Innovative Dst Predictions Using Ensemble Neural Networks

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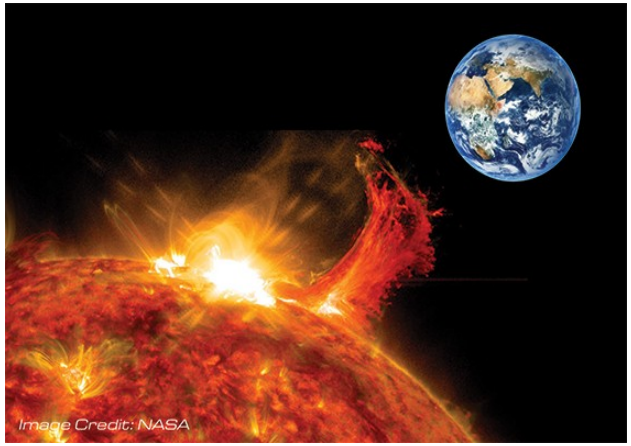


This research is developed in the framework of the NASA project SWQU (80NSSC20K1580)

CIRES

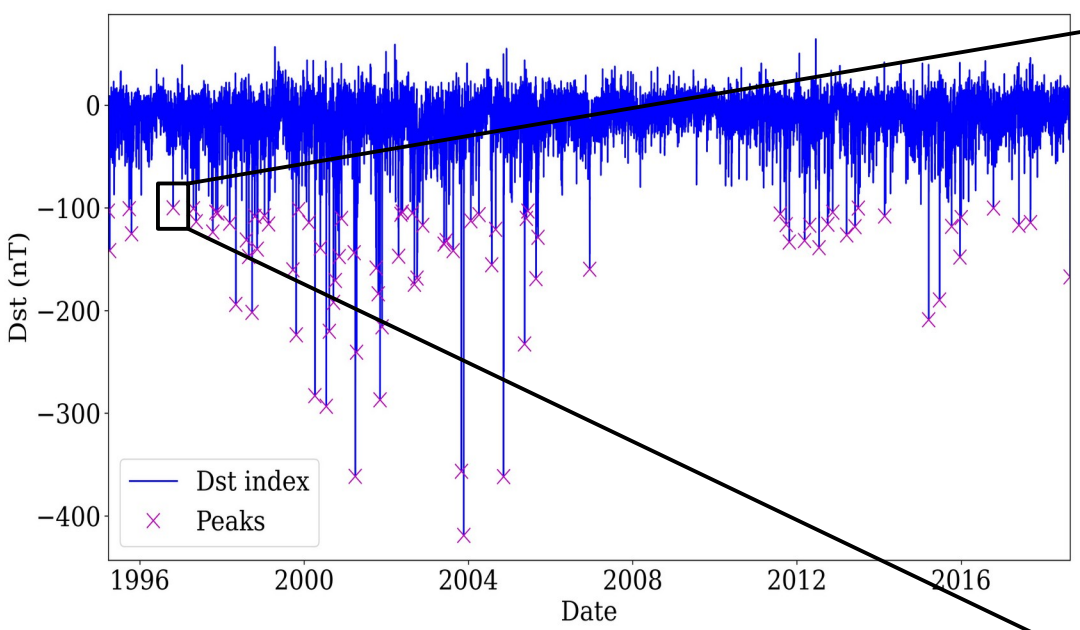
University of Colorado Boulder

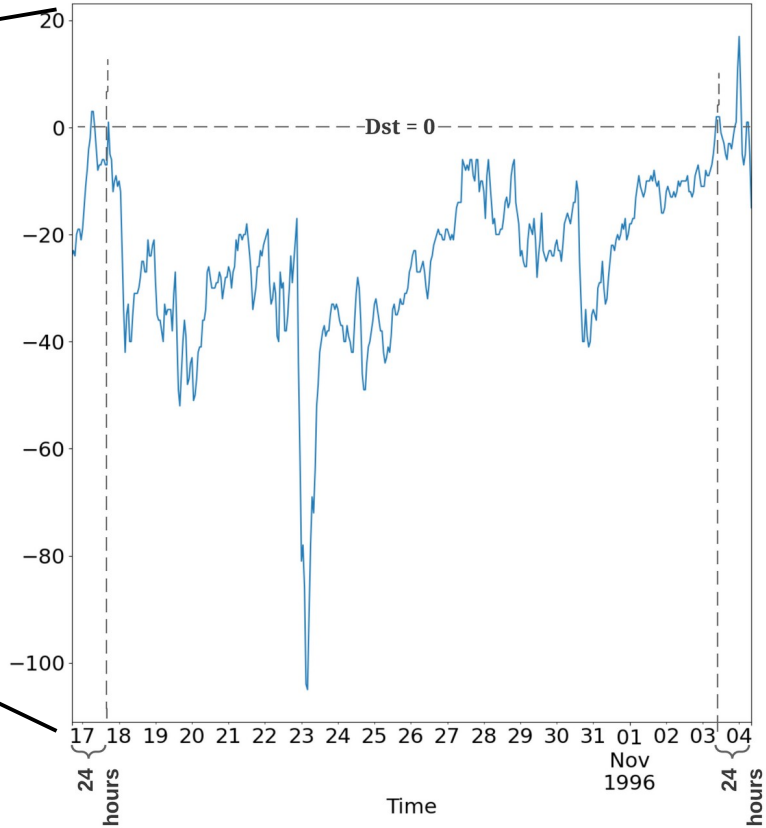
NOAA

Outlines

- **Storm Selection (training and validation data set preparation)**
- **Dst Probabilistic Forecast (1-2 days ahead forecast)**
- **Dst Deterministic Forecast (1-6 hrs ahead forecast)**
- **Future**

Storm Selection (training and validation data set preparation)





- How to select 51 storm events during 1996-2010 based Dst index.

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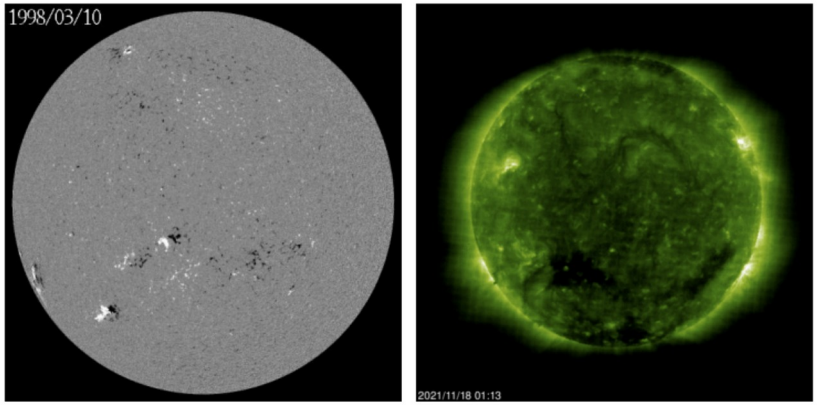
Dst Probabilistic Forecast (1-2 days ahead forecast)

- The model is trained using SoHO images.
- The goal of this study is to forecast Dst probability at least 1-2 days ahead (after the SoHO image was taken) over strong storm periods.
- Dst probability exhibits how much percentage that the Dst will exceed a certain threshold.

