PAPER CHECK · IONOSPHERE

A paywalled paper's record and open companions: density falls slowly, storms hit as before

Three researchers at DLR and Kyushu University presented a 4-page paper on long-term changes in the ionosphere's response to the Sun and to geomagnetic storms over five solar cycles [1][3 p. 18]. It is paywalled and no abstract is public, so we checked it through its record and its authors' two open papers on the same questions, read in full [6][7]. Those find that at one German station the peak electron density for the same solar flux has fallen since the 1960s, and that the summer storm response at six stations shows no significant change; our re-runs from public data agree, with limits [7 p. 73][6 p. 1]. S0 News linked the paper on November 6, 2026 [2].

By Fact-Checked Science · Published November 6, 2026

OUR ANALYSIS marks our own reasoning and calculations, including every number from our re-runs of the authors' analyses from public data, and the verdicts are our assessment. Everything else comes from the numbered sources. We could read only the record of the conference paper [1], so it has no locators; in its authors' two open papers [6][7], p. gives a page of the journal's PDF.

A paper we couldn't read; its authors' open papers check out on the slow change and the steady storm response; their explanation stays untested

OUR ASSESSMENT

−20%

NmF2 at the same solar radio flux in cycle 24 against cycle 20, at Juliusruh in January at 14 LT, in our re-run of the authors' comparison from public data; with another solar index, F10.7, the fall is about 0–8%, depending on the fit [7 p. 73][39]

±0.8–3.2

points of NmF2 a cycle: the 95% margins of a trend in the summer storm response across the five cycles in our Juliusruh re-run, about a third of the response. No trend showed, as the authors found none at six stations [6 p. 1]

34

days a year with Kp of 5− or more in cycle 24, against 65–101 in cycles 20–23: the quietest of the five cycles, on GFZ's Kp [36]

THE AUTHORS' CLAIMS

CONTEXT

"Long-Term Changes in the Ionospheric Response to Solar and Geomagnetic Forcing Over the Past Five Solar Cycles"

The conference paper's title, its only public words [1]

A title that names its subject. The paper is paywalled and no abstract is public [1][5]. The authors' two open papers on the same questions find one change and not the other: at one German station NmF2 at a given solar flux has fallen since the 1960s [7 p. 73], while at six stations the summer storm response shows no significant change [6 p. 1]. See section 1.

TRUE

"Between SC20 and SC24, the observed decrease is consistently higher than 2.9 % per decade, reaching 4.4 % per decade at 90 sfu between 1964 and 2019."

Tan Jun Rios and colleagues, *Annales Geophysicae* 2025, abstract; the decrease is in NmF2's response to solar flux [7 p. 73]

Our re-run from Juliusruh's public record, with our reading of the *Annales* paper's cleaning, the one that matches its counts, finds cycle 24 about 19–24% below cycle 20 at every F30 from 60 to 120 sfu, 4.5–5.4% a decade, with 95% intervals well below zero [39][40]. It is one station, one month and one hour, and the size depends on the solar index, as the authors warn [7 p. 74]: with F10.7 the fall is about 0–8%, depending on the fit. Independent work favours F30 for this purpose [12 Abstract]. Our analysis; see section 4.

TRUE

"However, no significant long-term changes in the relationship between NmF2 and GA are identified within the Kpm range of 1–5."

Tan Jun Rios and colleagues, *JGR Space Physics* 2025, abstract; GA is geomagnetic activity [6 p. 1]

Our re-run at Juliusruh, the one station whose record we could rebuild, agrees: the five cycles' median storm-time depletions differ by 3 points or less at Kpm 1–3 and by up to 7 at Kpm 3–5, cycle 22 the deepest, and no trend across the cycles is significant [39][36]. The authors note one exception: at Hobart, cycle 24's medians are "notably higher than those of the other SCs" [6 p. 10]. It says nothing about large storms, too rare to test, or about winter, which the authors call inconclusive [6 p. 12]. Our analysis; see section 5.

UNCONFIRMED

"This is mainly attributed to the combination of small changes in CO_2 concentration (compared to simulation results from models) and increasing solar wind forcing during SC 23 and 24 than previous SCs."

The same paper's abstract [6 p. 1]

The CO_2 numbers hold, and the rise since 1964 is about a third of what the models assume, in doublings [6 p. 13][41]. The solar-wind part means more solar-wind forcing for the same Kp [6 p. 14], and in NASA's OMNI data that pattern is there: measured against each cycle's own solar wind, cycles 23 and 24 need more of it for the same Kp than one shared relation would give [37]. What no test shows is that the CO_2 and solar-wind effects cancel. Our analysis; see section 6.

PARTLY TRUE

"Nevertheless, given the locations of the selected ionosonde stations, long-term geomagnetic changes are expected to be relatively minor, with negligible effects on NmF2 (Cnossen & Richmond, 2013)."

The same paper, discussion [6 p. 13]

Over Juliusruh, Slough/Chilton and Moscow the field at 300 km changed by 2.5% or less from 1965 to 2015, and over Hobart by −1.7%, though Hobart's magnetic latitude moved 1.6° [38]. Over Port Stanley it fell 10.9%, three times the dipole's 3.5%, more than over all but about 7% of the globe, by our count. The "relatively minor" fails at Port Stanley; whether the effect on NmF2 is negligible there is untested. The model the authors cite puts its strongest effects outside all six stations [20 Abstract], and they add that the field's change "may complicate the detection of trends" [6 p. 13]. Our analysis; see section 7.

1 · WHAT WE COULD READ

A paywalled 4-page paper, read through its record; two open papers by the same authors, read in full

Three researchers, at the German Aerospace Center (DLR) in Neustrelitz and at Kyushu University, presented the paper at the Kleinheubach Conference in Miltenberg in September 2026, in its Young Scientist Award session [1][3 p. 18]. We could read its record, not the paper.

What the record shows

Maria Gloria Tan Jun Rios and Claudia Borries of DLR's Institute for Solar-Terrestrial Physics and Huixin Liu of Kyushu University; pages 1–4 of the 2026 Kleinheubach Conference proceedings, published by IEEE and dated September 2026; 13 references; no abstract; IEEE's text-and-data-mining terms, not an open licence [1]. OpenAlex lists it as closed, with no copy in any repository [5]. It was talk KH2026-YSA-1-4, on September 23 [3 p. 18], and the first author is listed among the conference's Young Scientist Award recipients [3 p. 9]. The call for papers says of such 4-page papers: "After the usual peer review, this paper will be submitted to the IEEE Xplore Digital Library shortly after the conference, provided that the conference presentation actually took place" [4].

OUR ANALYSIS

What that means for this check

The site's owner reports the paper is paywalled, and we found no public copy: DLR's repository refused our search as too many requests, which we didn't retry, and the indexes list none [5]. So the only words of the paper we rate are its title. The authors' claims rated here come from their two open papers on the same questions, read in full: on storms, *JGR Space Physics* 2025 [6]; on the Sun's steady forcing, *Annales Geophysicae* 2025 [7]. They are not the conference paper, and each card names its paper. The first author's doctoral thesis of September 2026 has nearly the same title, but it is open only inside DLR [8]. If you have the conference paper, tell us through the correction form below, and we will revise this page.

