Author comment in response to Anonymous Referee #2

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We thank the referee for identifying the need to distinguish the physical interpretation of the measurements from a reconstruction of ionospheric structures. We agree that some expressions in the submitted manuscript made the spatial inference sound more direct than the observations allow. We address the major concerns and each language example below. In accordance with the editorial instruction for the final-response phase, these are explanations and proposed changes; a revised manuscript has not been prepared.

R2.1. What the GEO and moving-IPP comparison can distinguish

Referee comment

> *1. The nearly fixed IPP of GEO satellites can sample only a limited region; and since TEC is an integrated quantity, GEO TEC does not necessarily represent the physical state at a strictly fixed ionospheric location. Observations from moving IPPs, by contrast, contain the effects of both temporal evolution and spatial sampling. Please state more explicitly in the text what a comparison between GEO TEC and TEC from other satellites can and cannot distinguish.*

Response

We agree. A thin-shell IPP is a representative intersection used to describe observing geometry. It is not the location of a point measurement of electron density. Even after vertical mapping, satellite-specific TEC is derived from an integral along the signal path. A nearly repeated GEO path samples a limited volume, and changes in its TEC may arise from density changes anywhere along that path, from structures moving through it, or from changes in the vertical distribution of plasma and its contribution to the integral. Small residual path motion also remains.

The useful distinction is therefore between nearly repeated and substantially changing viewing paths. In winter, the afternoon enhancement occurs in both groups, including the common elevation-azimuth sample. For that sample, both groups have negative night-minus-afternoon contrasts, and their paired difference is -0.00458 TECU (95% interval -0.01745 to 0.00489; 174 dates; Table S16). This supports time-varying disturbances along the repeatedly sampled paths: local evolution and the passage of a disturbance are both possible. Satellite motion across an otherwise stationary horizontal gradient is not a satisfactory explanation by itself. The unresolved group difference does not establish equality of the two groups or uniformity over the whole Hainan region.

In summer, the aggregate GEO contrast is positive (0.00508 TECU, 95% interval 0.00035 to 0.00985; 450 dates; Table S18), and the near-fixed group also remains positive in the matched comparisons. There is thus evidence of a near-midnight increase along nearly repeated paths, not only along moving ones. Individual directions differ, however. In Table S16, the paired moving-minus-near-fixed difference is positive with elevation matching and negative in the more restricted elevation-azimuth sample. The latter is -0.02666 TECU (95% interval -0.05152 to -0.00300; 114 dates). This does not support a universal rule that faster IPP motion produces a stronger summer enhancement.

Together, the repeated-path enhancement and the directional variation favor an interpretation in which the nighttime disturbance develops with time and has nonuniform horizontal organization. Distinct regions or preferred orientations are plausible explanations for why different paths record different amplitudes. They are not uniquely reconstructed structures. Joint direction matching also reduces the summer support from 442 to 114 dates, so the change in the group contrast cannot be assigned entirely to azimuth independently of sample composition. Line-of-sight integration, geometry, and temporal evolution prevent a quantitative partition of these contributions from this single receiver.

We would revise Sect. 2.2 to explain this observational distinction before introducing speed thresholds, and Sect. 4.2 to develop the winter and summer interpretations at this level. Abstract and conclusion wording would refer to nearly repeated viewing paths and to evidence consistent with horizontal organization, rather than implying a measurement at a strictly fixed point or a recovered spatial distribution. Regional TEC maps or coordinated multi-station measurements are needed to determine structure extent, orientation, and propagation.

