Forecast of the Geomagnetic Index ap during CME events

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Abstract: A new tool based on a machine learning approach was developed in order to predict the upcoming ap geomagnetic index values for three ongoing days with a 3-hour time resolution (24 values). This tool is using the archived time series of the ap index with a 3-hour time interval resolution based on archived data of the solar cycles 23 and 24 to train the Long short-term memory (LSTM) model and predict the new values in the future. In this work this tool is applied to predict the ap index values during disturbed geomagnetic conditions resulted from Coronal Mass Ejections (CME). Information about the occurred coronal mass ejection is introduced in the toll through a specific function. The input data are the CME time arrival as calculated from the Effective Acceleration Model, the maximum value of the estimated daily geomagnetic index Ap and the index time which defines the time profile for the duration of this event and are based on the analysis of the profiles of historical events. A first validation of ap prediction tool in the case of twenty CME events that are associated with geomagnetic storms from minor G1 storm to major G4 are analyzed and presented.

Introduction:

Geomagnetic indices are a measure of geomagnetic activity, which is a signature of the response of the Earth magnetosphere and ionosphere to solar forcing. The 3-hourly ap and the daily Ap indices are planetary magnetic activity indices with units of 2nT. Related to the Kp index, they are averaged values of the irregular disturbance levels in the horizontal field components, observed at selected magnetic observatories worldwide. A new product based on a machine learning approach is provided to forecast the ap index values with prediction lead time up to 72 hours and is named "a_p Prediction" (*http://apprediction.phys.uoa.gr/)*. This product is utilizing the archived time series of the ap index with a 3-hour time interval resolution based on archived data of the solar cycles 23 and 24 to train the Long short-term memory (LSTM) model and predict the future values (forecasts) from t_0 (the time of the most recent run of the code) up to three days in total (24 values of 3-hour time interval forecasts) in the future. The model is capable of reproducing and forecasting quiet or active conditions. In case of extreme Space Weather events (i.e. CME) arrival and/or high-speed streams of solar wind originating from coronal holes (CH) the model is inserted by human intervention. In this work this tool is applied to predict the ap index values during geomagnetic storms periods and specifically after the effects of CMEs.