Three papers, kept apart

	THE CONFERENCE PAPER (2026)	*JGR SPACE PHYSICS* (2025)	*ANNALES GEOPHYSICAE* (2025)
Question	The ionosphere's response to solar and geomagnetic forcing over five solar cycles, by its title [1]	Has NmF2's response to geomagnetic activity changed from cycle 20 to cycle 24? [6 p. 2]	Is NmF2's dependence on solar indices the same in every cycle? [7 p. 74]
Data	Not known	Hourly NmF2 at six midlatitude ionosondes, 1964–2019 [6 p. 3]	Hourly NmF2 at Juliusruh, Germany, 1957–2023 [7 p. 73]
What we read	The record and the programme	The whole paper	The whole paper
Licence	IEEE's terms	CC BY 4.0 [6 p. 1]	CC BY 4.0 [7 p. 73]
Review	Conference review, if it followed the call for papers [4]; the record doesn't say whether it is an award application's extended abstract [3 p. 8]	Peer reviewed	Peer reviewed, after open discussion [7 p. 87]

NmF2 is the peak electron density of the ionosphere's F_2 layer, derived from its critical frequency, foF2 [6 p. 2]. A related talk by the group at AOGS 2026 and a 2026 paper with Norbert Jakowski we read as abstracts [9][10].

2 · WHAT THE RECORD ADDS

By its references, the paper puts the Sun's steady forcing beside storms; nothing in its record points to new data

Its title adds "Solar" to the subject of the authors' *JGR* paper [1][6 p. 1], and its 13 references, which we looked up one by one, add the papers on the solar side [1].

The conference paper's 13 references, by subject

SUBJECT	REFERENCES
Long-term change and its causes	Roble and Dickinson 1989 on CO_2 cooling [14 Abstract]; Bremer 1998 on trends over Europe [33 Abstract]; Cnossen 2014 on the magnetic field against CO_2 [21]; Laštovička 2024 on trends and the choice of solar index [13]
The Sun's forcing	Two papers on how foF2 and NmF2 level off at high solar activity [34 Abstract][35 Abstract]; the authors' *Annales* paper [7]
Storms	Prölss 1995 [28]; Fuller-Rowell and colleagues 1996 on the seasons [27 Abstract]; Buonsanto 1999 [30]
CO_2 and storms in models	Liu and colleagues 2021 [18 Abstract]; Pedatella and colleagues 2025 [19 Abstract]
The authors' storm paper	Their *JGR* paper [6]

OUR ANALYSIS

What that tells us, and what it doesn't

The record suggests a 4-page summary of the two lines of work, which the thesis title also brings together [8]. It can't show whether the paper adds stations, numbers or another solar index, or how it words its findings. So the claims below come from the open papers, and nothing here is attributed to the conference paper beyond its title.

3 · WHY THE IONOSPHERE WOULD CHANGE

Storms deplete summer NmF2 and lift winter NmF2; rising CO_2 slowly cools and lowers the upper atmosphere

Two pieces of well-established physics frame both open papers: how the F_2 layer answers a storm, and how it may drift over decades [6 p. 2][7 p. 73].

Storms, by season

A storm heats the polar upper atmosphere, and the heating drives winds and upwelling that carry air rich in molecular nitrogen to greater heights [26 Abstract]. In summer the prevailing circulation carries that air to middle latitudes, where it speeds the loss of electrons: a negative storm. In winter the circulation holds it back, and downwelling of atomic oxygen raises NmF2: a positive storm [27 Abstract]. Reviews describe the same pattern [29][30], as does a review of storms in total electron content [31 Abstract]. The *JGR* paper finds it in its data: negative on summer mornings, positive on winter afternoons [6 p. 6], and weaker correlations at the stations nearest the magnetic equator, which it ties to Field and Rishbeth's finding of deeper depletions at higher magnetic latitudes [6 p. 9][32].

Decades: CO_2 cooling

In a 1989 model, doubling CO_2 and methane cooled the thermosphere by about 50 K [14 Abstract]. Rishbeth, and then Rishbeth and Roble, carried the idea to the ionosphere: a cooler, contracted upper atmosphere with its layers lower down [15][16], as the *Annales* paper recounts [7 p. 73]. Observations since then show a thinning thermosphere and, in foF2, "very weak but statistically significant negative trends" [11 Abstract][17]. Other drivers matter too: the magnetic field's slow change, dominant in some regions, and long-term swings in geomagnetic activity [11 §7][25 Abstract].

4 · THE SOLAR HALF

At the same F30, Juliusruh's NmF2 fell about a fifth from cycle 20 to cycle 24; with F10.7 it shrinks to a few per cent

The *Annales* paper fits NmF2 against the Sun's radio flux cycle by cycle and finds the curves falling [7 p. 73]. We repeated its main comparison, January at 14 local time, from Juliusruh's public record [39], with the solar flux [40] and Kp [36].

In the authors' words SC20 and SC24 are solar cycles 20 (1964–1975) and 24 (2008–2019); sfu is the solar flux unit.

> *"Most importantly, the response of NmF2 to solar flux shows a clear long-term change as the slopes of the model curves decrease with time for each solar cycle."*
>
> Tan Jun Rios and colleagues (2025), abstract [7 p. 73]

> *"we have identified and removed days where the Kp index is equal to or exceeds 3, together with the 48 h succeeding them."*
>
> The same paper, on its quiet days [7 p. 76]

> *"So far, the data for five ionosonde station for five complete solar cycles have been analyzed."*
>
> The same paper, conclusions [7 p. 82]

F30, CYCLE 24 AGAINST 20 · OUR ANALYSIS

−19 to −24%

at every F30 from 60 to 120 sfu; the 95% intervals run from −31% to −13% [39][40]

