A sign of the dayside current wedge in geomagnetic observations at Stará Ďala (present-day Hurbanovo) on 16 April 1938

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Abstract: The recently proposed dayside current wedge likely explains the mechanism behind the well-known Carrington geomagnetic storm on 2 September 1859, as well as an event observed in Europe on 29 October 2003. Both events were swift and intense, had unusually short recovery phases, and the most violent variation of the horizontal intensity within them occurred at mid-latitudes in the morning MLT (magnetic local time) sector. In this paper, we add the third event to the two mentioned above, a short-lasting intense mid-latitude geomagnetic field variation that occurred on 16 April 1938. We present the reconstructed magnetogram with magnetic declination recorded at Stará Ďala on 16 April 1938 and demonstrate that, at around 08:30 of MLT, the Stará Ďala Observatory was likely situated within the central part of the wedge. The time series of horizontal intensity and declination from Western Europe and North America are consistent with our hypothesis that the dayside current wedge played a role in the event of 16 April 1938.

Key words: magnetic storm, magnetic declination, field-aligned current, dayside current wedge

1. Introduction

Intense magnetic storms are a phenomenon in near-Earth space that requires attention for both practical and scientific reasons. In practice, such events can, for example, threaten the operation of electrical power grids (*Boteler, 2019*) or artificial Earth satellites (*Horne et al., 2013*). From a scientific perspective, magnetic storms are part of solar-terrestrial relationships, which, when generalized, is a starting point for a deeper understanding also of the relations between solar activity and environments on other planets.

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The mechanisms of how intense magnetic storms form may not be the same for all events. However, there is general agreement that the primary causes of these phenomena are coronal mass ejections (CMEs) that have struck the Earth (e.g., Fig. 1 in *Tsurutani et al., 2003*). In some storms, other phenomena take on this primary role, particularly corotating interaction regions (CIRs) (*Revallo et al., 2015*). Even the two mentioned drivers (CMEs and CIRs) are shown to intensify different geomagnetic and ionospheric current systems to varying extents (*Verbanac et al., 2013*). The orientation of the north-south component of the interplanetary magnetic field also plays an important role. South orientation is typically a good condition for the development of enhanced geomagnetic activity (e.g., *Tsurutani, 2001; Valach et al., 2014*). Such a configuration of the interplanetary magnetic field leads to an open configuration of the Earth's magnetospheric field lines (*Dungey, 1961*) and thus to efficient generation and intensification of the electric current systems.

Sometimes, magnetic storms develop into disturbances lasting several tens of hours, and the entire planet is involved in intense geomagnetic variations. More rarely, however, a violent disturbance can last for a surprisingly short time, and that disturbance is in some particular part of the Earth much more intense than elsewhere. At this point, we want to emphasize that, in our work, we restrict our study to geomagnetic variations observed at mid- and low geomagnetic latitudes. Such an unusually brief storm of a local character occurred on 16 April 1938.

Lakhina et al. (2005) included the storm of 16 April 1938 in their list of 14 intense storms that occurred from September 1859 to November 2003. They characterised its intensity using the difference between the maximum and minimum value of the horizontal intensity during the storm as observed by the Alibag (India, low geomagnetic latitude) and Potsdam (Germany, middle geomagnetic latitude) observatories being 530 nT and up to 1900 nT, respectively. Note that the lower limit of the K = 9 index for Potsdam was 500 nT (*Bartels et al., 1939; Matzka et al., 2021b*). *Cid et al. (2014)* pointed out the very short, less than hour-long recovery phase of this locally occurring variation.

The manifestations of this storm appeared to be more pronounced at mid-latitudes than at low latitudes. For example, at all geomagnetic observatories in the former Soviet Union, geomagnetic activity in the three-hour interval between 06:00 and 09:00 UT reached the K index of 9 (*Sergeyeva et al., 2021*). The Kp index also reached the value of 9 in this time interval (*Matzka et al., 2021a*). However, *Cid et al. (2013)* retrospectively calculated that the Dst index only reached −263 nT during this storm.

