) values, computed in TEC units (TECU; 1 TECU = $10^{16} \text{ e}^-/\text{m}^2$) for the mean ionospheric height of 350 km, from the worldwide ground-based Global Navigation Satellite System (GNSS) receiver network. Published by the Madrigal Database, these TEC values are automatically processed, averaged over 5 min (in UT), and binned in 1° latitude by 1°

longitude (geographic) cells [52]. By plotting ~ 1 hour worth of TEC data covering the time-period of interest on the days of 3 March and 1 - 3 April 2022, we created a series of GNSS TEC maps where we indicated the local time (marked in magenta or red) at each major longitude increment.

3. Results

3.1. Equatorial Upward ($V_{E \times B}$) $_{\perp}$ Drift and EIA Variations in the American Longitude Sector on 3 April 2022

Overall, **Figure 1** illustrates the daily variation of vertical upward/downward ($V_{E \times B}$) $_{\perp}$ drift measured at Jicamarca (near the dip equator) and averaged for 360 km altitude and the resultant TEC distribution at 350 km latitude in the American longitude sector on the magnetically quiet ($K_p \leq 3$) day of 3 April 2022.

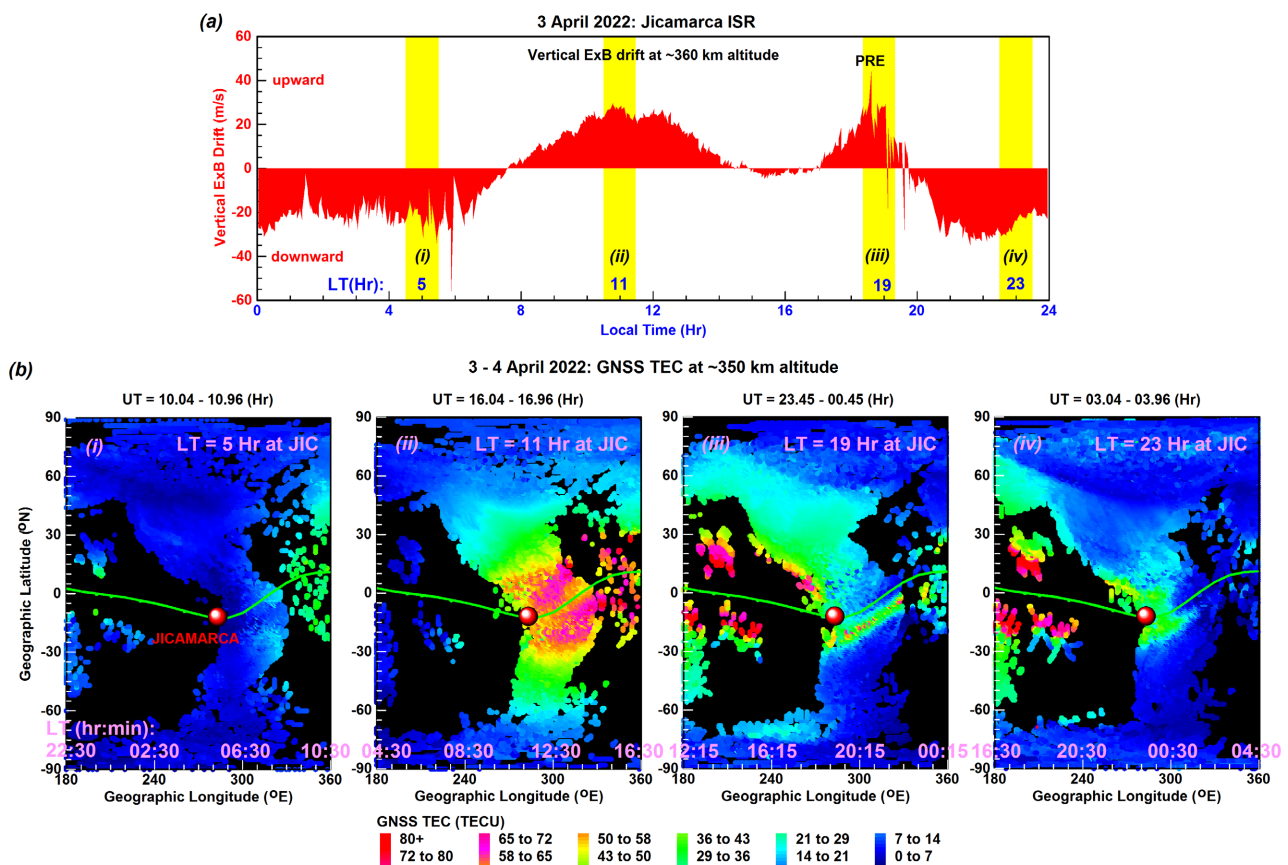


Figure 1. (a) The averaged Jicamarca ISR vertical drift measurements depict the daily variation of vertical $E \times B$ drift over the dip equator at ~ 360 km altitude on 3 April 2022. (b) For the 1-hour time intervals of interest (marked as shaded intervals in yellow covering a 1-hour time period), the GNSS TEC maps illustrate the resultant TEC distributions at 350 km altitude over the Western Hemisphere on 3 - 4 April 2022.

In **Figure 1(a)**, the upward/downward ($V_{E \times B}$) $_{\perp}$ drift (m/s) over Jicamarca is plotted against the local time ($LT = UT - 5$ hours). Here, we indicated (shaded intervals in yellow) a few LT values ranging from 5 LT marked as (i) to 23 LT marked as (iv). Here, the shaded intervals in yellow mark the 1-hour time-period

covered by the TEC maps. As shown, the downward $(V_{E \times B})_{\perp}$ drift, varying between -20 m/s and -30 m/s, persisted from midnight to morning (0 - 8 LT; where 5 LT is marked as (i)). After the downward $(V_{E \times B})_{\perp}$ drift's upward turning, the upward $(V_{E \times B})_{\perp}$ drift peaked (~ 30 m/s) first just before midday at ~ 11 LT (marked as (ii)) in the 8 - 14 LT sector, decreased in the 15 - 17 LT sector, reached 0 m/s at 15 LT and slightly negative values (~ -3 m/s) at 16 LT, and maximized at dusk, at ~ 19 LT (marked as (iii)). This is known as the PRE (upward $(V_{E \times B})_{\perp}$ = maximum) reaching ~ 40 m/s and thus exceeding the daily peak of ~ 30 m/s. Soon after the PRE, this upward $(V_{E \times B})_{\perp}$ drift turned downward at ~ 20 LT. Subsequently, the downward $(V_{E \times B})_{\perp}$ drift increased to -33 m/s and remained comparable in magnitude with the upward $(V_{E \times B})_{\perp}$ drift measured during the PRE's larger time interval where 23 LT is marked as (iv).