A DECADE · OUR ANALYSIS

4.5–5.4%

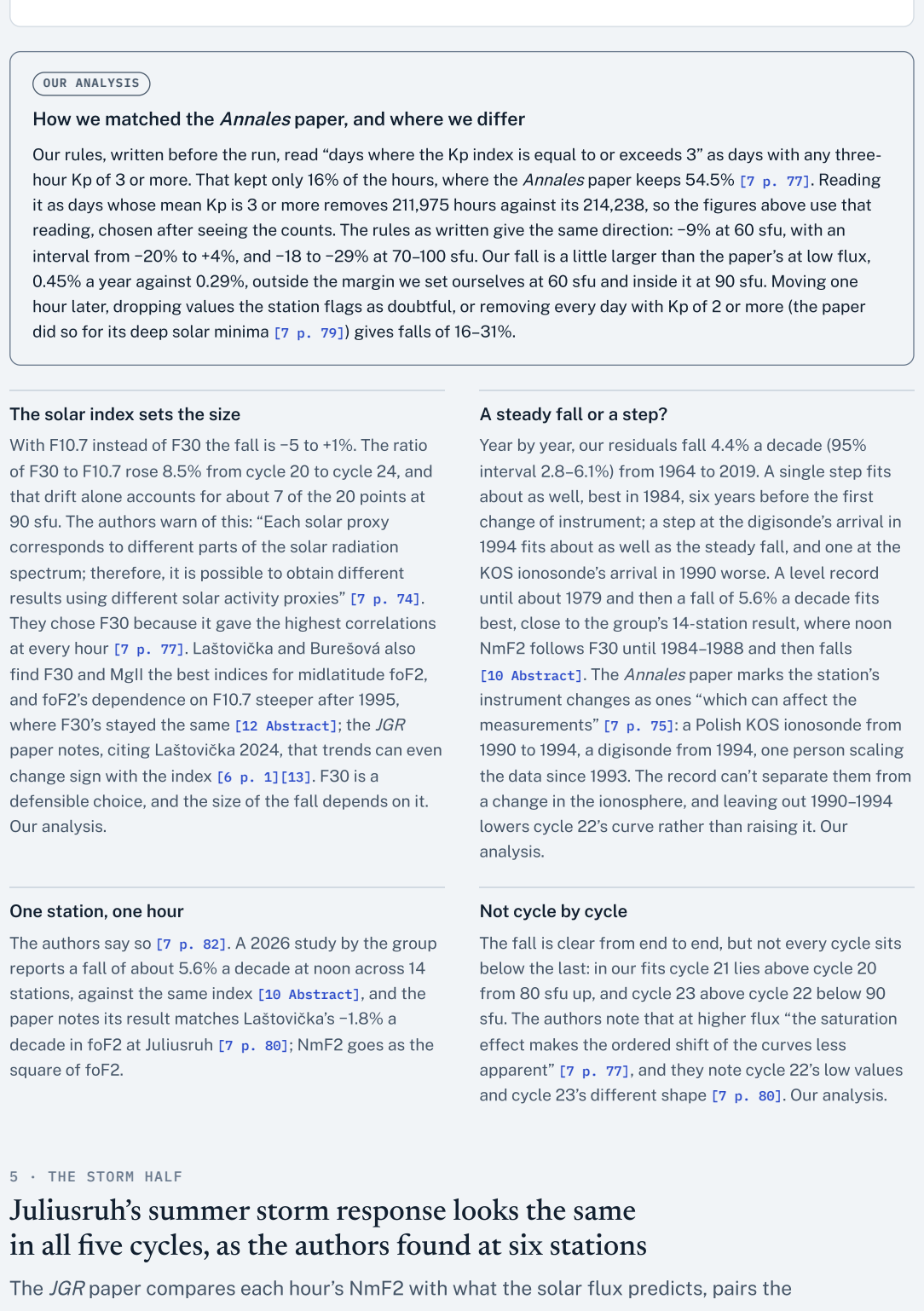
over the 43.6 years between the cycles' midpoints; the paper reports more than 2.9%, reaching 4.4% at 90 sfu [7 p. 73]

THE SAME WITH F10.7 · OUR ANALYSIS

−5 to +1%

at 80–120 sfu with the *Annales* paper's curves, and −6 to −8% with straight lines [36]

NmF2 in cycle 24 against cycle 20, at the same solar flux OUR ANALYSIS



Our chart of our re-run: hourly foF2 from the Juliusruh ionosonde via the World Data Centre [39], F30 from Nobeyama via IUP Bremen [40], F10.7 and Kp from GFZ [36]; a cubic fit per cycle on quiet days, the paper's method [7 p. 76]; 95% intervals by resampling the days. Not redrawn from the paper.

OUR ANALYSIS

How we matched the *Annales* paper, and where we differ

Our rules, written before the run, read "days where the Kp index is equal to or exceeds 3" as days with any three-hour Kp of 3 or more. That kept only 16% of the hours, where the *Annales* paper keeps 54.5% [7 p. 77]. Reading it as days whose mean Kp is 3 or more removes 211,975 hours against its 214,238, so the figures above use that reading, chosen after seeing the counts. The rules as written give the same direction: −9% at 60 sfu, with an interval from −20% to +4%, and −18 to −29% at 70–120 sfu. Our fall is a little larger than the paper's at low flux, 0.45% a year against 0.29%, outside the margin we set ourselves at 60 sfu and inside it at 90 sfu. Moving one hour later, dropping values the station flags as doubtful, or removing every day with Kp of 2 or more (the paper did so for its deep solar minima [7 p. 79]) gives falls of 16–31%.

The solar index sets the size

With F10.7 instead of F30 the fall is −5 to +1%. The ratio of F30 to F10.7 rose 8.5% from cycle 20 to cycle 24, and that drift alone accounts for about 7 of the 20 points at 90 sfu. The authors warn of this: "Each solar proxy corresponds to different parts of the solar radiation spectrum; therefore, it is possible to obtain different results using different solar activity proxies" [7 p. 74]. They chose F30 because it gave the highest correlations at every hour [7 p. 77]. Laštovička and Burešová also find F30 and MgII the best indices for midlatitude foF2, and foF2's dependence on F10.7 steeper after 1995, where F30's stayed the same [12 Abstract]; the *JGR* paper notes its result matches Laštovička 2024, that trends can even change sign with the index [6 p. 1][13]. F30 is a defensible choice, and the size of the fall depends on it. Our analysis.

A steady fall or a step?

Year by year, our residuals fall 4.4% a decade (95% interval 2.8–6.1%) from 1964 to 2019. A single step fits about as well, best in 1984, six years before the first change of instrument; a step at the digisonde's arrival in 1994 fits about as well as the steady fall, and one at the KOS ionosonde's arrival in 1990 worse. A level record until about 1979 and then a fall of 5.6% a decade fits best, close to the group's 14-station result, where noon NmF2 follows F30 until 1984–1988 and then falls [10 Abstract]. The *Annales* paper marks the station's instrument changes as ones "which can affect the measurements" [7 p. 75]: a Polish KOS ionosonde from 1990 to 1994, a digisonde from 1994, one person scaling the data since 1993. The record can't separate them from a change in the ionosphere, and leaving out 1990–1994 lowers cycle 22's curve rather than raising it. Our analysis.

One station, one hour

The authors say so [7 p. 82]. A 2026 study by the group reports a fall of about 5.6% a decade at noon across 14 stations, against the same index [10 Abstract], and the paper notes its result matches Laštovička's ~1.6% a decade in foF2 at Juliusruh [7 p. 80]; NmF2 goes as the square of foF2.