Among the intense locally occurring geomagnetic variations at middle and low latitudes, we can include two particularly notable events: the Carrington storm of 2 September 1859 observed in India (*Tsurutani et al., 2003*) and the Carrington-like event of 29 October 2003 observed in Central Europe (*Cid et al., 2015*). For these two events, (*Ohtani, 2022*) proposed an explanation in the form of a dayside current wedge. This current wedge concept for the 2003 event was also supported by *Valach et al. (2025).*

The dayside wedge is a concept that probably might also explain some other short-lasting intense mid-latitude geomagnetic variations, besides the 1859 and 2003 events mentioned above (*Ohtani, 2022*). The important parts of this dayside R1-sense current wedge system are two field-aligned currents (FACs): one is an upward-flowing FAC that emerges from the auroral oval in the post-noon sector (taking the time sector relative to magnetic local time, MLT); the other is a downward FAC that flows into the early-morning sector (Fig. 6 in *Ohtani, 2022*). The upward-flowing FAC is stationary; its point of connection to the ionosphere does not change (it remains at the same position relative to MLT). However, the point at which the downward FAC connects to the ionosphere moves westward. For the 29 October 2003 event, *Valach et al. (2025)* showed that the shifting of that FAC occurred at a rate of $-2.51°/\text{min} \pm 0.39°/\text{min}$ (the centre of the wedge moved at a rate of $-1.08°/\text{min} \pm 0.38°/\text{min}$, the minus sign showing the westward movement). The current system, spreading westward as described above, affects the horizontal intensity and magnetic declination observed in the mid-latitudes in the MLT sector ranging from the early to late morning.

In the archive of the Hurbanovo Geomagnetic Observatory (formerly known as Stará Ďala), we have found a previously unexplored record of magnetic declination from 16 April 1938. We believe that it could provide additional confirmation of the validity of Ohtani's current wedge concept in explaining the rapid variations in the early sector. In this paper, we present the reconstructed geomagnetic observation of magnetic declination on 16 April 1938 at Stará Ďala and show that the observed course of the declination can be considered as due to the dayside current wedge.

2. Materials

In our paper, two data sets of geomagnetic data are studied. One of the sets is the time series of magnetic declination we got from the analogue photo-paper record made on 16 April 1938 by the Stará Ďala observatory. The supplementary data observed at Stará Ďala from selected days in the surrounding years around the event were also necessary to obtain comprehensive and reliable information on the magnetic declination in question. The other data set is the hourly averages of declination and horizontal intensity that the worldwide network of observatories recorded on 16 April 1938, and that are available to the scientific community via the data centres. The following two sections provide more detailed information about the studied materials.

2.1. Declination at Stará Ďala on 16 April 1938

In the archives of the geomagnetic observatory Hurbanovo (IAGA code HRB, previous names Ógyalla and Stará Ďala – the latter was in use in April 1938), there is a record of magnetic declination from 15/16 April 1938. We provide a pair of dates because the records in the variation station were changed once a day, in the morning. Thus, the magnetograms catch the second part of the previous day (in this case it was the 15 April) and the beginning of the following day (16 April, in our case). However, it was not possible to obtain the sensitivity of the apparatus directly from the magnetogram; a complication is that no numerical values are available from 1938.

The studied magnetogram contained only the recorded curve of the geomagnetic element (declination), incomplete baseline value ($44.2'$), dates (15 and 16 April 1938), tick marks on the time axis, and digits indicating the Universal Time (UT; Greenwich Mean Time, GMT, to be exact). We made sure that it was UT time by comparing the magnetogram with available geomagnetic field records from other observatories (global data will be introduced in Section 2.2).

To determine the positive direction of the east declination, we consulted records from nearby geomagnetically quiet days; the quiet-day Sq variation of the (east) magnetic declination in the Northern Hemisphere at middle geomagnetic latitudes is expected to show an increase in the morning and a decrease in the evening. Regarding the incompletely listed baseline value, some magnetograms from surrounding days had complete values written on them starting with 2°. Thus, the actual baseline value for the magnetogram under study was $-2°44.2'$.