In **Figure 1(b)**, a series of GNSS TEC maps shows the resultant TEC distribution (at ~ 350 km altitude) during the marked ((i) - (iv)) time-periods. Here, we also show the local time computed for the main longitude increments indicated. Each TEC map is constructed with data covering the ~ 1 UT hour time-period of interest, covers the Western Hemisphere ($180 - 360^{\circ}$ E; geographic), and shows the modeled dip equator (in green) along with the location of Jicamarca (symbol dot in red) situated just 2° north of the dip equator. Since the Jicamarca $(V_{E \times B})_{\perp}$ drift (m/s) values were computed for the altitude of 360 km and the GNSS TEC values were calculated for the mean ionospheric height of 350 km, these TEC maps demonstrate how the low-latitude TEC became distributed by the direct action of equatorial vertical $(V_{E \times B})_{\perp}$ drift measured over Jicamarca. Firstly, map (i) shows the minimum TEC values (< 14 TECU; shades of dark blue) of the depleted ionosphere at ~ 5 LT over Jicamarca, when the downward $(V_{E \times B})_{\perp}$ drift reached ~ -30 m/s many hours after the previous evening PRE. Map (ii) illustrates a well-developed daytime EIA (> 80 TECU; red) at 11 LT over Jicamarca when the upward $(V_{E \times B})_{\perp}$ drift reached its daytime maximum of ~ 30 m/s. Map (iii) demonstrates the sudden redevelopment of evening EIA (> 50 TECU; shades of red) over Jicamarca at 19 LT, during the PRE when the upward $(V_{E \times B})_{\perp}$ drift varied between 30 m/s and 40 m/s. Finally, map (iv) depicts a collapsed EIA at 23 LT over Jicamarca, ~ 4 hours after the PRE when the downward $(V_{E \times B})_{\perp}$ drift reached ~ -20 m/s.

3.2. EIA and Underlying Forward Fountain Signatures Observed by ICON at Dusk: 1 April 2022 Event

Figure 2 was constructed with equatorial vertical $(V_{E \times B})_{\perp}$ drift data provided by the Jicamarca ISR, with GNSS TEC measurements, and with ICON IVM-A data sets. Overall, **Figure 2** demonstrates how ICON observed the EIA and underlying forward fountain's signatures that are depicted by the V_{VER} and V_{MER} drift measurements during the PRE's early stage (*i.e.*, pre-PRE phase), before the vertical upward $E \times B$ drift peaked, under magnetically quiet conditions ($K_p \leq 3$) on 1 April 2022 over the Mid Pacific. In the absence of local ground-based equatorial $(V_{E \times B})_{\perp}$ drift measurements taken at the dip equator in the Mid Pacific, we used

the Jicamarca ISR drift data. Based on previous statistical studies [25] [37] and recent investigations [38], we assumed that the PRE varied in local time in a similar way over the Pacific and Jicamarca because of the similar declination values along the dip equator (see details in section 1).

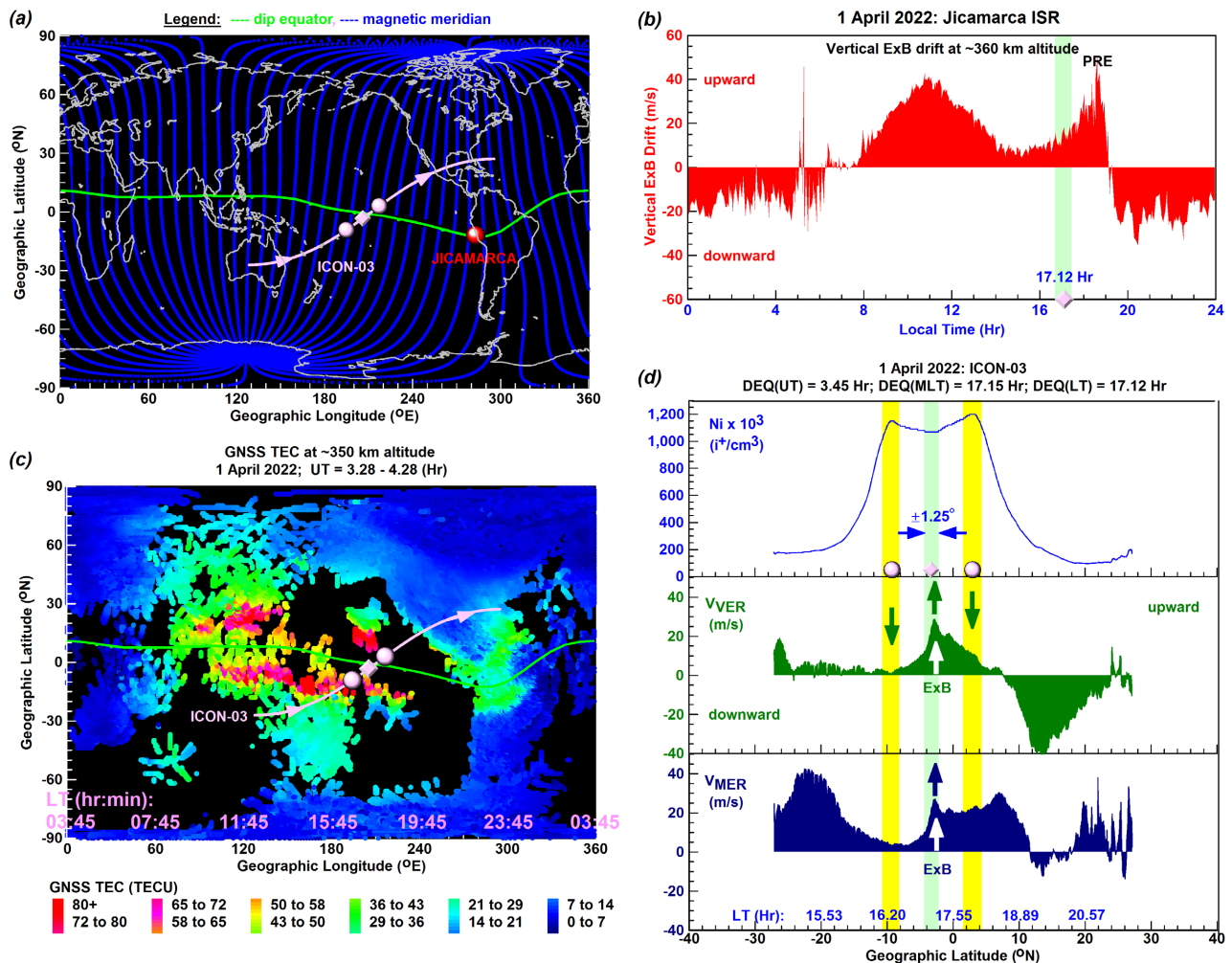


Figure 2. Constructed for the 1 April 2022 event's first two-peak EIA observation. (a) The global map shows the ascending ICON pass-03 with the magnetic field lines and dip equator. (b) The averaged Jicamarca ISR vertical drift measurements depict the equatorial upward/downward ($V_{\text{ExB}} \perp$) drift's daily variation over the dip equator at ~360 km. (c) At 350km altitude, the GNSS TEC map depicts the two-peak EIA and the ascending ICON-03 pass. (d) The ICON line plots illustrate the two-peak EIA along with the underlying upward V_{VER} and V_{MER} drifts that locally peaked within a narrow ($\pm 1.25^\circ$; latitude) region of the dip equator. Legend: symbol dots = EIA crests, symbol diamond = EIA trough, shaded intervals in yellow = EIA crest regions, shaded interval in light green = $\pm 1.25^\circ$ latitude region of the dip equator.