Not cycle by cycle

The fall is clear from end to end, but not every cycle sits below the last: in our fits cycle 21 lies above cycle 20 from 80 sfu up, and cycle 23 above cycle 22 below 90 sfu. The authors note that at higher flux "the saturation effect makes the ordered shift of the curves less apparent" [7 p. 77], and they note cycle 22's low values and cycle 23's different shape [7 p. 80]. Our analysis.

5 · THE STORM HALF

Juliusruh's summer storm response looks the same in all five cycles, as the authors found at six stations

The *JGR* paper compares each hour's NmF2 with what the solar flux predicts, pairs the difference with geomagnetic activity some hours earlier, and compares the cycles in steps of Kpm, the Kp index in decimal steps [6 p. 4][6 p. 8]; its windows are 2 Kpm wide [6 p. 9].

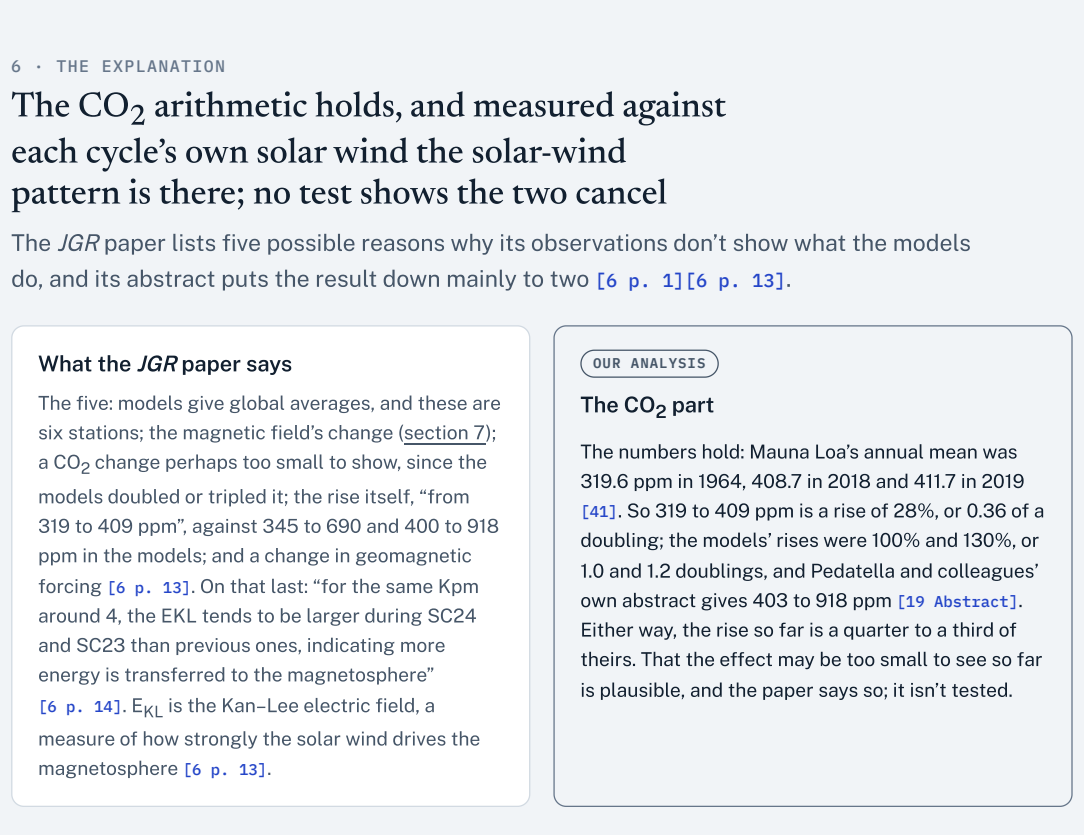
In the authors' words GA is geomagnetic activity; Kpm 5 is a minor (G1) storm on NOAA's scale [42].

> *"No clear long-term trend is detected in the response in local summer"*
>
> Tan Jun Rios and colleagues (2025), key points [6 p. 1]

> *"Only in Hobart (HO54K), the median values for SC24 are notably higher than those of the other SCs."*
>
> The same paper, of its summer results; at Chilton, Juliusruh and Moscow it finds cycle 24 slightly higher at Kpm 5, but not significantly [6 p. 10]

> *"Thus, these positive responses remain inconclusive."*
>
> The same paper, of the winter results [6 p. 12]

The summer-morning storm response at Juliusruh, cycle by cycle OUR ANALYSIS



Our chart of our re-run of the paper's method: May–July, 5–7 LT, Juliusruh foF2 [39], F30 [40], GFZ's Kp [36]; quiet-day background curves per cycle month, hour and cycle; windows 2 Kpm wide in steps of 1 [6 p. 4][6 p. 9]. Not redrawn from the paper.

CORRELATION AT 6 LT · OUR ANALYSIS

−0.69

between the NmF2 residual and Kpm, all five cycles; the paper: about −0.6, and about 0.06 stronger with its 17-hour window [6 p. 7][6 p. 8]

MARGIN FOR A TREND · OUR ANALYSIS

±0.8–3.2

points of NmF2 a cycle at Kpm 1–3 to 3–5, allowing for the scatter between cycles: about a third of the response over the five cycles

HOURS ABOVE KPM 5 · OUR ANALYSIS

2–3%

of summer mornings, 1964–2019, depending on how Kpm is paired; the paper: about 98% of its data within Kpm 0–5, too few storms above to test [6 p. 4][36]

Median change in NmF2 by cycle, and the trend across the cycles

KPM WINDOW	SC20	SC21	SC22	SC23	SC24	TREND A CYCLE, 95% (DAYS RESAMPLED)	95% MARGIN, WITH CYCLE-TO-CYCLE SCATTER
1–3	−8.9%	−9.5%	−11.2%	−9.8%	−11.7%	−0.59 (−1.03 to +0.07)	±0.83
2–4	−21.9%	−22.0%	−25.9%	−22.6%	−23.1%	−0.31 (−0.90 to +0.33)	±1.80
3–5	−33.5%	−34.4%	−40.4%	−36.0%	−34.3%	−0.31 (−1.11 to +1.01)	±3.16
4–6	−41.7%	−49.0%	−50.1%	−47.1%	−42.5%	not tested	

Our analysis. Trend: a straight line through the five cycles' medians, in percentage points a cycle, with intervals from resampling days, which count only day-to-day sampling; the last column also counts the scatter of the five medians about the line, chiefly cycle 22's (3 degrees of freedom). With the other reading of quiet days, or with a centred window, the picture is the same; one of the nine trends, in the centred version at Kpm 2–4, just excludes zero (−0.65, interval −1.35 to −0.09), about what chance gives among nine.

What a null can show

Resampling days, which counts only day-to-day sampling, gives the narrower intervals in the table; allowing also for the scatter between cycles, the margins are ±0.8, ±1.8 and ±3.2 points a cycle at Kpm 1–3, 2–4 and 3–5. A trend that size would have had about an even chance of showing; a trend of about 1, 2.4 and 4.1 points a cycle, about a third of the response over the five cycles, would show four times in five. Whether the CO_2 effect the models expect is that large for the rise so far, the abstracts we could read don't say [18 Abstract][19 Abstract]. Our analysis.