We had to determine the scale value for the declination record using records from other periods. This was because, unfortunately, there are no known numerical values for the period in question. The nearest preceding year with the necessary data is 1936, and the nearest subsequent year with known instrument sensitivity data is 1939. However, in December 1938, a new Mascart-Carpentier variometer was installed at the observatory for declination recording, replacing the previous variometer (*OGY, 1941*, p. 10). We could thus only use the 1936 data to determine the scale value.

To determine the scale coefficient in the records for 1938, we proceeded in three steps: (1) calculated the proportion of Sq variations in 1936 and 1938; providing the Sq variations at a given place should be approximately the same in the same part of not very distant years, in this way we obtain the inverse of the ratio of the scaling coefficients; (2) calculated the scale value for 1936; and (3) adjusted that scale value according to the proportion of the sizes of Sq variation in 1936 to those in 1938.

The course of the Sq curve varies throughout the year, their amplitudes being most pronounced around the summer solstice and, conversely, least pronounced around the winter solstice. Therefore, to determine the ratio of the Sq variations (taken from the magnetograms in millimetres) in 1936 and 1938, we selected sets of quiet days from the same parts of the years. The biggest difference in dates between our corresponding pairs of data was only 11 days (Table 1). When comparing the yearbook numerical values with the 1936 analogue records, we also found that the values recorded in the yearbook were instantaneous values at the given hours; they are not hourly averages as would be expected based on current observatory practice.

The median of the sensitivity ratios in Table 1 was 1.014, for which the MAD (median absolute deviation) was 0.156. The median value was close to the mean value of 0.976 ± 0.071, variability is expressed here with the standard error of the mean. As both the median and the mean are so close to value one, we might take that the scale coefficient of the measuring instrument did not change, or changed only by a minimal amount, between

Table 1. Calculating the ratio of amplitudes of quiet variations for 1936 and 1938. In the case where we selected multiple values of the amplitudes from a given period, we averaged them.

Year 1936		Year 1938		
Date	Amplitude (mm)	Date	Amplitude (mm)	Ratio
10 MAR	8.4	19 MAR	12.6	
11 MAR	8.6			0.675
04 APR	11.2	30 MAR	13.2	0.848
08 MAY	10.6	29 APR	8.8	1.205
23 MAY	11.7	23 MAY	10.3	
24 MAY	12.3			1.170
23 JUN	11.4	14 JUN	11.0	1.036
23 JUL	11.7	25 JUL	13.2	0.886
03 OCT	11.8	12 OCT	11.6	
04 OCT	10.4	14 OCT	10.3	1.014

1936 and 1938. Nevertheless, we will apply a fine correction, admitting thus that there was a subtle change. For a restricted number of statistical samples (unfortunately, the number of quiet periods that would fall in equal parts of both years is limited), the median as a representative of the middle value is less affected by outliers than the mean. Therefore, we consider the median (1.014) to be a reliable value.

To calculate the station sensitivities for 1936 (step 2 in our procedure), we used both magnetograms from quiet days, which we also used in the previous step, and magnetograms from selected geomagnetically disturbed days (Table 2). We calculated the sensitivity of the instrument (the scale coefficient) for 1936 as the median of the values in Table 2, i.e., $1.179'$/mm $\pm\,0.055'$/mm (MAD). In the last step of our procedure, we quantified the sensitivity of the variometer in 1938 (up to November) from the sensitivity in 1936 and the ratio of the amplitudes of the quiet daily variations, yielding a value of $1.163'$/mm $\pm\,0.193'$/mm.

Figure 1 displays the manually digitized Stará Ďala's magnetogram of declination during the studied magnetic storm. In the figure, at the top of the graph, we added an axis indicating magnetic local time (MLT), in addition to the axis indicating UT at the bottom. In April 1938 at Stará Ďala, there was a 2.18-hour difference between MLT and UT. For calculating the

Table 2. Determination of variometer sensitivity (scale coefficients) in 1936.