R2.2. Disturbance classification and candidate mechanisms

Referee comment

> *2. dTEC RMS can be used to measure the amplitude of short-timescale TEC variability, but it is not the only criterion for identifying MSTIDs, spread-F structures, or other small- and medium-scale processes. Identifying MSTIDs requires observations of the propagation of the disturbance in TEC from multiple GNSS stations; spread F requires direct observation with an ionosonde, or discrimination using the S4 index or ROTI from GNSS scintillation receivers. Unless the manuscript provides diagnostic evidence that supports such attribution, please avoid wording that implies a specific disturbance type. In the Discussion, the observed seasonal variations should be distinguished from hypotheses about the underlying mechanisms, and the observations still needed to determine the physical processes should be stated.*

Response

We agree that dTEC RMS alone does not identify a disturbance class. It measures the amplitude of short-timescale variability under the stated detrending and RMS definition. The winter and summer enhancements, and their differing responses to viewing geometry, are observations; MSTIDs, evolving density gradients, and irregularity boundaries are candidate explanations.

We would organize the interpretation around that distinction. Winter supports evolving or passing daytime disturbances along both types of viewing path. Summer supports a near-midnight increase whose strength differs among directions. These features can be compared with the timing and directional characteristics reported in regional MSTID and spread-F studies, without relabeling our complete sample as those phenomena. The response to Referee #1 provides the proposed regional comparison and the completed F10.7 split. The latter leaves the high-minus-low amplitude difference uncertain and does not select a mechanism.

For identification, coordinated GNSS receivers or spatially resolved airglow observations would establish wavefronts, coherent propagation, and horizontal scales. Ionograms would establish spread-F morphology. Simultaneous S4 and ROTI would characterize associated scintillation and rapid TEC variability; they are complementary diagnostics rather than interchangeable definitions of spread F. Spatially resolved depletions and coordinated optical or GNSS observations would help test a plasma-bubble interpretation. These are the additional kinds of evidence needed, not analyses claimed to have been performed in this study.

We would make the candidate status explicit where these processes are introduced in Sect. 4.2 and collect the required discriminating observations in Sect. 4.3. The scientific conclusion would remain that the seasonal enhancements have different temporal and directional characteristics, without claiming that the present RMS data identify their unique generation mechanism.

R2.3. General language clarity

Referee comment

> *The grammar throughout the text needs careful revision. A few examples are listed here:*

Response

We agree that several compact expressions obscured the measurements and the processing. In a subsequent revision we would review the language throughout, with particular attention to what was measured, what was averaged, and which statements are interpretations. We would use direct physical descriptions and avoid introducing technical shorthand such as “daily-balanced” before explaining it. The specific corrections proposed below illustrate that approach; we do not claim that a full manuscript language revision has already been completed.

R2.4. Line 14: daily-balanced observations

Referee comment

> *Line 14: “analyzed daily-balanced GPS and BeiDou observations” - I do not fully understand what this means.*

Response

This refers to giving each represented date one contribution to a climatological cell, rather than pooling all samples and allowing densely sampled dates to dominate. Within each source-UTC-date and local-time cell, we first calculate a median; the climatological value is then the median of these date-level values. The observations themselves are not “balanced” by changing their measured values. We propose to state in the abstract that the climatologies use daily medians with equal weight for each represented date, and to give the aggregation explicitly in Sect. 2.1.

R2.5. Line 15: daytime plasma buildup

Referee comment

> *Line 15: “VTEC followed daytime plasma buildup and was strongest in autumn” is a vague description. What is “daytime plasma buildup”?*

Response

The intended description is the measured daily curve in Fig. 2: VTEC increases after sunrise, reaches a post-noon maximum, and declines at night. Its daytime values are highest in autumn in this record. We would use that direct description in the abstract. Discussion of solar production, loss, and transport would remain in the Discussion rather than being compressed into the phrase “plasma buildup”.

R2.6. Line 17: what is compared along BeiDou paths

Referee comment

> *Line 17: “We then compared BeiDou paths...” - do you mean “we then compared the VTEC measured along BeiDou paths...”?*

Response

The quantity compared is satellite-specific dTEC RMS derived from the BeiDou ATEC records, not the multi-satellite background VTEC series. We would state this explicitly: the comparison concerns dTEC RMS along nearly repeated and moving BeiDou viewing paths. IPP motion describes the geometry used to group those measurements, not a separate measured disturbance amplitude.