SoHO images

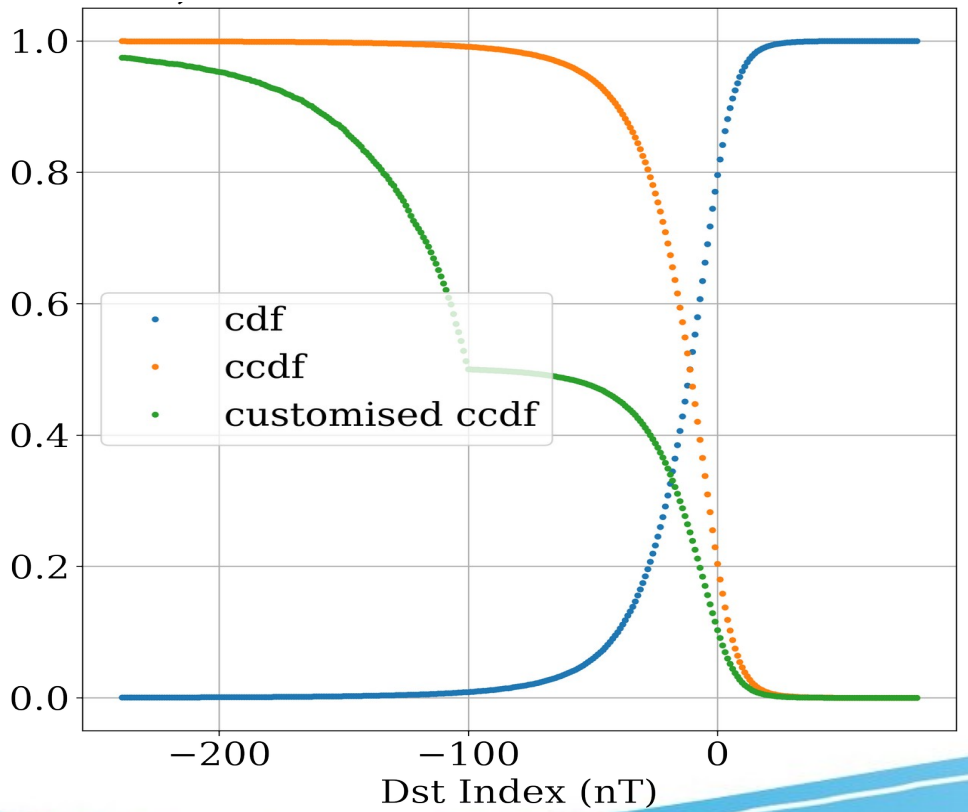


(a) MDI (b) EIT 195

(c) LASCO C2

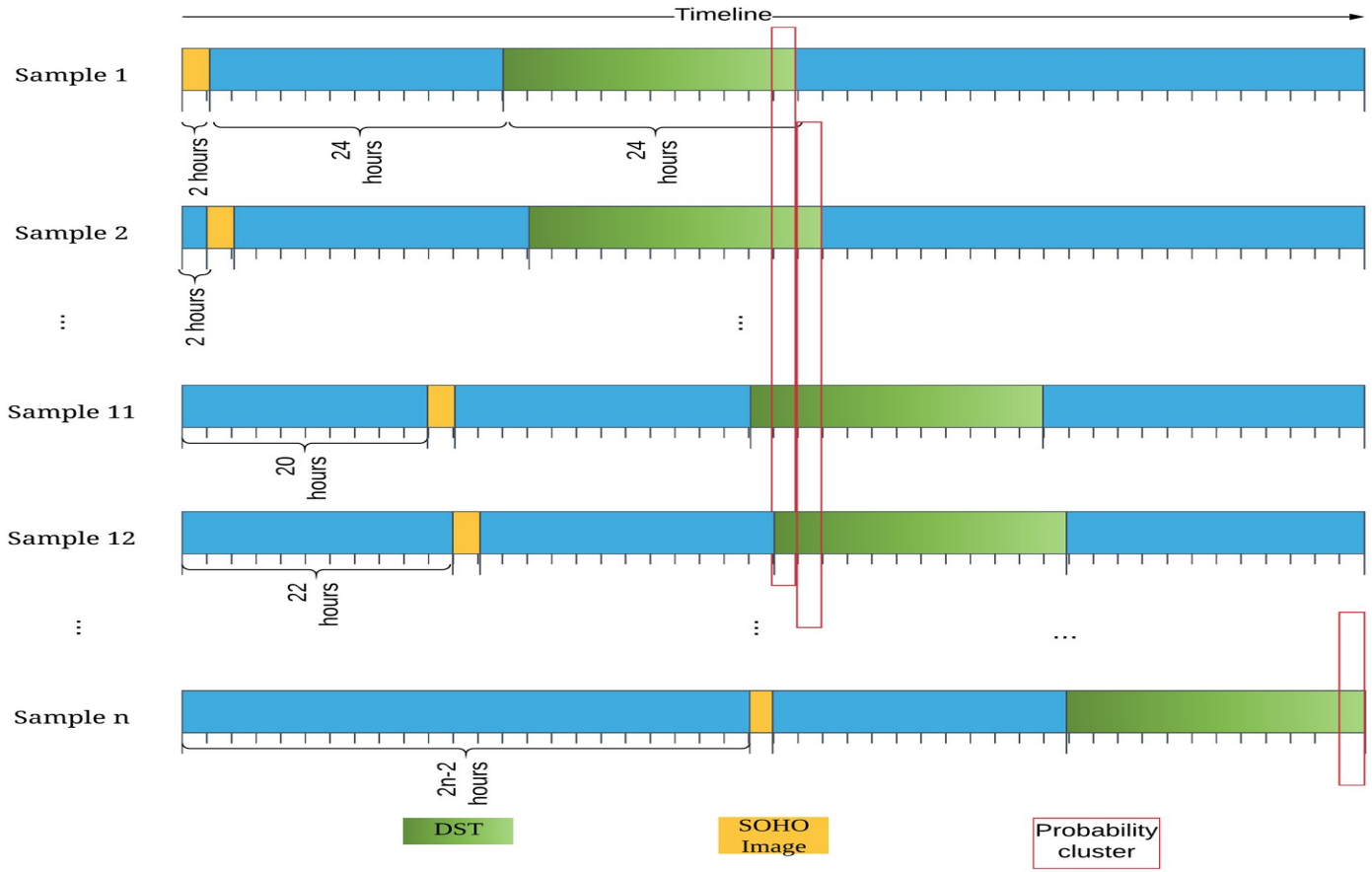
- A pipeline has been created and published by (Shneider et al., 2021) for automatically downloading, cleaning and synchronizing these original images from SDAC and VSO. A machine-learning-ready image data set is then provided.
- The paper is available on https://arxiv.org/pdf/2108.06394.pdf
- The code is available on https://github.com/cshneider/soho-ml-data-ready
- An example of synchronized data set is available on https://surfdrive.surf.nl/files/index.php/s/NYHm1b9hOKMMcw0