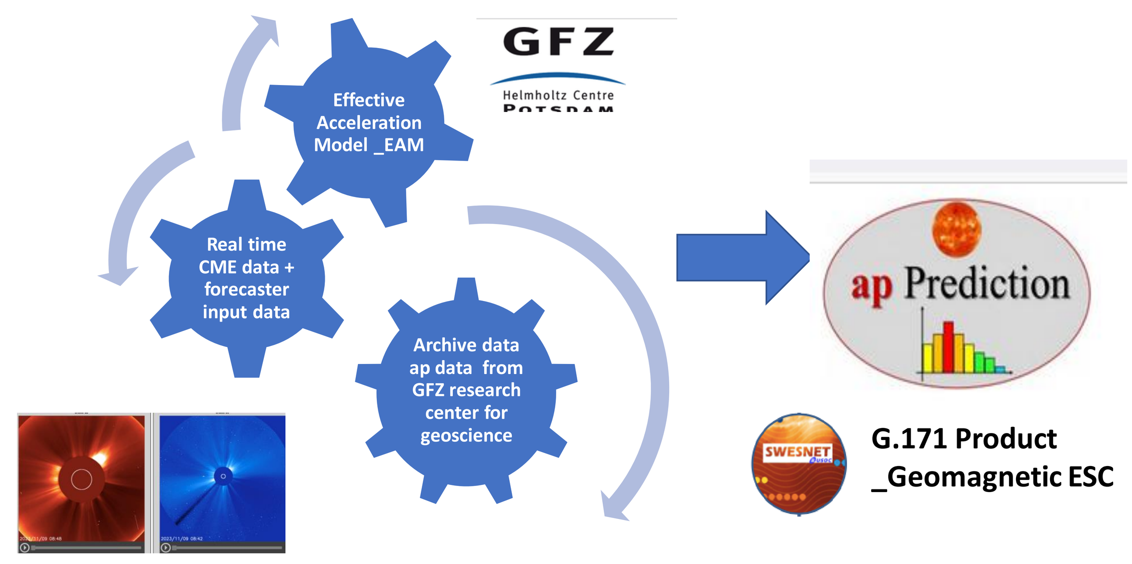
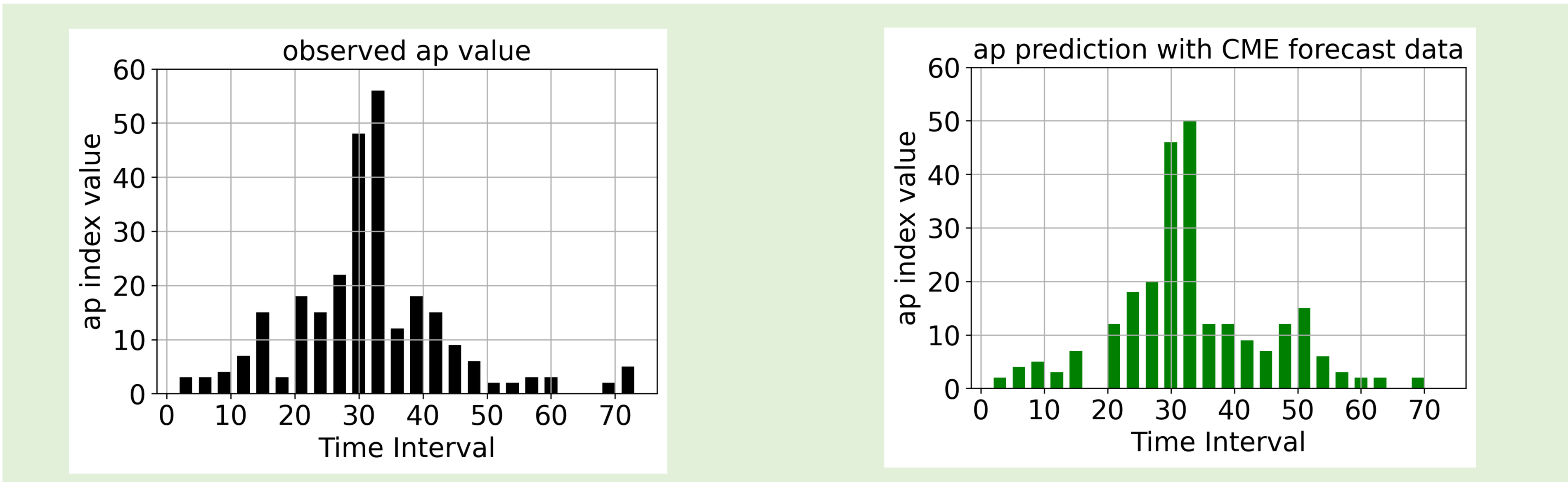
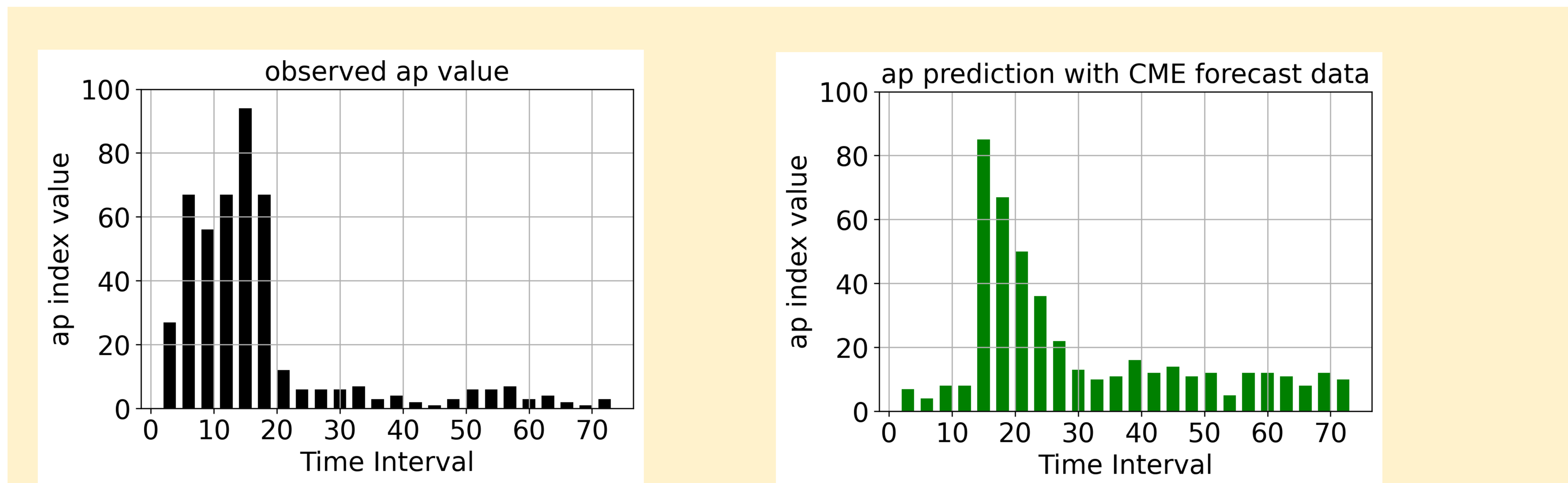