Large storms and winter

Above Kpm 5 there are too few hours to test, as the authors say [6 p. 14]. In winter the correlation is weak; cycle 24 shows a larger positive response at three stations, which the authors call inconclusive [6 p. 12].

Cycle 24's data, as reasoning only

At four of the six stations cycle 24 rests entirely on the GIRO database, and at Hobart from 2015, from which the *JGR* paper keeps values "only … if it has a confidence score of 70 or higher" [6 p. 3][6 p. 15]. Whether storm-time values pass that filter as often as quiet-time ones the paper doesn't test, and we couldn't. Juliusruh's record is scaled by hand throughout [7 p. 75]. Our analysis.

6 · THE EXPLANATION

The CO_2 arithmetic holds, and measured against each cycle's own solar wind the solar-wind pattern is there; no test shows the two cancel

The *JGR* paper lists five possible reasons why its observations don't show what the models do, and its abstract puts the result down mainly to two [6 p. 1][6 p. 13].

What the *JGR* paper says

The five: models give global averages, and these are six stations; the magnetic field's change (section 7); a CO_2 change perhaps too small to show, since the models doubled or tripled it; the rise itself, "from 319 to 409 ppm", against 345 to 690 and 400 to 918 ppm in the models; and a change in geomagnetic forcing [6 p. 13]. On that last: "for the same Kpm around 4, the EKL tends to be larger during SC24 and SC23 than previous ones, indicating more energy is transferred to the magnetosphere" [6 p. 14]. E_{KL} is the Kan–Lee electric field, a measure of how strongly the solar wind drives the magnetosphere [6 p. 13].

OUR ANALYSIS

The CO_2 part

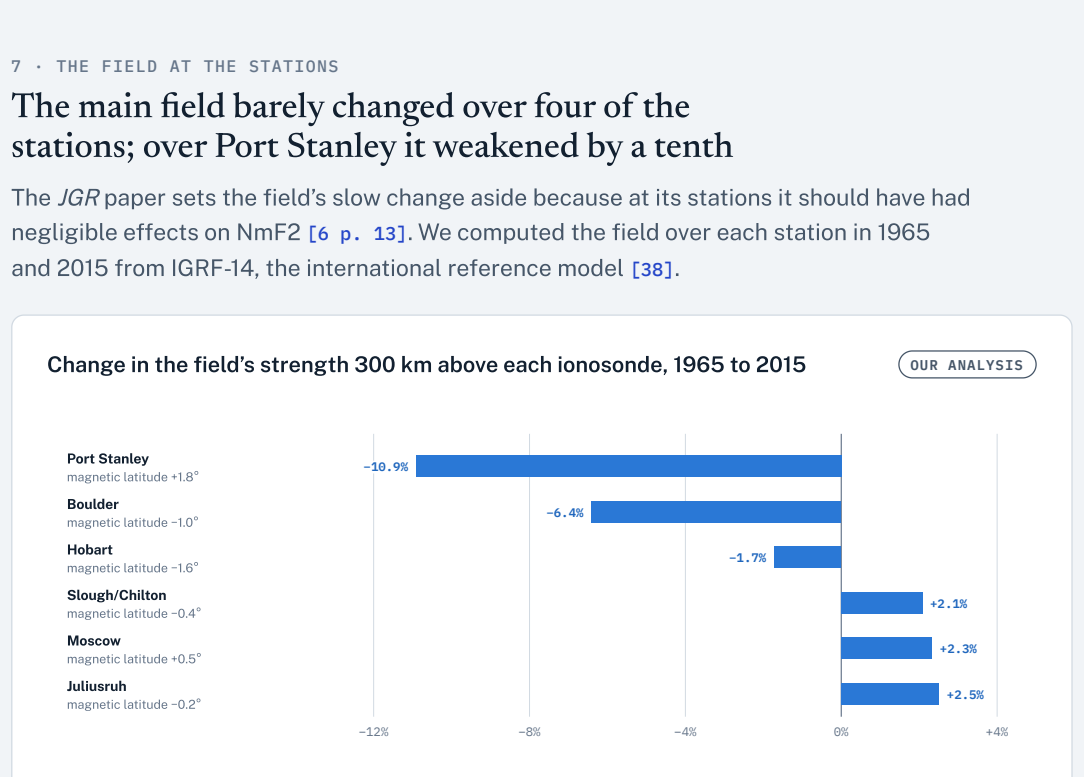
The numbers hold: Mauna Loa's annual mean was 319.6 ppm in 1964, 408.7 in 2018 and 411.7 in 2019 [41]. So 319 to 409 ppm is a rise of 28%, or 0.36 of a doubling; the models' rises were 100% and 130%, or 1.0 and 1.2 doublings, and Pedatella and colleagues' own abstract gives 403 to 918 ppm [19 Abstract]. Either way, the rise so far is a quarter to a third of theirs. That the effect may be too small to see so far is plausible, and the paper says so; it isn't tested.

OUR ANALYSIS

"Increasing solar wind forcing", in plain terms

The authors mean forcing for a given level of Kp: the solar wind's driving that goes with the same geomagnetic activity [6 p. 14]. Read plainly, the phrase would mislead: cycle 24 had the weakest solar-wind forcing and the fewest storms of the five, a mean daily Kan–Lee field of 0.67 mV/m against 0.82–0.95 in cycles 20–23 [37], and 34 storm days a year against 65–101 [36].

Storm days a year, by solar cycle OUR ANALYSIS



Our chart of GFZ's definitive Kp, CC BY 4.0 [36]; cycle dates as in the *Annales* paper [7 p. 75]. Mean Ap, cycle by cycle: 12.6, 15.7, 15.6, 12.2, 8.0, and 9.6 so far.

The Kan–Lee field against Kp, cycle by cycle, from NASA's OMNI data

CYCLE	HOURS WITH SOLAR-WIND DATA	FIELD WHERE THE MEDIAN KP REACHES 3 / 4	FIELD FOR THE SAME KP, AGAINST ONE SHARED RELATION	MEAN DAILY FIELD
SC20	46%	1.50 / 2.50	−0.12	0.82
SC21	58%	1.50 / 2.50	0.00	0.95
SC22	46%	1.40 / 2.33	−0.18	0.89
SC23	100%	1.64 / 2.50	+0.06	0.86
SC24	100%	1.80 / 3.00	+0.17	0.67

Our analysis, in mV/m, from OMNI's hourly solar wind [37] and GFZ's Kp [36]: daily medians, days with at least 12 hours of data. The third column follows the *JGR* paper's presentation, bins of the field 1 mV/m wide [6 p. 14]. The fourth compares each cycle with what its own solar wind would give if all five cycles shared one relation between Kp and the field: the median field on days of Kpm 3.5–4.5, observed minus expected, from 500 draws among days of similar field strength.