Target

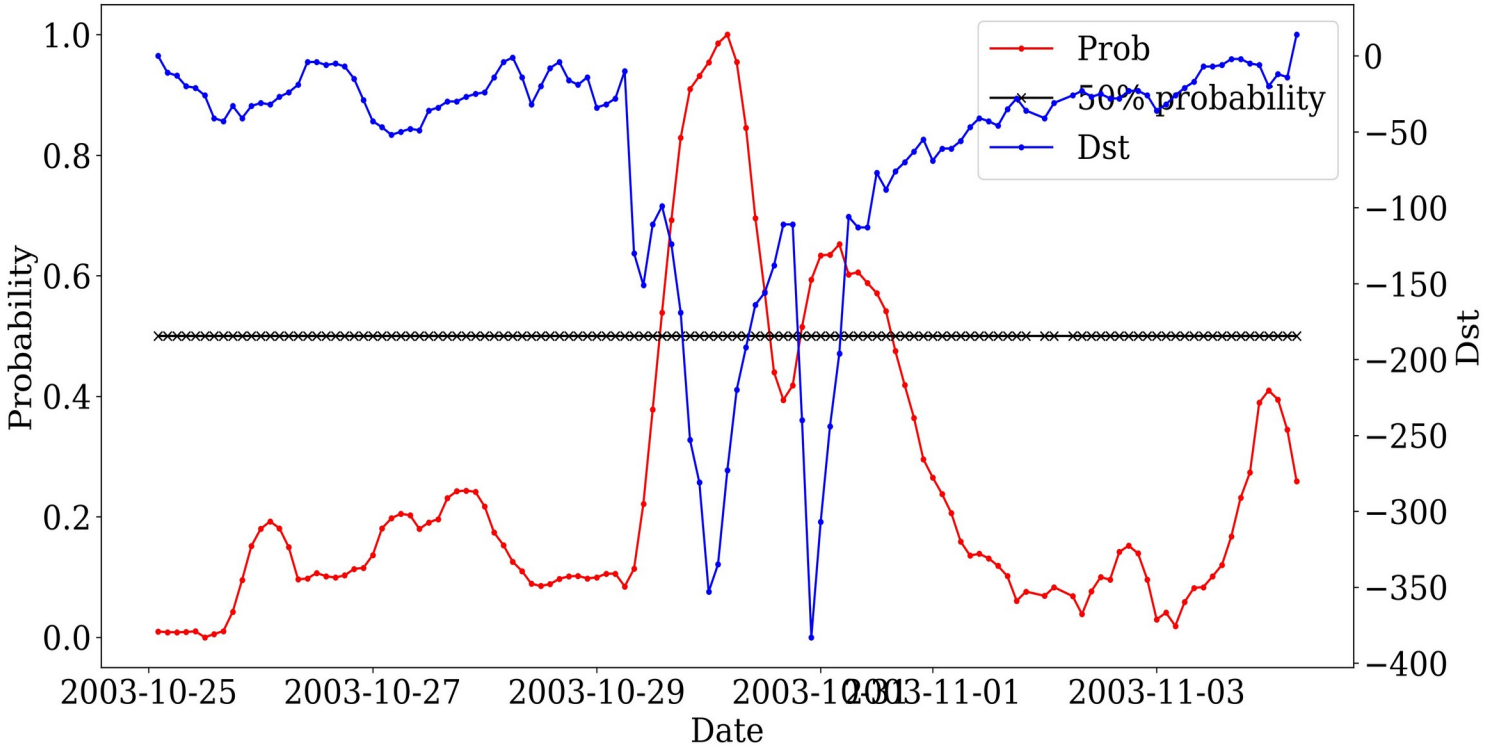


- Cumulative Distribution Function (CDF);
- Complementary Cumulative Distribution Function (CCDF); and
- Customised Complementary Cumulative Distribution Function (CCCDF)

Ensemble Method



- We can make a prediction for 24-48h ahead with a 2hr resolution (as shown in green);
- For each target, we can have 12 predictions from different inputs (as shown in red).
- we come up an ensemble method to have a final prediction.



- The figure displays the Dst probabilities of the developed model and corresponding Dst during this selected event.

Conclusion

1. We have developed a CNN ensemble model that estimates the probability of Dst exceeding a given threshold (e.g., -100 nT) 1-2 days ahead based on SoHO images.

2. The purposed model can also forecast Dst probability even during a non-Earth-direct CME period (details are not shown here).