In **Figure 2(a)**, the global map shows the modeled magnetic meridians (in blue) and dip equator (in green) and the ground track of the ascending ICON pass-03 of interest (in light red) crossing the dip equator at 210°E geographic longitude over the Mid Pacific on 1 April 2022 at 17.12 LT. This map reveals that ICON crossed the magnetic meridians and magnetic field lines because of its 27°-inclined orbit. Therefore, ICON could not provide field-aligned observations that

are crucial for observing the EIA and underlying forward plasma fountain characterized by field-aligned plasma flows near the EIA crests. Along its ascending pass-03, ICON observed the EIA trough region (symbol diamond in light red) over the dip equator and the two EIA crests (symbol dots in light red) on different magnetic field lines and thus provided a non-field-aligned observation of the two-peak EIA.

In **Figure 2(b)**, the Jicamarca ISR-detected equatorial vertical ($V_{\text{ExB}} \perp$) drift is plotted against the local time. Its diurnal variation is characterized by a day-time peak (at ~ 11 LT) and the evening PRE (upward ($V_{\text{ExB}} \perp$) = maximum) peaking at ~ 19 LT. As marked (shaded interval in light green), ICON crossed the dip equator at 17.12 LT when the upward ($V_{\text{ExB}} \perp$) drift started increasing in the dusk sector before reaching its peak of ~ 50 m/s (*i.e.*, the PRE) at 19 LT.

Figure 2(c) shows the global GNSS TEC map constructed with data covering the 1-hour period of 3.28 - 4.28 UT, during which ICON crossed the dip equator (at 3.45 UT). As before, we indicated the computed local time values for the major longitude increments. As shown by the GNSS TEC map, the two-peak EIA appeared well developed over the Mid Pacific where the EIA crests reached over 80 TECU (in red) and the EIA trough was deep (43 - 29 TECU; shades of green). These GNSS TEC values (computed for 350 km altitude) correlate well with the high vertical upward ($V_{\text{ExB}} \perp$) drift values (computed for 360 km altitude) at Jicamarca. However, at ~ 600 km altitude, ICON observed the EIA crests (symbol dots in light red) closer to the dip equator than the EIA crests detected by the GNSS TEC values at 350 km altitude, since the EIA crests develop closer to the dip equator with increasing altitude [23].

In **Figure 2(d)**, the line-plot sets are constructed with ICON ion density (N_i), cross-track vertical (V_{VER}) or radial drift, and meridional (V_{MER}) drift data. These are plotted in geographic latitudes where the local time (LT; Hr) is marked for the major latitude increments. While the N_i plot shows the two-peak EIA, the V_{VER} and V_{MER} drift plots depict the underlying forward fountain signatures seen in the radial (V_{VER}) and meridional (V_{MER}) drift data.

Although the ICON detection was not field aligned, the N_i plot depicts an almost symmetric two-peak EIA. We marked each EIA crest (symbol dot in light red; shaded interval in yellow) located at $\sim 6^\circ$ away from the dip equator, and the dip equator's $\pm 1.25^\circ$ latitude region (shaded interval in light green) covering 2.5° latitudes from 1.25°N to 1.25°S wherein the EIA trough (symbol diamond in light red) was located. This is the region, where the V_{VER} and V_{MER} plots (within $\pm 1.25^\circ$ latitudes) show strong similarities (see details below).

We know from the published SUPIM simulation results [10] [24] that during the forward fountain's operation, the equatorial upward ($V_{\text{ExB}} \perp$) drift drives the plasma up over the dip equator and across the horizontal magnetic field lines until the plasma loses momentum. This is demonstrated with the V_{VER} and V_{MER} plots depicting their maximized values over the dip equator and in the EIA trough region. Thus, as the V_{VER} and V_{MER} plots show, this part of the forward plasma foun-

tain circulation was dominated by radially outward plasma motion driven by the equatorial upward $(V_{\text{ExB}})_\perp$ drift. By comparing the V_{VER} and V_{MER} plots within $\pm 1.25^\circ$ latitudes, they show strong similarities where these drifts locally maximized ($V_{\text{VER}} \approx 28.67$ m/s; $V_{\text{MER}} \approx 27.09$ m/s) simultaneously. Their respective peaks were located within this narrow $\pm 1.25^\circ$ latitude region of the dip equator, covering 2.5° in latitudes (shaded interval in light green), where they measured the equatorial upward $(V_{\text{ExB}})_\perp$ drift. These ICON-measured drift values are higher than the ISR measured drift value (~ 15 m/s) because of the longitudinal variation of the equatorial upward $(V_{\text{ExB}})_\perp$ drift's magnitude. But the ISR drift data provide observational evidence that ICON made its observations during the pre-PRE phase, before the equatorial upward $(V_{\text{ExB}})_\perp$ drift reached its peak value at ~ 45 m/s, as the PRE's LT occurrence is independent of longitude outside the Brazilian sector due to the similar magnetic declination values along the dip equator outside the Brazilian sector [38].

We also know from the published SUPIM simulation results [10] [24] that during the forward fountain's operation, the upward driven plasma subsequently loses momentum and diffuses down the inclined magnetic field lines in each hemisphere. This is demonstrated with both the vertical upward V_{VER} and the meridional poleward V_{MER} drifts that both decreased in each EIA crest region. Thus, this part of the forward fountain circulation is driven by the off-equatorial downward $(V_{\text{mecha}}\sin I)_\parallel$ drift. Therefore, the total downward $(V_{\text{mecha}}\sin I)_\parallel$ drift drove the plasma down the inclined magnetic field lines. Consequently, both the V_{VER} and V_{MER} drift plots depict the signatures of this off-equatorial total downward $(V_{\text{mecha}}\sin I)_\parallel$ drift. While the V_{VER} plot shows the net radial downward vertical drift component of this total downward $(V_{\text{mecha}}\sin I)_\parallel$ drift, the V_{MER} plot shows the net meridional poleward drift component of this total downward $(V_{\text{mecha}}\sin I)_\parallel$ drift. However, from these *in situ* net radial V_{VER} and meridional V_{MER} drift measurements, we cannot specify the individual contributing $(V_{\text{g,p}})\sin I$ and $U\sin I$ drift components.

Figure 3 is constructed the same way as **Figure 2** and illustrates another set of observations made on 1 April 2022 during the pre-PRE phase, before the equatorial upward $(V_{\text{ExB}})_\perp$ drift peaked (*i.e.*, the PRE) at ~ 19 LT. Thus, **Figure 3** shows with ICON pass-04 the continuation of the scenario depicted by the previous ICON pass-03 in **Figure 2**. Because of the strong similarities, we highlight here only the new features shown by **Figure 3**.

In **Figure 3(a)**, the global map illustrates the ascending ICON pass-04 that crossed the dip equator at $\sim 185^\circ\text{E}$ geographic longitude over the Mid Pacific at a slightly later local time (17.52 LT) than the ascending ICON pass-03 shown in **Figure 2(a)**.

Figure 3(b) is the same as **Figure 2(b)**. Here, we marked that later dip equator crossing local time (17.52 LT), which still occurred during the pre-PRE phase but closer to the PRE. Because of the strong underlying equatorial upward $(V_{\text{ExB}})_\perp$ drift, the EIA was well developed over the Mid Pacific (see also GNSS TEC map in **Figure 3(c)**).