Quiet days		Disturbed days	
Date in 1936	Scale coeff. (′/mm)	Date in 1936	Scale coeff. (′/mm)
10 MAR	1.023	19 APR	1.169
11 MAR	1.186	20 APR	1.164
04 APR	1.285	21 APR	1.124
08 MAY	1.179	22 APR	1.127
23 MAY	1.180	18 MAY	1.216
24 MAY	1.325	19 MAY	1.111
23 JUN	1.293	19 JUN	1.161
23 JUL	1.105	16 OCT	1.270
03 OCT	1.240	21 NOV	1.125
04 OCT	1.272	—	—

MLT, we utilised the online calculator (*Papitashvili and Papitashvili, 2025*).

The storm took place almost entirely between 06:00 and 09:00 UT, which was the period when the Kp index was 9. A sharp decrease in magnetic declination (by $36' \pm 6'$) occurred around 08:00 MLT and lasted 0.38 h. A sharp increase followed at around 08:30 MLT. The difference between the recorded maximum and minimum variation in declination was $73' \pm 12'$, and this happened within only 0.44 h. The subsequent part of the original magnetogram

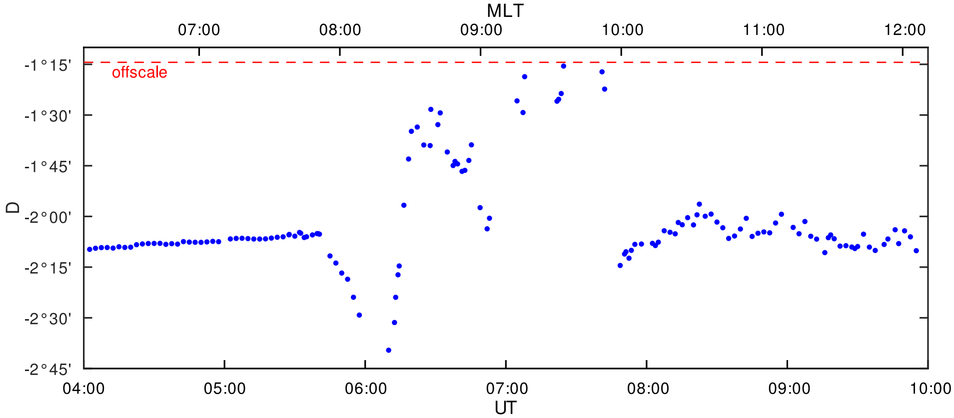

Fig. 1. The magnetogram recording the magnetic declination during the studied event on 16 April 1938 at Stará Ďala. The line marked as "off scale" represents the edge of the photographic paper, which was the recording medium.

was less illegible; therefore, the points displayed in Fig. 1 are more sparse. Here, except for the three readings around 09:00 MLT, all declination readings up to about 10:00 MLT had a strong positive value.

2.2. Global geomagnetic data

To sketch a global picture of the geomagnetic storm under study, we used the hourly means of magnetic declination and horizontal intensity of the geomagnetic field that we obtained via the World Data Centre for Geomagnetism, Kyoto (*WDCG, 2025*). The data covered the period from 05:00 UT to 09:00 UT and most of them are from observatories located in the Northern Hemisphere. The observatories whose data we used in creating the global picture are listed in Table 3. We utilised the polar coordinate system to display the data graphically. Figure 2 shows the differences between the hourly means of the declinations and horizontal intensities and their respective quiet values. The quiet values are the values taken for each of the observatories and represent the undisturbed conditions before the onset of the geomagnetic storm.

The origin of the coordinate system, which we used to show the locations of the magnetic stations, is set in the north geomagnetic pole. The radial coordinate is for the quasi-dipole latitude (*Laundal and Richmond, 2017*) of the stations, and the azimuth coordinate represents the MLT. The variations in declinations and horizontal intensities at individual stations are displayed with arrows: the ones pointing to the east (west) mean positive (negative) variation in declination, and those pointing to the pole (equator) stand for increase (decrease) of the horizontal intensity. For three observatories from the Southern Hemisphere having negative geomagnetic latitudes (namely API, CTO, and WAT), we adjusted the directions of their arrows so that they show variations as if the observatories were in the Northern Hemisphere with respect to the geomagnetic equator (similarly we treated the southern-hemisphere observatories in *Koči and Valach, 2023*).