Figure 1. Block diagram of ap prediction tool (*https://swe.ssa.esa.int/ap_Prediction-federated*)

G1 Event : CME No 11



G2 Event : CME No 4



G3 Event : CME No 18

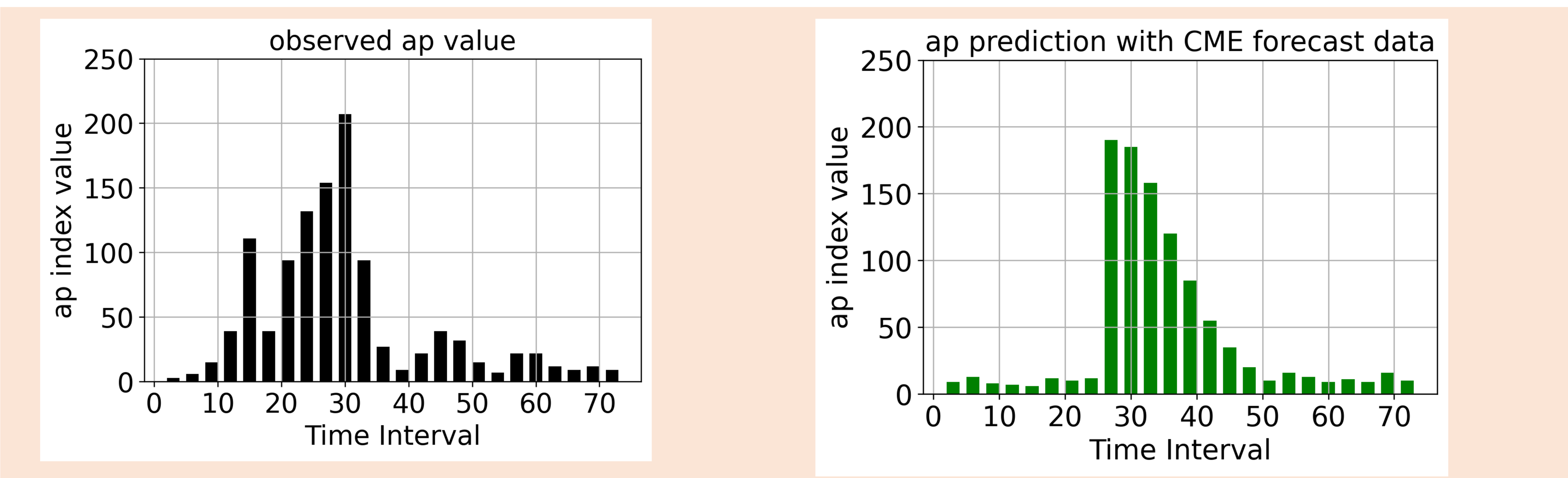


Fig. 2 : The values of observed ap index (GFZ) for three CME events with different level of geomagnetic storms G1, G2, G3 (left column) and the corresponding results of ap predicted values from the ap tool (right column).