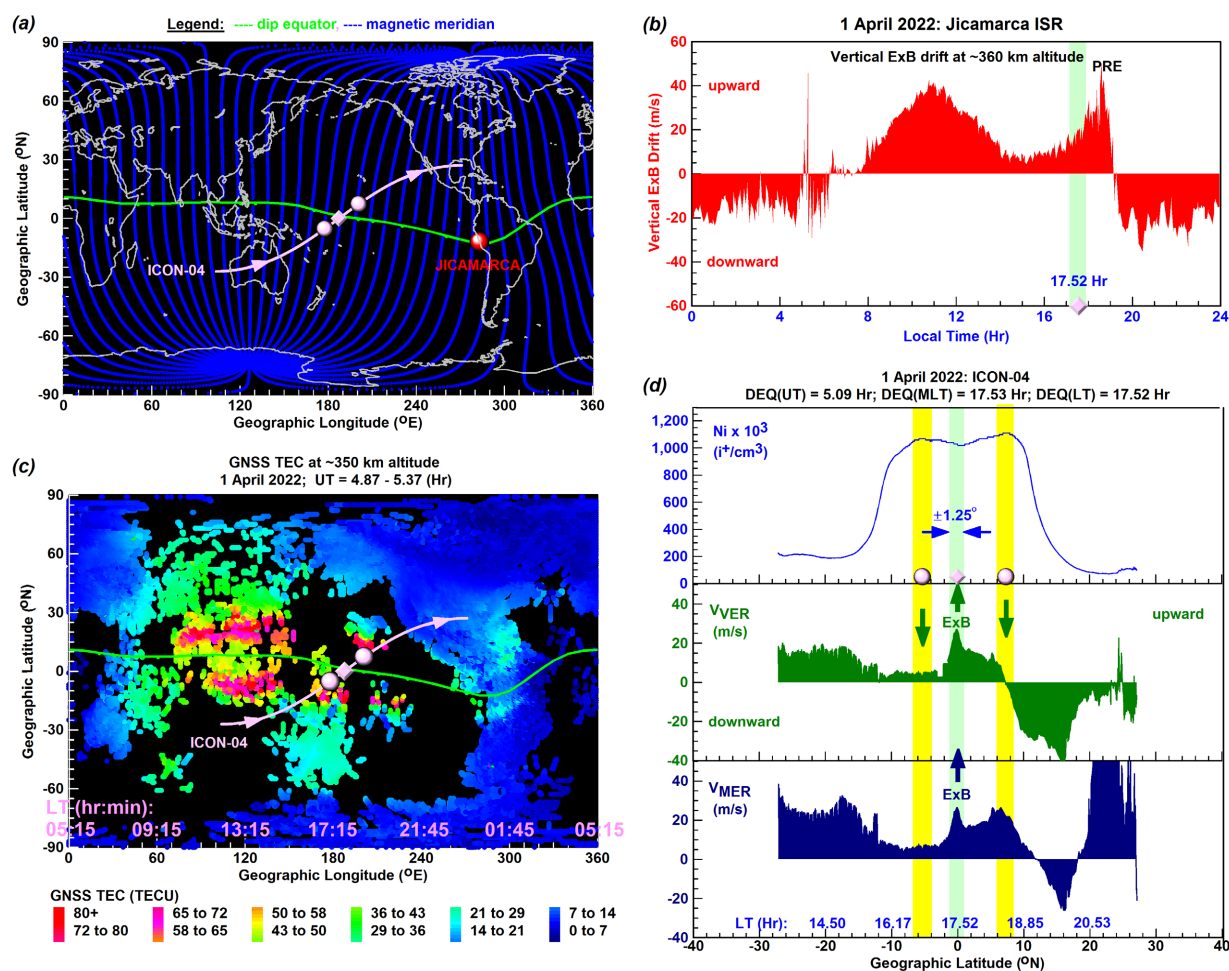


Figure 3. Constructed for the 1 April 2022 event's second two-peak EIA observation. (a) The global map shows the ascending ICON pass-04 with the magnetic field lines and dip equator. (b) The averaged Jicamarca ISR vertical drift measurements depict the equatorial upward/downward (V_{ExB})_⊥ drift's daily variation over the dip equator at ~360 km. (c) At 350 km altitude, the GNSS TEC map depicts the two-peak EIA and the ascending ICON-04 pass. (d) The ICON line plots illustrate the two-peak EIA along with the underlying upward V_{VER} and V_{MER} drifts that locally peaked within a narrow ($\pm 1.25^\circ$; latitude) region of the dip equator. Legend: symbol dots = EIA crests, symbol diamond = EIA trough, shaded intervals in yellow = EIA crest regions, shaded interval in light green = $\pm 1.25^\circ$ latitude region of the dip equator.

In **Figure 3(d)**, the ICON line plots depict an almost symmetric EIA. Both the V_{VER} and the V_{MER} line plots show the locally increased upward (V_{ExB})_⊥ drift over the dip equator, within its 2.5° latitude range or within $\pm 1.25^\circ$ (dip) latitudes. There, the forward fountain's dominating radially outward plasma motion was driven by the equatorial upward (V_{ExB})_⊥ drift measured as $V_{VER} \approx 27.10$ m/s and $V_{MER} \approx 26.43$ m/s. Again, these ICON-measured drift values are higher than the ISR measured drift value (~ 20 m/s) due to the longitudinal variation of the equatorial upward (V_{ExB})_⊥ drift's magnitude. Since the LT occurrence of PRE is independent of longitude outside the Brazilian sector, because of the similar magnetic declination values along the dip equator outside the Brazilian sector [38], the ISR drift data provide observational evidence that ICON made its observations during the pre-PRE phase, before the upward (V_{ExB})_⊥ drift reached its peak value of ~ 50

m/s. Away from the dip equator and at each EIA crest, the locally decreased V_{VER} and V_{MER} values depict the forward fountain's dominating downward field-aligned diffusion driven by the total downward $(V_{\text{mecha}}\sin I)_I$ drift. Thus, the locally decreased V_{VER} and V_{MER} values depict the total downward $(V_{\text{mecha}}\sin I)_I$ drift's respective net vertical and net meridional components.

3.3. Breaking-Down EIA and Underlying Reverse Fountain Signatures Observed by ICON at Dawn: 2 April 2022 Event

Figure 4 was constructed the same way as **Figure 2** and **Figure 3**. **Figure 4** covers the following day, 2 April 2022, and illustrates the breaking down of the two-peak EIA and the underlying reverse fountain signatures observed by ICON under magnetically quiet conditions ($K_p < 3$).