3. Results and discussion

The studied magnetic declination record in the first half of the day of 16 April 1938 appears to provide a substantial argument for suggesting the ex-

Table 3. Names, IAGA codes and coordinates (in °) of the magnetic observatories.

Observatory	IAGA	Geographic		Geomagnetic	
Name	Code	Latitude	Longitude	Latitude	Longitude
Alibag	ABG	18.638	72.872	11.46	142.02
Abinger	ABN	51.185	359.613	49.18	79.79
Agincourt	AGN	43.783	280.733	57.28	348.73
Apia	API	−13.815	171.781	−18.23	242.90
Chambon la Foret	CLF	48.025	2.260	45.11	80.72
Cheltenham	CLH	38.733	283.158	52.40	351.8
Cape Town	CTO	−33.950	18.467	−40.09	76.79
De Bilt	DBN	52.102	5.177	49.37	84.38
Eskdalemuir	ESK	55.314	356.794	54.24	79.32
Qeqertarsuaq/Godhavn	GDH	69.252	306.467	78.03	41.96
Honolulu	HON	21.320	202.000	21.65	266.67
Huancayo	HUA	−12.050	284.670	1.11	353.27
Kakioka	KAK	36.232	140.186	29.32	208.24
Lerwick	LER	60.138	358.817	59.05	83.35
Lovo	LOV	59.344	17.824	55.88	97.08
Meanook	MEA	54.616	246.653	62.62	299.24
Niemegk	NGK	52.072	12.675	48.43	90.10
Rude Skov	RSV	55.850	12.450	52.65	91.41
Sitka	SIT	57.067	224.670	59.81	274.59
San Juan	SJG	18.117	293.850	32.36	3.78
Sodankyla	SOD	67.367	26.633	63.41	108.44
Sheshan (Zo-Se)	SHH	31.097	121.187	24.27	189.75
Stará Ďala	HRB	47.874	18.188	43.14	93.80
Vysokaya Dubrava	SVD	56.733	61.067	51.71	131.97
Tucson	TUC	32.170	249.270	39.64	310.29
Watheroo	WAT	−30.318	115.877	−42.01	183.80
Wien-Auhof	WIA	48.203	16.235	43.68	91.62

istence of such a dayside current wedge as that described by *Ohtani (2022)*. Placing this record in the context of global geomagnetic field variations during the same period strengthens this argument even further.

The sharp drop in declination lasting 0.38 h indicates that the Stará Ďala Observatory (Fig. 1) came under the influence of the downward-directed FAC that was a part of the dayside current wedge (*Ohtani, 2022*) shortly