This paper is under review by Journal “Space Weather”. The preprint version can be found on http://arxiv.org/abs/2203.11001. All the codes can be found on https://github.com/HuanWinter/Dst_SoHO

Future updates can be also found on https://ml-space-weather.github.io/projects.html (under construction)

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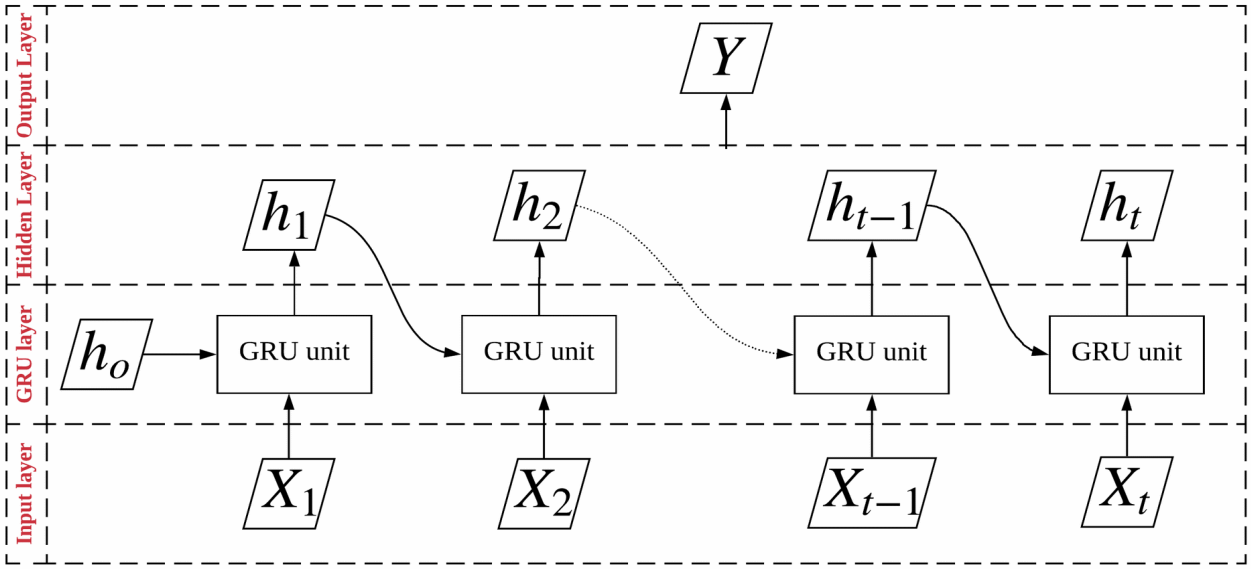
Input Variables

Reference	Variable	Symbol
Gruet et al. (2018)	electron density	n
	solar wind velocity	V
	Norm of IMF magnetic field vector	$\|B\|$
	IMF magnetic field vector in z direction	B_z
	Dst	Dst
Weimer (2013)	clock angle from tangential IMF in the GSM Y-Z plane	θ_c
	square root of F10.7 one day before	$\sqrt{F10.7}$

- Gruet et al. (2018) selected the electron density n, the solar wind velocity V, IMF|B|, and IMF Bz. Several variables used to estimate geomagnetic field in Weimer (2013) are also taken into account.

Method



$$z_t = \sigma_g(W_z x_t + U_z h_{t-1} + b_z)$$
$$r_t = \sigma_g(W_r x_t + U_r h_{t-1} + b_r)$$
$$h_t = \Phi_h(W_h x_t + U_h(r_t \odot h_{t-1}) + b_h)$$
$$h_t = (1 - z_t) \odot h_{t-1} + z_t \odot \hat{h}_t$$

Dst model is developed based on a vanilla GRU method with a length of 6hr. The ΔDst model is then developed based on the same architecture as for the Dst model but with ACCRUE (Camporeale et al. 2020) as the cost function.

Ensemble

An ensemble boost method is developed for further imporving the performance of the Dst predictions:

1) Train Δdst model for the 1-hr ahead persistence model using ACCRUE method;