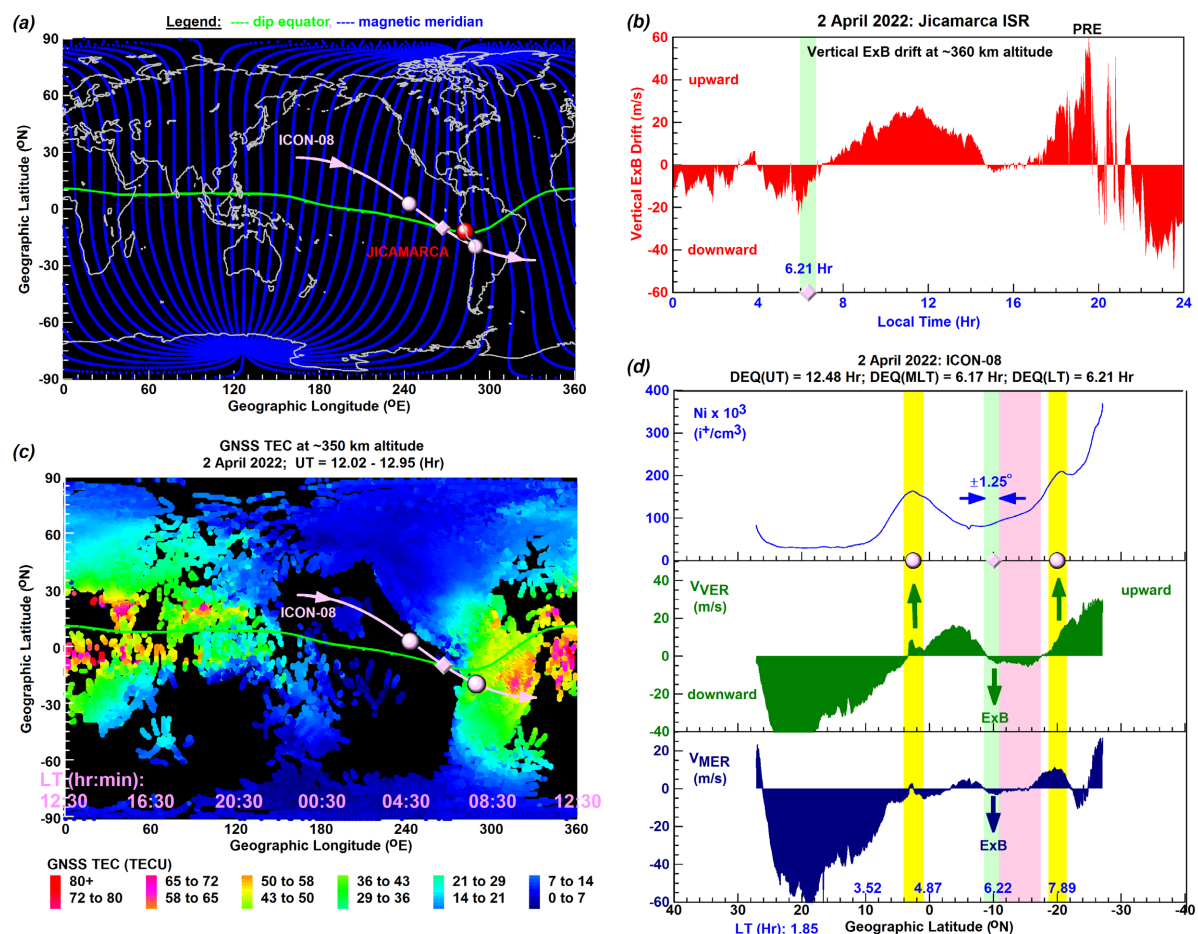


Figure 4. Constructed for the 2 April 2022 event's breaking-down EIA observation. (a) The global map shows the descending ICON pass-08 with the magnetic field lines and dip equator. (b) The averaged Jicamarca ISR vertical drift measurements depict the equatorial upward/downward $(V_{\text{ExB}})_I$ drift's daily variation over the dip equator at ~360 km. (c) At 350 km altitude, the GNSS TEC map depicts the breaking down two-peak EIA and the descending ICON-08 pass. (d) The ICON line plots illustrate the two-peak EIA's breaking down along with the underlying downward V_{VER} and V_{MER} drifts that locally maximized in the downward direction within a narrow ($\pm 1.25^\circ$; latitude) region of the dip equator. Legend: symbol dots = EIA crests, symbol diamond = EIA trough, shaded intervals in yellow = EIA crest regions, shaded interval in light green = $\pm 1.25^\circ$ latitude region of the dip equator, shaded interval in light red = larger region of the dip equator.

In **Figure 4(a)**, the global map shows the descending ICON pass-08 that crossed the dip equator at $\sim 265^\circ\text{E}$ geographic longitude, near Jicamarca, at local dawn (6.21 LT). Because of ICON's 27° -inclined orbit, crossing the magnetic field lines and preventing conjugate observations, ICON observed the breaking-down EIA crests on different magnetic field lines located far apart. While the northern EIA crest observed was located over the Western Pacific, the EIA trough region was detected near Jicamarca and the southern EIA crest observed was located over the South American continent, south of Jicamarca. Therefore, in our reverse fountain interpretation, we mainly consider the regions of EIA trough and southern crest.

Figure 4(b) is the continuation of **Figure 3(b)** and shows with ISR measurements how the equatorial vertical $(V_{\text{E} \times \text{B}})_\perp$ drift variation continued over Jicamarca on the following day, 2 April 2022. After the equatorial upward $(V_{\text{E} \times \text{B}})_\perp$ drift reversal at ~ 19 LT on 1 April (shown in **Figure 3(b)**), the equatorial downward $(V_{\text{E} \times \text{B}})_\perp$ drift prevailed during the local nighttime hours (shown in **Figure 3(b)**) and during the following dawn (shown in **Figure 4(b)**). This equatorial downward $(V_{\text{E} \times \text{B}})_\perp$ drift drove the reverse fountain and caused the EIA's breaking down. Since ICON crossed the dip equator near Jicamarca, the equatorial downward $(V_{\text{E} \times \text{B}})_\perp$ drift measured at Jicamarca by the ISR is well correlated with the descending ICON pass-08 crossing the dip equator near Jicamarca.

In **Figure 4(c)**, the GNSS TEC map shows the breaking down of the two-peak EIA near Jicamarca at local dawn. The weak EIA crests observed by ICON are indicated by the northern lower (14 - 21 TECU; in light blue) and southern higher (29 - 36 TECU; in light green) TEC values.

Figure 4(d) shows the breaking-down EIA with the Ni plot and the reverse fountain's signatures with the V_{VER} and V_{MER} drift plots. We know from the published SUPIM simulation results [10] [24] that during the reverse fountain's operation, the strong equatorial downward $(V_{\text{E} \times \text{B}})_\perp$ drift drives the plasma vertically downward across the horizontal magnetic field lines over the dip equator. This radially inward plasma motion, driven by the locally increased equatorial downward $(V_{\text{E} \times \text{B}})_\perp$ drift, is demonstrated with the ICON measured values of $V_{\text{VER}} \approx -3.60$ m/s and $V_{\text{MER}} \approx -3.19$ m/s over the 2.5° latitude region of the dip equator located within $\pm 1.25^\circ$ dip latitudes (shaded interval in light green). However, because of the alignment of descending ICON pass-08, this pass covered a larger region of the dip equator (shaded intervals in light green and light red). Therefore, ICON tracked the equatorial downward $(V_{\text{E} \times \text{B}})_\perp$ drift over an extended region (shaded interval in light red) of the dip equator (shaded interval in light green), additionally to the crossing point (shaded interval in light green). We also know from the published SUPIM simulation results [10] [24] that as the reverse fountain circulation continues and due to the low plasma pressure created in the EIA trough region by the downward $(V_{\text{E} \times \text{B}})_\perp$ drift, the plasma starts flowing upward at the EIA crest regions and toward the dip equator and starts filling up the EIA trough region. The signatures of off-equatorial total upward $(V_{\text{mecha}} \sin I)_\parallel$ drift, driving upward field-aligned diffusions by the dominating upward pressure gradient forces, are illustrated with the locally increased V_{VER} and V_{MER} values near

the EIA crests (shaded intervals in yellow).