CME No	Actual Shock Arrival YYYY:MM:DD; hh:mm	Kp	ap predicted max value	ap observed max value	Type of Geomagnetic storm	RMSE without forecast data	RMSE with forecast data
1	2021:04:24; 22:24	5+	50	48	G1	13.71	9.22
2	2021:05:12; 05:48	7	105	132	G3-G4	34.54	17.18
3	2021:09:17; 01:29	5+	55	56	G1	14.85	4.60
4	2021:10:12; 01:46	6+	80	94	G2	21.05	12.69
5	2021:11:03; 19:23	7+	155	179	G3-G4	51.17	17.76
6	2022:02:09; 20:09	5+	40	48	G1	13.06	6.25
7	2022:03:13; 10:11	6+	90	94	G2	30.01	24.06
8	2022:03:31; 01:41	5-	35	39	G1	10.52	8.76
9	2022:04:14; 03:37	6	70	80	G2	21.78	14.14
10	2022:06:15; 04:01	4+	30	32	G1	8.16	6.69
11	2022:07:23; 02:28	5+	50	56	G1	11.52	8.33
12	2022:08:17; 02:16	7-	100	111	G3-G4	33.26	25.51
13	2022:08:29; 02:57	4-	25	27	G1	14.33	12.69
14	2022:10:04; 07:05	4+	52	67	G2	13.20	11.60
15	2022:10:04; 07:05	4	35	32	G1	9.45	6.38
16	2023:02:27; 10:15	7-	110	111	G3-G4	44.45	27.21
17	2023:03:15; 03:48	6-	65	67	G2	21.18	16.83
18	2023:03:20; 22:37	8	200	207	G3-G4	66.81	48.43
19	2023:04:23; 17:00	8+	200	236	G3-G4	79.03	28.39
20	2023:05:09; 22:06	5+	50	56	G1	15.91	9.71

Table 1 : The list of twenty CME events with their main characteristics from January 2021 to May 2023 used for the validation procedure.

First validation results of ap Prediction tool

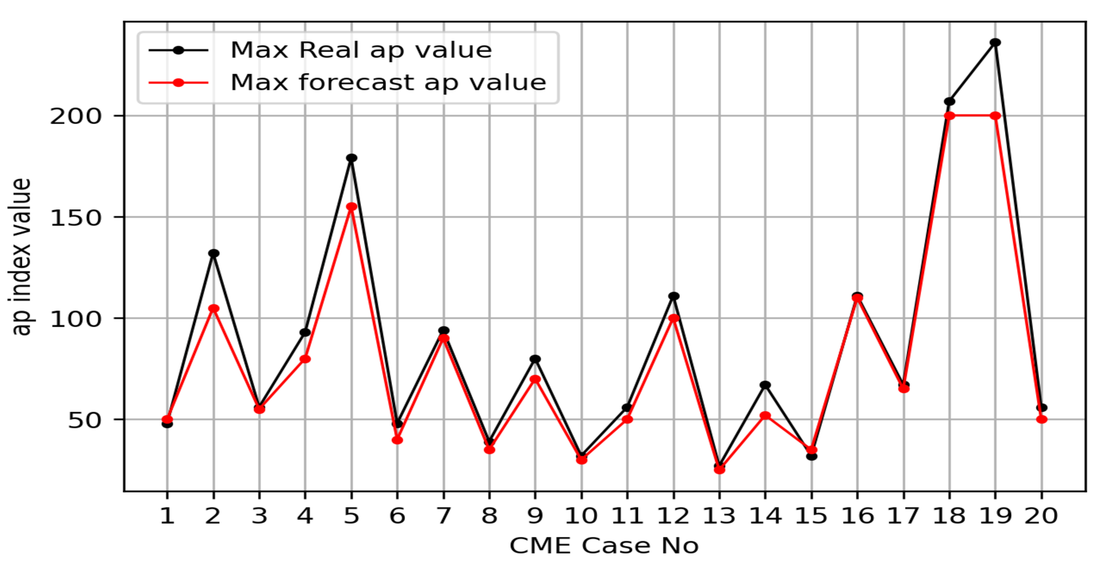


Fig. 3: Observed ap max values vs Forecast ap max values for all examined CME cases.