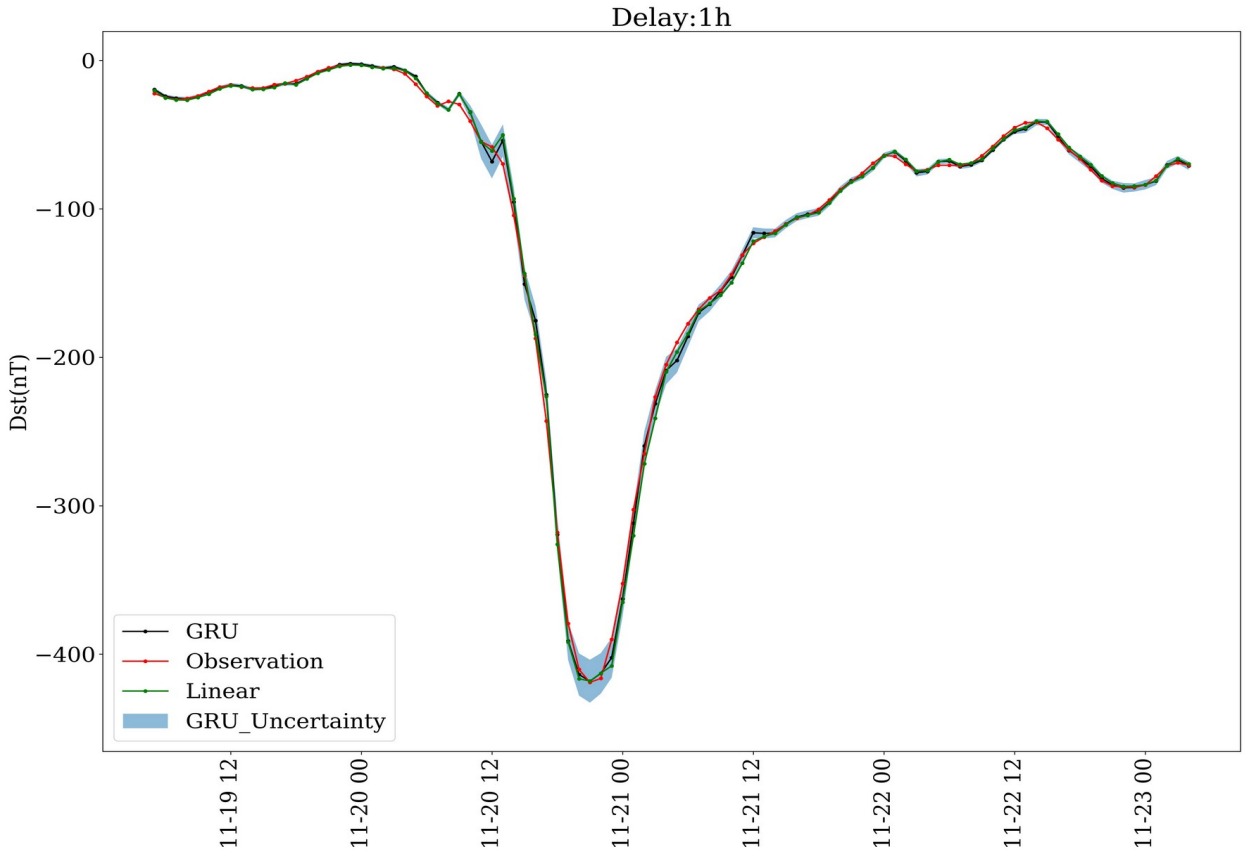
2) Generate criteria predicted by Dst and Δdst model on the train set and sort them;

3) subsample the data based on the performance of the previous model;

4) train a new Dst and Δdst model on the new samples, back to step 2);