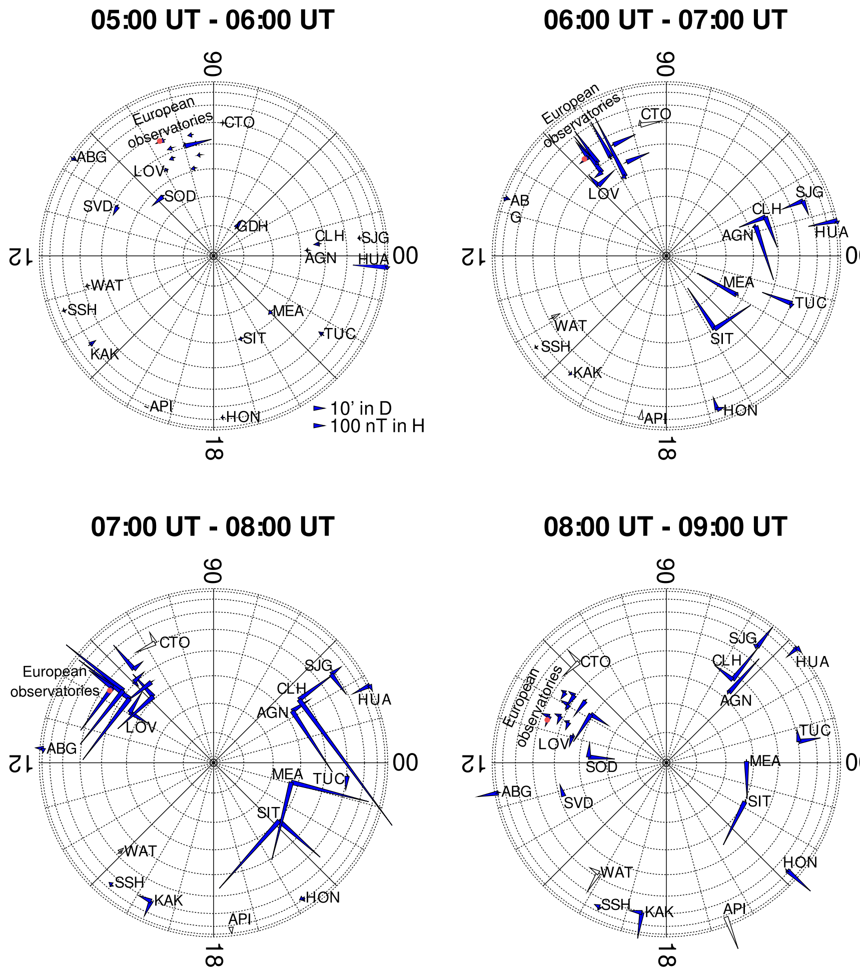

Fig. 2. Changes in horizontal intensity and declination variations on 16 April 1938 between 05:00 UT and 09:00 UT. The location of the Stará Ďala observatory is shown by a red mark (dot).

before 08:00 MLT. At around 08:30 MLT, at the moment when the declination reached the level comparable with the previous quiet values, the observatory likely found itself in the central part of the wedge. Subsequently, the declination continued to increase, suggesting that Stará Ďala was likely approaching the noon sector of the wedge, characterised by upward-directed field-aligned currents. The portion of the magnetogram that followed was less legible; nevertheless, the deviation in declination is beyond doubt positive there.

There are three values marked on photosensitive paper at approximately 09:00 MLT that are worthy of note, those three dots lying approximately at the level of quiet values. With a degree of certainty, we can explain them with the fact that the variometer at that time was constructed by installing perpendicular mirrors at its edges on the recording medium, which projected the beam back onto the recording medium (photo-paper). Thus we infer that these three values were strongly positive, which points out that the Stará Ďala observatory was under the influence of upward FACs on the outside of the auroral oval until about 10:00 MLT. A similar asymmetric variation, where a shorter period of decrease followed by a longer period of increase in declination was observed at the easternmost observatories (e.g., observatories Istanbul, Nurmijarvi, and Surlari) in the early morning sector during the geomagnetic storm on 29 October 2003 – the event in which the dayside current wedge probably played a role (*Valach et al., 2025*).

The global picture of the event (Fig. 2) shows that geomagnetic activity was highest in mid-latitude Europe between 06:00 UT and 08:00 UT, and it was most pronounced in the late morning sector 07:00 – 10:00 MLT. The decrease in horizontal intensity observed during that time interval in the mid-latitudes was significantly larger than the horizontal intensity decrease at the low-latitude observatories. The NGK observatory experienced the most severe horizontal intensity decrease (−671.51 nT; 07:00 UT – 08:00 UT). By contrast, on the evening side, where the partial ring current should amplify the ring current due to the greater density of charge carriers (*Liemohn et al., 2001*), the observatories HON and API recorded, against expectations, positive horizontal intensity variations or at least unexpectedly small decreases between 06:00 UT and 08:00 UT (HON: 116.67 nT and −36.33 nT, API: −84.92 nT and 58.71 nT, within 06:00 UT – 07:00 UT and 07:00 UT – 08:00 UT, respectively).