3.4. EIA and Underlying Forward Fountain Signatures Observed by ICON at Dusk: 3 March 2022 Events

Overall, **Figure 5** and **Figure 6** were constructed for the four 3 March 2022 events observed by ICON in the Asian sector along four consecutive descending passes numbered as 07, 08, 09, and 10 by our software (see details in section 2). In these events, the EIA appeared as a single-peak ion density feature over the dip equator at ~ 600 km altitude, where the two EIA crests merged (by developing closer to the dip equator) under the prevailing weaker solar conditions [12] [13] [21]–[23]. In the absence of Jicamarca ISR data, we computed $\Delta H = \Delta H_{\text{DLT}} - \Delta H_{\text{KTB}}$ by using ground-based magnetometer data provided by the equatorial station of DLT (Dalat) and off-equatorial station of KTB (Kototabang) in the Asian sector, at $\sim 105^\circ\text{E}$ (geographic) longitude (see details in section 2), where the nearby ICON passes of interest crossed the dip equator.

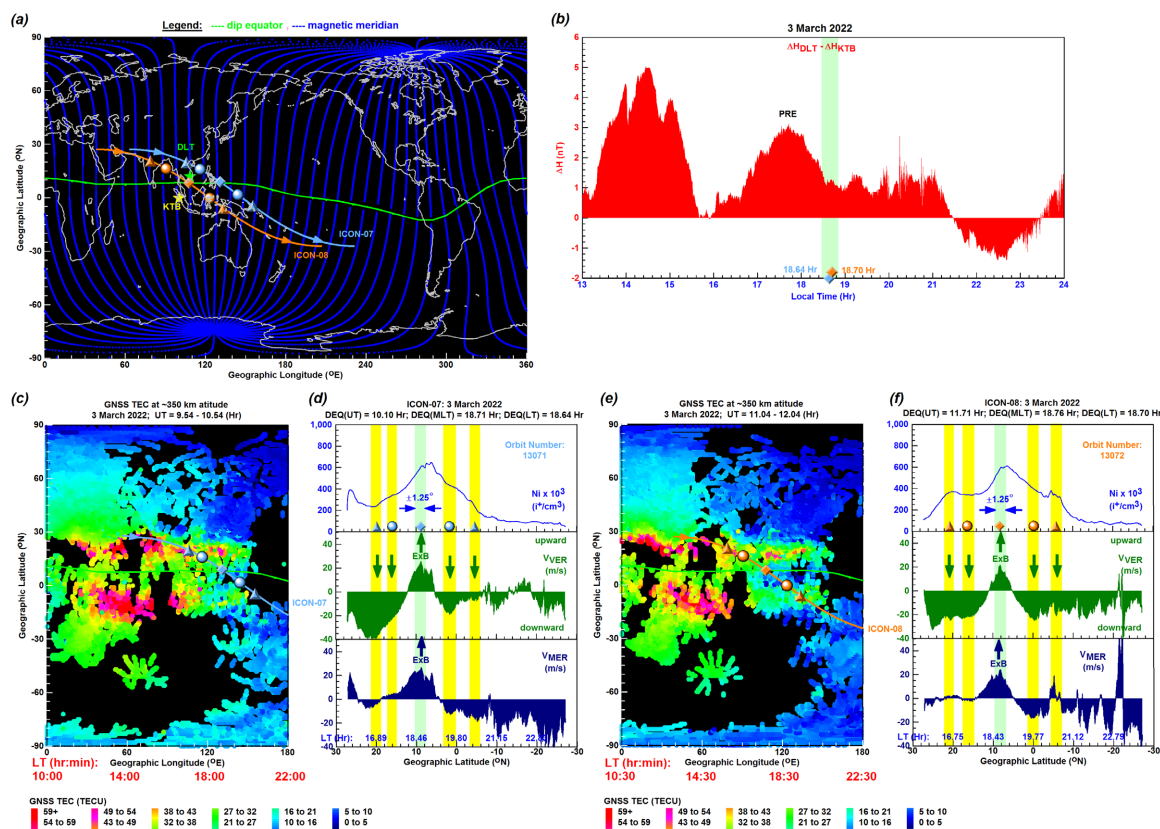


Figure 5. Constructed for the 3 March 2022 event's first and second single-peak EIA observations. (a) The global map shows the descending ICON pass-07 and pass-08 with the magnetic field lines and dip equator. (b) The computed ΔH plot provides a good proxy for the equatorial upward/downward (V_{ExB}) drift's daily variation over the dip equator in the Asian sector at $\sim 105^\circ\text{E}$ (geographic) longitude. (c) and (e) At 350 km altitude, the GNSS TEC map depicts the two-peak EIA and the descending ICON 07 and 08 passes. (d) and (e) The ICON line-plot sets illustrate the single-peak EIA along with the underlying V_{VER} and V_{MER} drifts that locally peaked within a narrow (1.25° ; latitude) region of the dip equator. Legend: symbol dots and triangles = EIA crest crossings, symbol diamond = peak of the single-peak EIA over the dip equator, shaded intervals in yellow = EIA crest crossings, shaded interval in light green = $\pm 1.25^\circ$ latitude region of the dip equator.

In **Figure 5(a)** and **Figure 6(a)**, the global map illustrates the two descending ICON passes of interest crossing the dip equator (in green) near the ground-based magnetometer stations of DLT (symbol star in green) and KTB (symbol star in yellow) along with the modeled magnetic meridians (in blue). For each ICON pass, we also marked the dip equator crossing (symbol diamond) point and the EIA crest crossing (symbol dot and symbol triangle) locations.