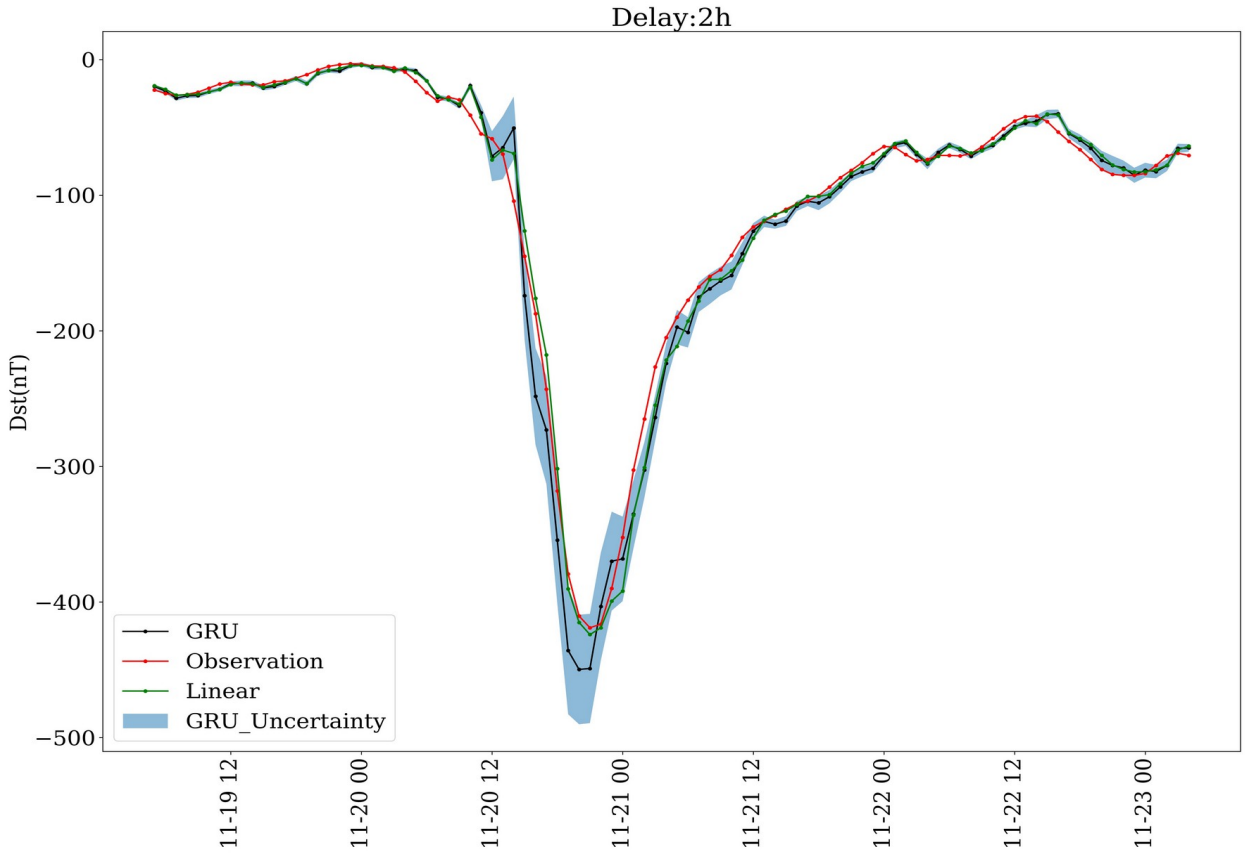
We do step 2-4 **four** times, then we can obtain **5** Dst models (together with the persistence model). Finally, the 'best' model is the combination of this 5 models, each one weighted by using their precision from Δdst models.