The decrease in the Dst index was only 263 nT (*Cid et al., 2013*). Simultaneously, the geomagnetic activity at observatories over a relatively large area of the former Soviet Union (east of the Western and Central European observatories) reached the K index of 9 (*Sergeyeva et al., 2021*). Therefore, we infer that the European observatories were under the influence of the westward electrojet, which is one of the current systems located in the auroral oval.

The decrease in horizontal intensity that occurred in the interval 07:00 UT – 08:00 UT was accompanied by a sharp and significant increase in declination at most European observatories (up to 61.1′ at the NGK observatory). It suggests that these observatories were under the influence of upward FACs on the outer side of the auroral oval in the morning sector. Some observatories showed even more interesting behaviour of the series of the declination hourly averages: DBN recorded a decrease by 30.1′ within the time interval 05:00 UT – 06:00 UT and a subsequent increase by 26.0′ in the next hourly interval. A similar variation, but one hour later, was also observed by observatories ESK (decrease of 24.8′ and increase of 51.7′) and CLF (decrease of 25.3′ and increase of 11.6′).

The variation seen in the hourly averages recorded by DBN occurred too early to be due to the dayside current wedge (*Ohtani, 2022*) since the DBN observatory was displaced westward from the HRB by approximately 0.64 hours in MLT. However, similar variations recorded one hour later at the European observatories ESK and CLF (not marked in the diagrams in Fig. 2), which lie more westerly from HRB (ESK by 1.08 h in MLT, CLF by 0.91 h in MLT), could be explained by the current wedge.

Observatories AGN and CLH in North America recorded pronounced negative variations in declination (−52.49′ and −30.20′, respectively) in the interval 06:00 UT – 07:00 UT. They might be caused by the substorm electrojet. In the following hourly interval, when the observatories appeared in the MLT sector around 02:30, the influence of the substorm electrojet should not be so significant. In defiance of that, the observatories recorded even deeper declination decreases (by 113.80′ and by 15.20′). These declination decreases could be caused by the downward FAC of the dayside current wedge (*Ohtani, 2022*). Although we believe the current wedge is the highly probable explanation for the deep decreases, we cannot reliably rule out that there could have been a significant amplification of the substorm electrojet. At subsequent intervals, the intense geomagnetic activity suddenly ceased.

4. Conclusion

In the present study, we provided support for the idea of a dayside current wedge (*Ohtani, 2022*) as a mechanism for rapid and intense geomagnetic field variations occasionally observed in the morning sector at mid- and low magnetic latitudes. Examples of the variations that the current wedge likely explains are the well-known Carrington geomagnetic storm (*Tsurutani et al., 2003; Ohtani, 2022*) of 2 September 1859 and an event observed in Europe on 29 October 2003 (*Cid et al., 2015; Ohtani, 2022; Valach et al., 2025*). We now add a third example, which is a short-lasting intense local mid-latitude geomagnetic field variation that occurred on 16 April 1938 and was most intensely manifested in the Potsdam Observatory record (*Lakhina et al., 2005*).

The reconstructed declination record from the Stará Ďala Observatory (present day's Hurbanovo) contributed to a closer examination of this event. The peculiar sequence of variations in magnetic declination recorded in Stará Ďala, where a negative variation occurred first, immediately followed by a very pronounced positive one, indicates that on the morning of 16 April 1938, this observatory appeared in the central part of the dayside current wedge. Available data from other observatories confirm this conjecture: traces of similar declination variations, as well as deep drops in horizontal intensity observed at Western European observatories, are one such confirmation. If more detailed data from several other European observatories were available, rather than just hourly means, it would even be possible to use them with the Stará Ďala data to determine the velocity of motion of the downward-directed FAC. Variations in declination observed in the observatories in America at the same time we also consider as such confirmation. With a high degree of certainty, we can consider those variations in America to be caused by that moving and downward-flowing FAC that is part of the dayside current wedge.

The number of dayside current wedge events remains relatively small due to their transient and localized nature. Moreover, specific upstream driving conditions are needed for their generation, e.g. strong foreshock transients. Highlighting the value of comparing modern data sets with historical records is key to improving identification and understanding of these phenomena.

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