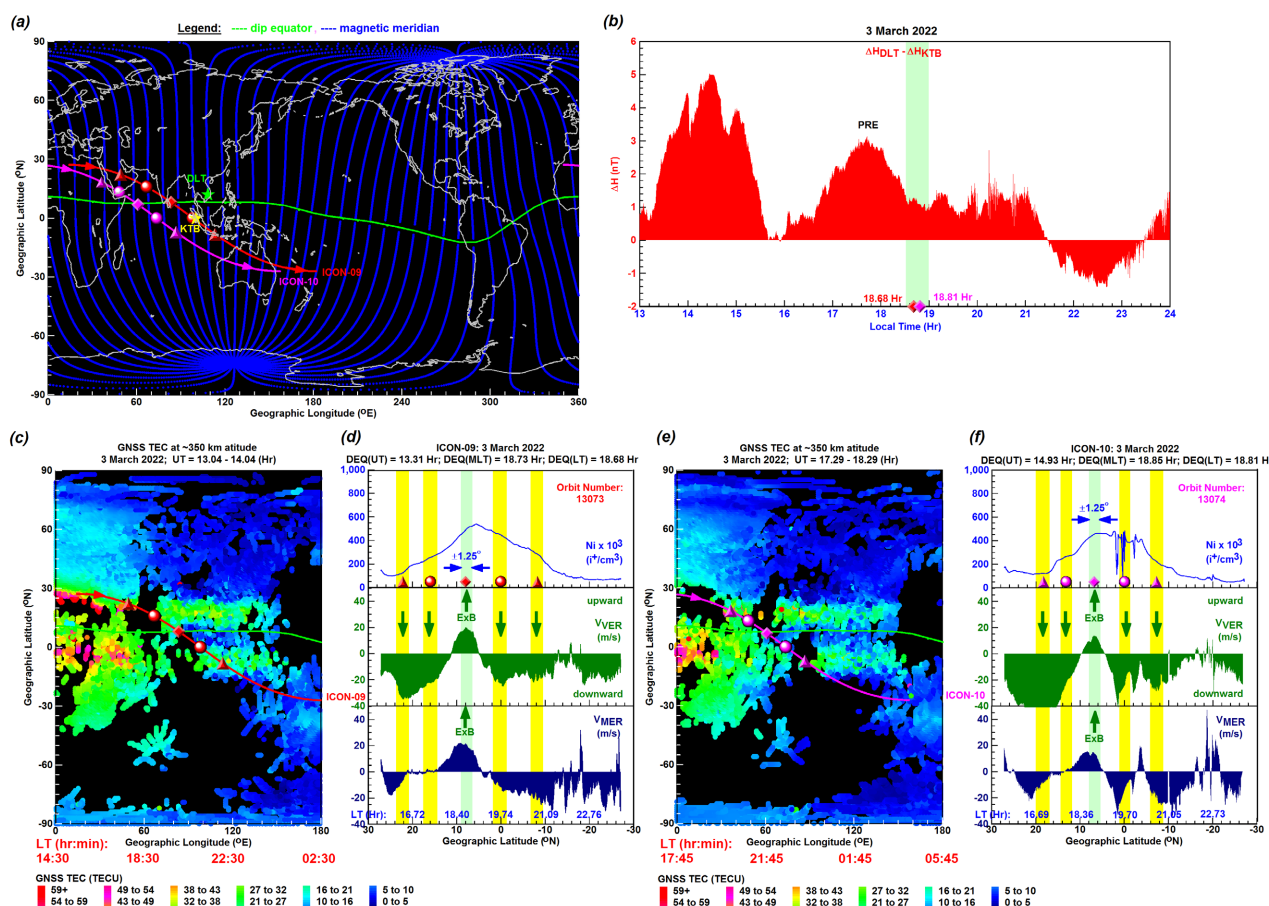


Figure 6. Constructed for the 3 March 2022 event's third and fourth single-peak EIA observations. (a) The global map shows the descending ICON pass-09 and pass-10 with the magnetic field lines and dip equator. (b) The computed ΔH plot provides a good proxy for the equatorial upward/downward (V_{ExB}) drift's daily variation over the dip equator in the Asian sector at $\sim 105^\circ \text{E}$ (geographic) longitude. (c) and (e) At 350 km altitude, the GNSS TEC map depicts the two-peak EIA and the descending ICON 09 and 10 passes. (d) and (e) The ICON line-plot sets illustrate the single-peak EIA along with the underlying V_{VER} and V_{MER} drifts that locally peaked within a narrow (1.25° ; latitude) region of the dip equator. Legend: symbol dots and triangles = EIA crest crossings, symbol diamond = peak of the single-peak EIA over the dip equator, shaded intervals in yellow = EIA crest crossings, shaded interval in light green = $\pm 1.25^\circ$ latitude region of the dip equator.

In **Figure 5(b)** and **Figure 6(b)**, the ΔH versus LT plot provides a good proxy for the equatorial vertical (V_{ExB}) drift and depicts its variation on 3 March 2022 from early afternoon (13 LT) to midnight (24 LT). While the daytime ΔH values peaked at ~ 14 LT implying that the daytime EIA was best developed then, the evening ΔH peak occurred at ~ 17.5 LT implying the evening PRE. But the actual equatorial vertical (V_{ExB}) drift reversal took place later, at ~ 21.5 LT, because of

the long post-PRE phase. We marked the equator-crossing LT values of the ICON passes of interest (shaded interval in light green) providing observational evidence that ICON observed the single-peak EIA and underlying forward fountain after the PRE (*i.e.*, in the post-PRE phase).

In **Figure 5(c)** and **Figure 5(e)** and in **Figure 6(c)** and **Figure 6(e)**, the GNSS TEC map was constructed as before, covers the Eastern Hemisphere (0 - 180°E; geographic), and shows the two-peak EIA detected at ~350 km altitude. In agreement with the ΔH plot, the two-peak EIA was well developed at ~14 LT and suddenly weakened after ~18 LT in the post-PRE phase. By plotting the descending ICON pass of interest over the respective TEC map, we can see clearly that ICON crossed each crest of the two-peak EIA more than once in each hemisphere because of its 27°-inclined orbit. For each ICON pass, we marked these EIA crest crossings (symbol dot and symbol triangle) along with the dip equator crossing (symbol diamond) location.

In **Figure 5(d)** and **Figure 5(f)** and in **Figure 6(d)** and **Figure 6(f)**, the ICON line-plot set was constructed as before. Here, the Ni plot reveals that at ~600 km altitude, ICON observed the EIA as a single-peak ion density feature under the weaker solar conditions, during which the two EIA peaks developed close to the dip equator at ~600 km altitude. We marked the crossings of GNSS TEC-detected EIA crests (symbol dot and symbol triangle; shaded intervals in yellow) along with the dip equator crossing (symbol diamond; shaded interval in light green). Although ICON observed a single-peak EIA feature at ~600 km altitude, it could still observe the underlying forward fountain signatures depicted by the V_{VER} and V_{MER} drift measurements. These fountain signatures included the equatorial upward ($V_{\text{E} \times \text{B}})_\perp$ drift over a narrow 2.5° latitude region of the dip equator (*i.e.*, $\pm 1.25^\circ$; dip) depicted similarly by the V_{VER} and V_{MER} plots along with the off-equatorial total downward ($V_{\text{mecha}} \sin I)_\parallel$ drift observed by ICON at each EIA-crest-crossing over the Northern Hemisphere earlier (in UT and LT) and over the Southern Hemisphere later on (in UT and LT). While the V_{VER} plot shows the net radial downward drift components of these total downward ($V_{\text{mecha}} \sin I)_\parallel$ drifts with the $V_{\text{VER}} < 0$ values, the V_{MER} plots show the net meridional drift components of these total downward ($V_{\text{mecha}} \sin I)_\parallel$ drifts. However, from these *in situ* net radial and meridional drift measurements, we cannot specify the individual contributing ($V_{\text{g,p}} \sin I$ and $U \sin I$) components.