Results



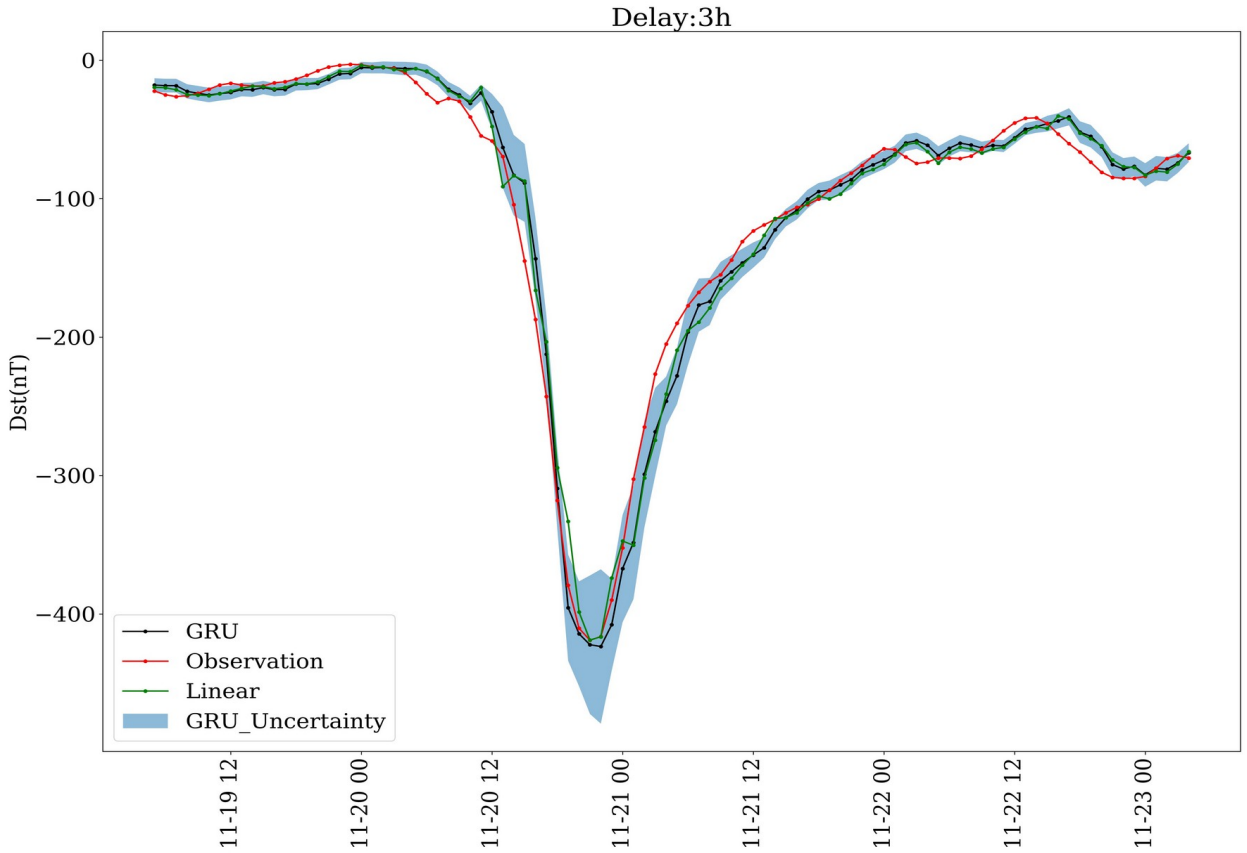
This figure displays the Dst predictions of the purposed model during the 2003-Halloween storm **1**hrs ahead.