As the *JGR* paper presents it

For cycle 24 the pattern is there: the median Kpm reaches 4 only at 3.0 mV/m, against 2.33–2.50 in the earlier cycles. Under one shared relation the expected value is about 2.5, and 3.0 or more came up in under 2% of our draws. Cycle 23 differs only at Kpm 3. Our analysis.

Against each cycle's own solar wind

Measured against what each cycle's own solar wind would give under one shared relation, cycles 23 and 24 need more field for the same Kp, by about 0.06 and 0.17 mV/m (as high in 2.4% and in none of 500 draws), and cycles 20 and 22 less. That is the pattern the authors describe [6 p. 14]. Our analysis.

Patchy early data

Cycles 20–22 have solar-wind data for only 46–58% of hours, so their figures rest on fewer days [37]. Our analysis.

No test of cancelling

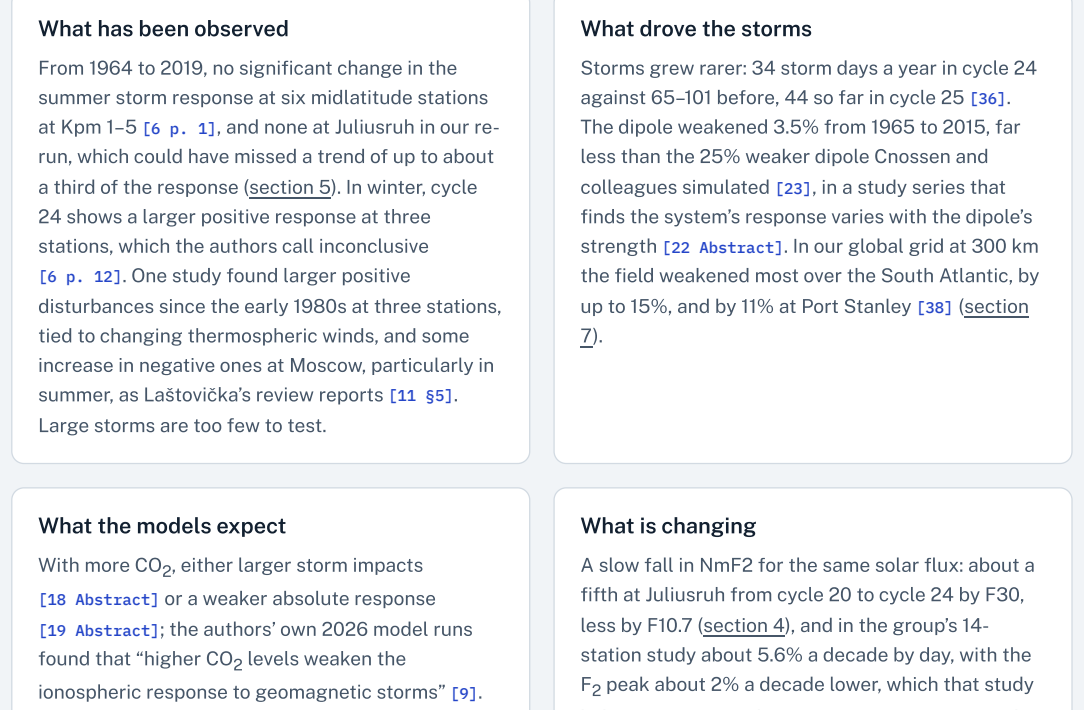
Neither effect is sized in the *JGR* paper, so whether they cancel is a hypothesis, which the paper words as "likely" in its key points [6 p. 1].

7 · THE FIELD AT THE STATIONS

The main field barely changed over four of the stations; over Port Stanley it weakened by a tenth

The *JGR* paper sets the field's slow change aside because at its stations it should have had negligible effects on NmF2 [6 p. 13]. We computed the field over each station in 1965 and 2015 from IGRF-14, the international reference model [38].

Change in the field's strength 300 km above each ionosonde, 1965 to 2015 OUR ANALYSIS



Our computation from IGRF-14's coefficients [38], at 300 km, the height the *JGR* paper uses for its magnetic equator [6 p. 3]; magnetic latitude is the centred dipole's, where + means further from the magnetic equator; Slough/Chilton compares Slough in 1965 with Chilton, its successor, in 2015. Our 2015 dipole latitudes come within about 0.2° of the *JGR* paper's Table 1 [6 p. 3], and a separate program gave the same field values to 0.1 nT.

Where models put the field's effect

In the model the authors cite, the strongest effects of the field's change over the past century fall between about 40° S and 40° N and 100° W and 50° E, where they exceed CO_2's and may dominate the trends [20 Abstract]: outside all six stations, with Boulder at its corner, as the authors expect. In whole-atmosphere runs summarised by Laštovička, the field's change dominates trends in NmF2 and its height at about 50° S–20° N, 60° W–20° E, whose edge Port Stanley sits on; is comparable to the greenhouse gases' across 120° W–20° E, a band that holds Boulder, Slough/Chilton and Juliusruh; and averages out globally [11 §7]. Field changes can't be ruled out where they are large [24 Abstract]; the conference paper cites Cnossen's comparison of the two drivers [21].

OUR ANALYSIS

What it means for the six stations

Juliusruh, Slough/Chilton and Moscow: +2.1 to +2.5%. Hobart: −1.7%, though its magnetic latitude moved −1.6°. Boulder: −6.4%. Port Stanley: −10.9%, three times the dipole moment's fall of 3.5%; in our global grid at 300 km only about 7% of the globe, by area, weakened more. So "relatively minor" fails at Port Stanley. Whether the effect on NmF2 is negligible there is untested: storm depletions deepen with magnetic latitude, as Field and Rishbeth found and the *JGR* paper notes [6 p. 9][32], and Port Stanley's rose 1.8°, but we haven't tested by how much. The authors add that the field's change "may complicate the detection of trends" [6 p. 13].

8 · A GROWING STORM RESPONSE?

The open papers find no clear sign that storms hit the ionosphere harder; what is changing is slow

One catastrophist idea holds that a weakening magnetic field or a changing Sun is letting storms strike the upper atmosphere harder, decade by decade. The authors' papers bear on it directly [6][7].

What has been observed

From 1964 to 2019, no significant change in the summer storm response at six midlatitude stations at Kpm 1–5 [6 p. 1], and none at Juliusruh in our re-run, which could have missed a trend of up to about a third of the response (section 5). In winter, cycle 24 shows a larger positive response at three stations, which the authors call inconclusive [6 p. 12]. One study found larger positive disturbances since the early 1980s at three stations, tied to changing thermospheric winds, and some increase in negative ones at Moscow, particularly in summer, as Laštovička's review reports [11 §5]. Large storms are too few to test.