4. Discussion

This study's two main objectives were 1) to address the knowledge gap related to the quiet-time equatorial plasma fountain and associated daily vertical $\text{E} \times \text{B}$ drift variations including the evening PRE and 2) to increase our understanding of how ICON can observe the signatures of forward fountain and reverse fountain at lower sunspot numbers within ICON's i) observational capability and ii) operational limitation. These (i - ii) include ICON's 27°-inclined ascending and descending passes crossing numerous magnetic meridians and magnetic field lines

and thus preventing the detections of conjugate EIA crests and field-aligned plasma diffusions. Specifically, the focus was on a) the equatorial forward fountain observed just before or after the PRE, b) the equatorial reverse fountain, and c) the latitude restriction that should be applied to the ICON drift data in order to investigate scientifically correctly the daily variability of equatorial vertical ($V_{\text{E} \times \text{B}})_\perp$ drift and to specify the PRE.

Unique to this study, we used the combination of ICON-measured ion density data to observe the EIA and drift velocity data recorded in two different local coordinate systems providing radial or vertical (V_{VER}) and meridional (V_{MER}) drift values to observe the fountain circulation underlying the EIA.

Scientifically, using V_{VER} and V_{MER} drift data was crucial since V_{VER} acted as an independent consistency to inspect V_{MER} near the dip equator. This permitted the identification of the spatial range, over which both (V_{VER} and V_{MER}) represented the same equatorial vertical ($V_{\text{E} \times \text{B}})_\perp$ drift. Thus, V_{VER} provided an independent diagnostic of the equatorial fountain circulation and allowed the specification of a narrow 2.5° latitude range of the dip equator (*i.e.*, within $\pm 1.25^\circ$ dip latitudes) extending from 1.25°N to 1.25°S . In this way, we could assess scientifically correctly how ICON observed the upward/downward ($V_{\text{E} \times \text{B}})_\perp$ drift over the dip equator in these two different local coordinate systems. Accordingly, this study's specific novelty and principal contribution include the specific use of ICON V_{VER} and V_{MER} drift data and the proposed $\pm 1.25^\circ$ (dip) latitude restriction that should be applied to the ICON V_{VER} and V_{MER} drift data in order to specify scientifically correctly the equatorial vertical ($V_{\text{E} \times \text{B}})_\perp$ drift. However, away from the dip equator, the V_{MER} and V_{VER} measurements represent different types of drift components. While V_{MER} measures the net poleward/equatorward component of the off-equatorial upward/downward ($V_{\text{mecha}}\sin I)_\parallel$ drift, V_{VER} measures the upward/downward ($V_{\text{mecha}}\sin I)_\parallel$ drift's vertical upward/downward component in the radial direction (pointing away/toward the Earth's centre) independently of ICON's circular orbit. Because of ICON's *in situ* measurements taken at ~ 600 km orbit altitude, both the V_{MER} and the V_{VER} measurements provide net velocity values. Therefore, the contributions of individual velocity components of the total upward/downward ($V_{\text{mecha}}\sin I)_\parallel$ drift, which are associated with gravitational and pressure gradient forces ($(V_{\text{g,p}})\sin I$) and neutral winds ($U\sin I$), cannot be specified.

We conducted case studies and interpreted the fountain circulations observed based on the published SUPIM simulation studies [1]–[3] [9] [20]. These case studies included the higher solar activity 1–3 April 2022 events unfolding over the Mid Pacific ($180 - 200^\circ\text{E}$) and demonstrated how ICON observed the two-peak EIA during a pre-PRE phase along with the underlying forward fountain circulation and the breaking-down two-peak EIA after the equatorial ($V_{\text{E} \times \text{B}})_\perp$ drift reversal along with the underlying reverse fountain circulation. For these events, Jicamarca ISR drift measurements specified the PRE's local time that was applicable to the Mid Pacific because of the PRE's longitudinally independent local time of occurrence [38]. Recent studies show [38] that the PRE's local time strongly de-

depends on the declination angle that varies little along the dip equator outside the Brazilian sector making the PRE's LT longitudinally independent outside the Brazilian sector. Also, we investigated the lower solar activity 3 March 2022 events unfolding in the Asian sector (70 - 140°E) and demonstrated how ICON observed the single-peak EIA (centered over the dip equator) during a post-PRE phase along with the underlying forward fountain circulation. In the absence of Jicamarca ISR data, the computed ΔH values obtained from a pair of local magnetometer stations [35] [36] provided an indication when the PRE occurred in LT at $\sim 105^\circ\text{E}$ (geographic) longitude. These single-peak EIA events demonstrated how ICON observed the underlying forward fountain circulation in the post-PRE phase.

Finally, we highlight that these case studies consistently provided observational evidence and thus confirmed the original definition of meridional drift (V_{MER}) and demonstrated that over a narrow 2.5° latitude range of the dip equator, within $\pm 1.25^\circ$ (dip) latitudes, $V_{\text{MER}} \equiv V_{\text{VER}}$. This is consistent with the latitudinal variation of $V_{\text{VER}}(\theta)$ as $V_{\text{VER}}^{\text{equ}} [\cos^3 \theta / (1 + 3 \sin^2 \theta)]$ [38] [50]. However, away from the dip equator, in the regime of field-aligned diffusions (*i.e.*, upward/downward ($V_{\text{mecha}} \sin I$)_I drift), V_{MER} and V_{VER} varied differently. While the radial V_{VER} measurements illustrated the total upward/downward ($V_{\text{mecha}} \sin I$)_I drift's vertical component during reverse/forward fountain circulation, the V_{MER} measurements illustrated the total upward/downward ($V_{\text{mecha}} \sin I$)_I drift's meridional component during reverse/forward fountain circulation.

5. Conclusion

From the observations presented in this study, we conclude that a dip latitude restriction of $\sim \pm 1.25^\circ$ (dip) should be applied to the ICON meridional (V_{MER}) and cross-track radial or vertical drift (V_{VER}) data in order to observe and investigate the equatorial upward/downward (V_{ExB})_⊥ drift variations over the dip equator scientifically correctly. Without such latitudinal restriction, the drift data considered contain off-equatorial upward/downward ($V_{\text{mecha}} \sin I$)_I drifts measured along the inclined magnetic field lines. Although the events presented did not demonstrate the evening PRE, only pre-PRE phase and post-PRE phase scenarios, this limitation had no effect on our interpretations and conclusions. Therefore, the findings of this study are still significant, as they improve our understanding of how ICON observed the equatorial upward/downward (V_{ExB})_⊥ drift over the dip equator and the off-equatorial upward/downward ($V_{\text{mecha}} \sin I$)_I drift's vertical and meridional components, and thus fill some of the existing knowledge gaps related to the scientific phenomena of forward and reverse fountain circulations.

Author Contributions

Conceptualization, I.H.; methodology, I.H.; software, I.H. and B.C.L.; validation, I.H. and B.C.L.; formal analysis, I.H.; investigation, I.H.; resources, B.C.L.; data curation, I.H.; writing—original draft preparation, I.H.; writing—review and editing, B.C.L. and I.H.; visualization, I.H.; supervision, B.C.L.; project administra-

tion, B.C.L.; funding acquisition, B.C.L.

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Conflicts of Interest

The authors declare no conflicts of interest.

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