R2.7. Line 33: plasma amount and short-timescale variability

Referee comment

> *Line 33: “The amount of plasma and the strength of short-timescale structure are related but different properties.” I cannot understand this.*

Response

We would replace this abstraction with the measurement definitions. VTEC describes the electron column content after vertical mapping. dTEC RMS describes the size of faster departures from the slowly varying satellite-specific TEC background. A daily change in the column content and a fluctuation superimposed on that background need not have the same seasonal or local-time maximum. This is the distinction intended in the introduction; it does not imply that the two quantities have unrelated physics.

R2.8. Line 34: a high-VTEC ionosphere can be smooth

Referee comment

> *Line 34: "A high-VTEC ionosphere can be smooth." I cannot understand this.*

Response

We would remove "smooth" here. The intended point is that a large but slowly varying TEC background may produce small detrended fluctuations, whereas a lower background can contain larger short-timescale departures. The revised explanation would refer to temporal variability along the measured paths, not infer a spatially smooth ionosphere from a large VTEC value. This clarification would be combined with the preceding response into one short introduction paragraph.

R2.9. Line 39: description of perturbation maps

Referee comment

> *Line 39: "Two-dimensional TEC perturbation maps made the spatial evolution of traveling ionospheric disturbances visible over dense receiver networks" should be revised to "The spatial evolution of traveling ionospheric disturbances is made visible in two-dimensional TEC perturbation maps constructed from dense receiver-network data".*

Response

We agree with the suggested clarification. We would use a direct description that maps constructed from dense receiver-network data reveal the spatial evolution of traveling ionospheric disturbances. This also makes clear why those network observations contain information about propagation that a single-receiver RMS comparison does not provide.

R2.10. Lines 78-80: processing procedure and equations

Referee comment

> *Lines 78-80: I do not quite follow the data-processing procedure described here. One or two equations would help clarify it.*

Response

We would explain the two processing branches separately. Background VTEC uses the accepted multi-satellite 5 min values. Satellite-specific detrending uses ATEC records with a nominal 30 s cadence; the resulting 30 min RMS is evaluated every 5 min. The opening description of the workflow currently compresses these different sampling intervals and should distinguish them.

For satellite s, let A_s(t) denote the supplied absolute TEC. Within an accepted continuous arc, define the detrended value and its RMS as

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delta A_s(t) = A_s(t) - median{A_s(u): u in B_60(t)},

R_s(t) = [ (1/N_s,t) sum_{u in W_30(t)} delta A_s(u)^2 ]^(1/2).
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Here B_60(t) is the centered 60 min background window, W_30(t) is the centered 30 min RMS window, and N_s,t is the number of valid residuals in that RMS window. Windows retain the existing sampling and two-sided-support requirements. Arcs are split at gaps longer than 90 s and at source-UTC-date boundaries; the equations do not bridge such gaps or boundaries.

For a month-local-time cell, its daily value is the median of accepted satellite RMS windows assigned to that date and cell; its climatological value is the median of these daily values. The VTEC branch applies the same two-stage date aggregation to the accepted multi-satellite VTEC values. The source UTC date, the local month/season, and the LST bin would be defined alongside this explanation. These equations restate the existing calculation; they do not introduce a new filter or change the results. We propose to place them in Sect. 2.1, with a short introductory description of the two cadences in the opening of Sect. 2.

R2.11. Figure 1a: numbers in the calendar

Referee comment

Line 160, Fig. 1a: What does the number given for each month in the calendar represent?

Response

Each value is the fraction of calendar dates represented in that source year-month in the coverage series plotted in the panel: represented dates divided by the number of calendar days in that month. Thus, 1.00 denotes a represented date on every calendar day, and 0.60 denotes approximately 60% of the calendar days. This does not mean continuous observations throughout every represented day. The number is not a satellite count, a count of RMS windows, or the coverage of each local-time bin. Gray cells precede the study period.

We would add this explicit definition to the caption and label the color scale as a fraction of calendar dates. In response to Referee #1, this methodological panel is proposed for the Supplement; its coverage definition would remain visible there.