What drove the storms

Storms grew rarer: 34 storm days a year in cycle 24 against 65–101 before, 44 so far in cycle 25 [36]. The dipole weakened 3.5% from 1965 to 2015, far less than the 25% weaker dipole Cnossen and colleagues simulated [23], in a study series that finds the system's response varies with the dipole's strength [22 Abstract]. In our global grid at 300 km the field weakened most over the South Atlantic, by up to 15%, and by 11% at Port Stanley [38] (section 7).

What the models expect

With more CO_2, either larger storm impacts [18 Abstract] or a weaker absolute response [19 Abstract]; the authors' own 2026 model runs found that "higher CO_2 levels weaken the ionospheric response to geomagnetic storms" [9]. All were for CO_2 rises about three times the rise so far (section 6).

What is changing

A slow fall in NmF2 for the same solar flux: about a fifth at Juliusruh from cycle 20 to cycle 24 by F30, less by F10.7 (section 4), and in the group's 14-station study about 5.6% a decade by day, with the F_2 peak about 2% a decade lower, which that study links to rising greenhouse gases [10 Abstract]. The *Annales* paper calls the decrease "not yet fully understood" and lists winds, electric fields, the magnetic field, geomagnetic activity and composition among its possible causes [7 p. 81]; the *JGR* paper notes that under CO_2 cooling "maximum electron densities may remain relatively unchanged" [6 p. 1].

OUR ANALYSIS

The papers cut against a storm response growing fast; they show a slow fall in electron density for the same solar flux, whose causes the authors call not yet fully understood.

Over five solar cycles the summer storm response above these stations shows no significant change at ordinary activity, and a trend of more than about a third of the response probably would have shown, while the storms themselves became rarer and the field over most of the stations barely changed. The "falling" upper atmosphere is real in a literal, gradual sense, about 5% a decade in daytime electron density and 2% in peak height in the group's 14-station study [10 Abstract], not a sudden one. None of this rules out a different response to a storm larger than any of the past five cycles, which no station has yet seen.

9 · REPEAT OUR NUMBERS

One script fetches the public data and recomputes every number of ours

We wrote the rules before each test and logged every later change with its hash. Three amendments came after seeing results, and say so: the reading of "disturbed days" that matches the *Annales* paper's counts; the check of the two solar indices with straight-line fits; and, after a fresh review, the trend margins that count the scatter between cycles, one more shape for the solar residuals and a global field grid. One registered rule, a comparison of the cycles' raw solar-wind medians, couldn't separate the hypotheses, because it depends on how strong each cycle's solar wind was overall; we withdrew it, and the matched comparison takes its place.

PY **ionosphere_numbers.py**
Downloads the inputs and recomputes the activity counts, the field and its global grid, both re-runs, the solar-wind comparison and the CO_2 arithmetic; needs numpy · 44 KB

JSON **ionosphere-numbers.json**
Its output: every number on this page that is ours, and the SHA-256 of each input file · 76 KB

TXT **The rules, written before each test**
common · activity · field · solar response · storm response · Kan–Lee field · CO_2; and the amendments: quiet days, after the first run · storm response, before its run · two indices, after the runs · after the review · 1–4 KB each

TXT **rules_sha256.txt**
The SHA-256 of each rules file as recorded, and when the amendments were written · 2 KB

TXT **run-logs.txt**
The logs of our verification runs: rules, scripts, inputs and outputs, each with its SHA-256 · 21 KB

Run it

`python3 -I ionosphere_numbers.py <folder>` downloads about 170 MB into that folder, reads it as data, and writes `ionosphere-numbers.json` next to the script. It takes a few minutes. The Kp and F30 files grow daily; only data before 2026 are used.

The data and their terms

Juliusruh's foF2 and **the F30 compilation** state no licence on the pages we read, so we publish only numbers derived from them [39][40]. **GFZ's Kp:** CC BY 4.0, with credit to GFZ and Matzka and colleagues [36]. **OMNI:** NASA's public data, with credit to the OMNI authors [37]. **IGRF-14:** IAGA's [38]. **CO_2:** NOAA's Global Monitoring Laboratory [41].

10 · LIMITS

What this check could and couldn't see

The record, not the paper

We rate the conference paper's title and nothing else of it [1]. Its four pages may add stations or numbers, or word things differently from the open papers.

One station rebuilt

Our re-runs use Juliusruh, whose record the World Data Centre holds in one series [39]. The other five stations mix three archives, and we didn't rebuild them; nor did we use the F30 series from CLS that the *JGR* paper cites [6 p. 15].

Our readings of the methods

Where the papers leave a choice open, the choice is ours: the reading of "disturbed days", a window of Kpm ending 9 hours before each hour, the World Data Centre's hours read as universal time, as its format note says, and an outlier cut that removed 4.1–4.9% of points per cycle where the *JGR* paper removed 0.5–2.5% [6 p. 8]. The figures shift with each, by up to 11 points, and none reverses a direction.

Abstracts only for the models

The model studies are read as abstracts [18][19], and so is the study of the dipole's strength [22], so we can't say how large a change they expect for the CO_2 rise so far.

Not put to the authors

The robustness points in sections 4–7 are our own checks. None claims an error, and none has been put to the authors: nothing has been sent to them.

What would change these verdicts

01
The conference paper's text. If it reports new stations, numbers or a different solar index, we would rate its own claims, not only its title.

02
A rebuild of the other five stations, with GIRO's filter tested on storm-time hours, showing a trend across cycles. That would move "No change in summer storm effect" toward Partly true.

03
A test that sizes both effects in the explanation, CO_2 and solar-wind driving, and shows them cancelling. That would move "CO_2 and solar wind explain it" toward True.

OUR ANALYSIS

Bottom line: a paper we could read only by its record, and two open papers by its authors whose central findings reproduce from public data, with an explanation that stays untested.

At Juliusruh, NmF2 for the same F30 fell about a fifth from cycle 20 to cycle 24, as the authors report, though how much depends on the solar index. The summer storm response shows no significant change in any of the five cycles, as they found at six stations. Their account of why the models' effect doesn't show is plausible: the CO_2 rise is about a third of the models', and the solar-wind pattern they describe is there; that the two effects cancel is untested. Over most stations the field barely changed, but not over Port Stanley.

Related checks

FALSE More auroras from less solar input? The Disaster Cycle, Fact-Checked

Sources

Bracketed numbers refer to this list. For the conference paper [1] we could read only its record, so it has no locators. In the authors' two open papers, p. gives a page of the journal's PDF: [6] runs 1–17 and [7] 73–89. In [3], p. gives a page of the conference programme; in [11], § is a section. Abstract marks the part of a source we rely on; a source marked "Abstract only" or "Record only" was read no further. NmF2 is the F2 layer's peak electron density and foF2 its critical frequency; F30 and F10.7 are the Sun's radio flux at 30 and 10.7 cm, in solar flux units (sfu); Kpm is Kp in decimal steps; LT is local time; SC20–SC25 are solar cycles 20–25. Publishers' hyphen characters are printed as ordinary hyphens. Links checked November 6, 2026.