Results



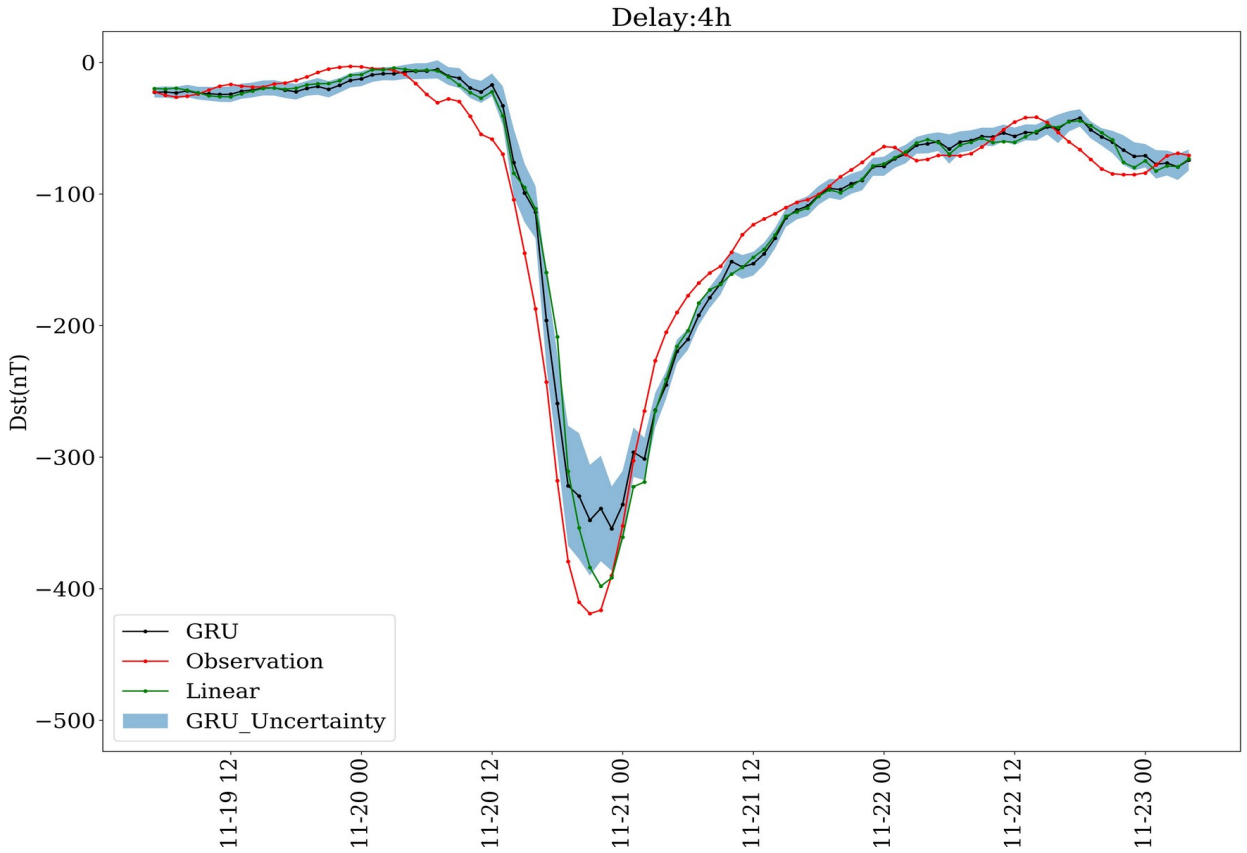
This figure displays the Dst predictions of the purposed model during the 2003-Halloween storm **2**hrs ahead.

Results



This figure displays the Dst predictions of the purposed model during the 2003-Halloween storm **3**hrs ahead.

Results



This figure displays the Dst predictions of the purposed model during the 2003-Halloween storm **4**hrs ahead.

Conclusion

1. We have implemented the ACCURE method to estimate the ΔDst by the residuals of the developed GRU model.

2. An ensemble boost GRU method is developed for forecasting Dst 1-6 hours ahead informed by the ACCRUE method.

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Future Prospect

1. Consider the SuperMag data into the Dst determinstic predictions.

2. Assimilate the Dst probability from SoHO into the Dst deterministic model.

3. A new NASA SWO2R project named Probabilistic forecast of Disturbance Storm Time (Dst) index for thermospheric models is looking for several day ahead predictions.

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