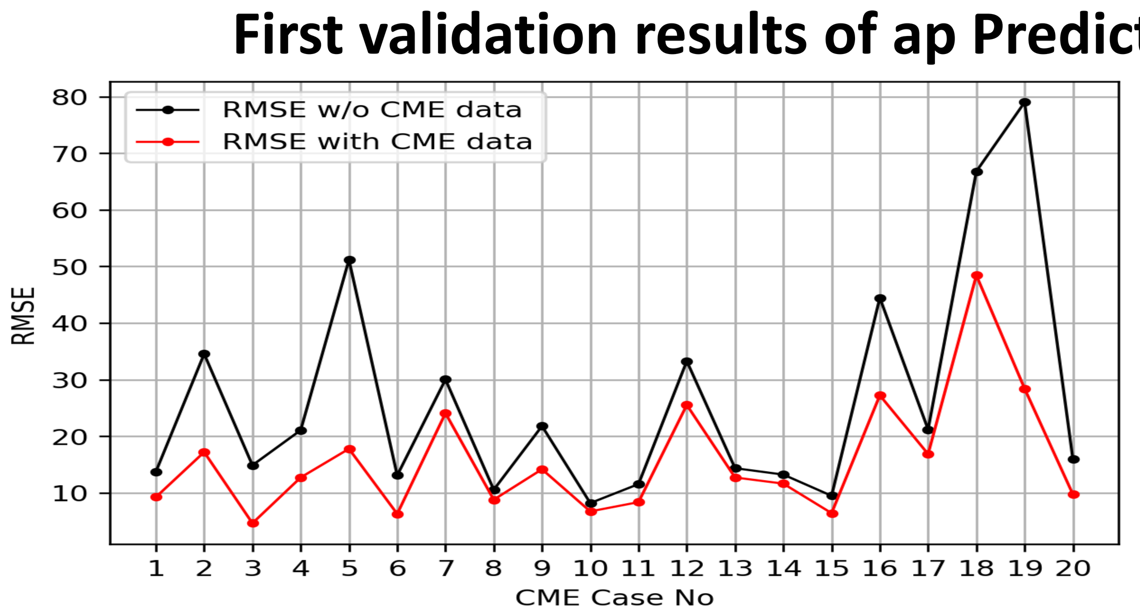


Fig. 4 : RMSE values for all examined CME cases.

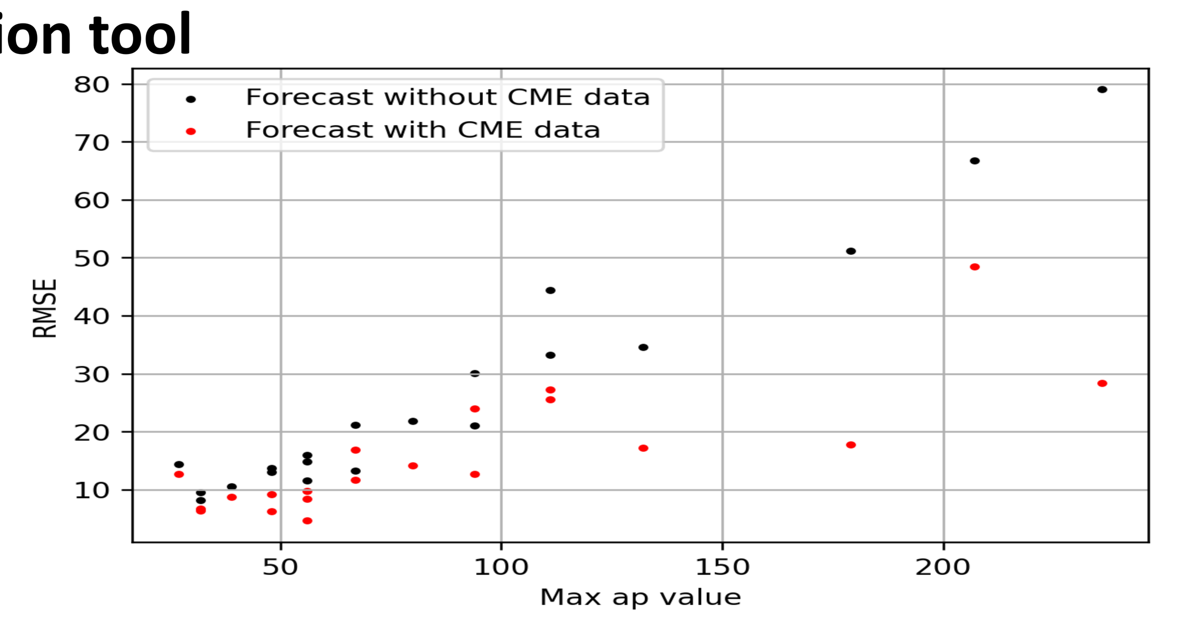


Fig. 5: RMSE values vs ap max values (without CME data/ with CME data).

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Conclusions

- Inserting ap data as resulted from CME characteristics the accuracy of the ap Prediction tool is improved. This accuracy seems to be more significant in the cases of G2 and G3-G4 storms, while in case of G1 storms the performance is slightly better.
- Given the fact the occurrence rate of G2 and G3-G4 events is very low (once or twice per month), and at the same time the shock arrival happens a few days after the event, there is enough time to adjust the related information and function to the system. An automated tool for this process is in progress.

Link: https://apprediction_phys_uoa_gr.content.swe.s2p.esa.int/

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