1 Tan Jun Rios, M. G., Borries, C., and Liu, H. (2026). Long-Term Changes in the Ionospheric Response to Solar and Geomagnetic Forcing Over the Past Five Solar Cycles. *2026 Kleinheubach Conference*, Miltenberg, Germany, September 22–24, 2026, pp. 1–4. IEEE, IEEE Xplore. Record only: the site's owner reports the paper is paywalled, and we found no public copy. We read its Crossref record, retrieved November 6, 2026: the title, the three authors and their affiliations, pages 1–4, issued September 2026, 13 references, which we looked up one by one, no abstract, and IEEE's text-and-data-mining terms, not an open licence.

2 SpaceWeatherNews (S0) (November 6, 2026). Sky Fall Continues, Solar Storms Linger for Days | S0 News Nov.6.2026. YouTube video, https://www.youtube.com/watch?v=VRbM1M44nik. No transcript was available.

3 U.R.S.I. Landesausschuss in Deutschland (2026). Kleinheubacher Tagung 2026: Conference Programme. 24 pages; p. gives its page. Read in full, November 6, 2026.

4 U.R.S.I. Landesausschuss in Deutschland (2026). Kleinheubacher Tagung 2026: Call-for-Papers and Young Scientist Awards pages, read November 6, 2026.

5 OpenAlex, record for the conference paper: closed, with no repository copy and no abstract; and the first author's works. Both read November 6, 2026.

6 Tan Jun Rios, M. G., Liu, H., and Borries, C. (2025). Examining Long-Term Changes in the Ionospheric Response to Geomagnetic Activity Over the Past Five Solar Cycles. *Journal of Geophysical Research: Space Physics* 130, e2025JA034840. CC BY 4.0. Peer reviewed. Full text: the publisher's version from DLR's electronic library; p. gives a page of that PDF, 1–17.

7 Tan Jun Rios, M. G., Borries, C., Liu, H., and Mielich, J. (2025). Long-term changes in the dependence of NmF2 on solar flux at Juliusruh. *Annales Geophysicae* 43, 73–89. CC BY 4.0. Peer reviewed, after open discussion. Full text; p. gives the journal's page.

8 Tan Jun Rios, M. G. (2026). Long-Term Changes in the Ionospheric Response to Solar and Geomagnetic Activity. Doctoral thesis, Kyushu University, September 2026, 111 pages. Record only: the PDF in DLR's library is open only inside DLR.

9 Tan Jun Rios, M. G., Liu, H., and Borries, C. (2026). Effects of Future CO_2 Levels on Ionospheric Electron Density Response to Geomagnetic Storms. Talk, AOGS 2026, Fukuoka, August 2–7, 2026. Abstract only, from DLR's library, which lists it as not peer reviewed; the talk itself is open only inside DLR.

10 Jakowski, N., Hoque, M. M., and Tan Jun Rios, M. G. (2026). Long-Term Trends of Ionospheric Peak Electron Density and Height. *Space Weather* 24, e2026SW005006. CC BY 4.0. Abstract only, as deposited with Crossref.

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12 Laštovička, J., and Burešová, D. (2023). Relationships Between foF2 and Various Solar Activity Proxies. *Space Weather* 21, e2022SW003359. CC BY 4.0. Abstract only, as deposited with Crossref.

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41 NOAA Global Monitoring Laboratory. Mauna Loa annual mean CO_2, read November 6, 2026.

42 NOAA Space Weather Prediction Center. NOAA Space Weather Scales: a G1 (minor) storm at Kp = 5, G2 (moderate) at Kp = 6. Read November 6, 2026.

METHOD

How this was checked

On November 6, 2026, we checked every statement, number, quotation and citation on this page against its source. The conference paper is paywalled, as the site's owner reports, and we found no public copy: DLR's repository refused our search as too many requests, which we didn't retry, and OpenAlex lists none. So we read its Crossref record, including its 13 references, looked up one by one, its OpenAlex record, the conference's programme and its call for papers. The authors' two open papers on the same questions we read in full, and kept apart from it, the JGR paper on storms and the Annales paper on solar flux, both CC BY 4.0. We also read in full Laštovička's 2023 review and NOAA's storm scales, and 27 other works as abstracts or records only, as the list marks; one, Cnossen (2014), sits behind a bot check, which we did not attempt.

The verdicts and the items tagged "Our analysis" are our own assessment, built on the cited sources. They rate the authors' claims as their open papers make them, and the conference paper only by its title. The robustness points in sections 4–7, the solar index, a steady fall or a step, the field over Port Stanley and Boulder, and GIRO's filter as reasoning only, claim no error and say nothing about intent; measured against each cycle's own solar wind, the solar-wind pattern the authors describe is there. None of these points has been put to the authors; nothing has been sent to them.

We re-ran the authors' two main comparisons at Juliusruh, the one station whose record a World Data Centre holds in one series, from public data, and added the solar wind from NASA's OMNI, the field from IGRF-14 and the CO_2 record. Rules were written before each test and hashed, and the two amendments made after seeing results are marked as such and hosted: the reading of "disturbed days" that matches the paper's own counts, and the straight-line and two-index check. Separate code reproduced the main numbers. A fresh reviewer then checked the finished page and recomputed our analysis in separate code. That review showed that one of our registered tests, a comparison of the cycles' raw solar-wind medians, couldn't separate the hypotheses, because it depends on how strong each cycle's solar wind was overall: we withdrew it and replaced it with a comparison against one shared relation, which bears out the authors' pattern. It also widened our margins for a trend in the storm response to allow for the scatter between cycles, added two shapes to the trend-or-step question and a global field grid, all logged in a further amendment, and corrected several wordings and locators. One hosted script fetches its inputs and recomputes every number of ours; it reproduced all 580 numbers we compared with our verification runs. We could not rebuild the JGR paper's other five stations, read the models' full texts, or test GIRO's filter in storm time.

This page was researched and written with Claude, an AI assistant made by Anthropic, and then re-checked against its sources in a separate verification pass.

The verdicts on this page

UNCONFIRMED	Rests on a preliminary result that hasn't been confirmed.
PARTLY TRUE	Part of the claim holds up and part doesn't.
TRUE	The evidence supports the claim.
CONTEXT	A question or aside rather than a claim. We add the facts it leaves out.

All ten verdicts, and how we check

CORRECTIONS

Corrections and changes

If we get something wrong, we fix it and record the change below with the date. If a correction changes a verdict, the log says what the old verdict was.

Change log

Nov 6, 2026 Published on factchecked.science after a full check against the sources. The conference paper is paywalled, so it is checked through its record, programme and call for papers, and its authors' claims through their two open papers, read in full and kept apart from it. Our re-runs from public data at Juliusruh, OMNI's solar wind, IGRF-14 and the CO_2 record are our own; nothing is redrawn from the papers, and nothing has been sent to the authors.

Fact-Checked Science is independent. It isn't affiliated with the channels, presenters or authors whose claims it checks.