Artificial Update of One-Day GIM-TEC Predictions Using the W-Index Map from the Preceding Hour

Tamara Gulyaeva[1] and Feza Arikan[2]

[1]IZMIRAN, Moscow, Russia tam.gulyaeva@gmail.com

[2]Hacettepe University, Department of Electrical and Electronics Engineering, Ankara, Türkiye arikan@hacettepe.edu.tr

The International Reference Ionosphere and NeQuick

Improving the Representation of the Real-Time Ionosphere

ICTP, Trieste, Italy; 6 -10 October, 2025

OUTLINE

- **INTRODUCTION**
- **W AND Wp INDICES**
- **W-MODEL**
- **RESULTS**
- **CONCLUSIONS AND FUTURE DIRECTIONS**

INTRODUCTION

- **Global Ionospheric Maps (GIM-TEC) are one of the most important sources of 2-D global imaging of ionosphere and plasmasphere.**
- **GIM-TEC are provided by various Data Analysis Centers with a one- to two-day delay such as**
  - **Jet Propulsion Laboratory (JPL) 1 h maps (jplr) with 1-day delay,**
  - **Rapid Universitat Politècnica de Catalunya (UPC)-IonSAT maps (uqrg) with a 15-minute cadence with a 2-day delay,**
  - **Center for Orbit Determination in Europe (CODE) 1-day predicted c1pg.**
- **Consequently, one or two day delays in prediction cause significant errors in GIM-TEC forecasts for the real-time services.**
- **One exception is uadg which is produced by UPC-IonSAT in quasi-real time with a 15-minute cadence and a 2-hour UT delay.**
- **We propose a method W-model for artificially updating GIM-TEC hour by hour, based on the rotation of the W-index map from the preceding hour by 15 degrees westward.**
- **The accuracy of TEC forecasting with W-model is compared with uadg, uqrg, jplr, c1pg, and the relevant GIM-W index maps.**

W and Wp Indices (1)

- **W-index is a logarithmic indicator of ionospheric and plasmaspheric disturbance. It can be applied to any ionospheric parameter.**
- **DNmF2 = log(Nm/Nm*(27 d median))**

W index	DN=log(Nm/Nm*)	P%
4	$0.301<DN$	$+200\%<P$
3	$0.155<DN\leq0.301$	$+43\%<P\leq+200\%$
2	$0.046<DN\leq0.155$	$+11\%<P\leq+43\%$
1	$0<DN\leq0.046$	$0<P\leq+11\%$
−1	$-0.046\leq DN<0$	$-10\%\leq P<0$
−2	$-0.155\leq DN<-0.046$	$-30\%\leq P<-10\%$
−3	$-0.301\leq DN<-0.155$	$-50\%\leq P<-30\%$
−4	$DN<-0.301$	$P<-50\%$

- Gulyaeva, T.L.,, I. Stanislawska, Derivation of a planetary ionospheric storm index. Annales Geophysicae, 26, N.9, 2645-2648, www.ann-geophys.net/26/2645/2008/, 2008. DOI:10.5194/angeo-26-2645-2008.

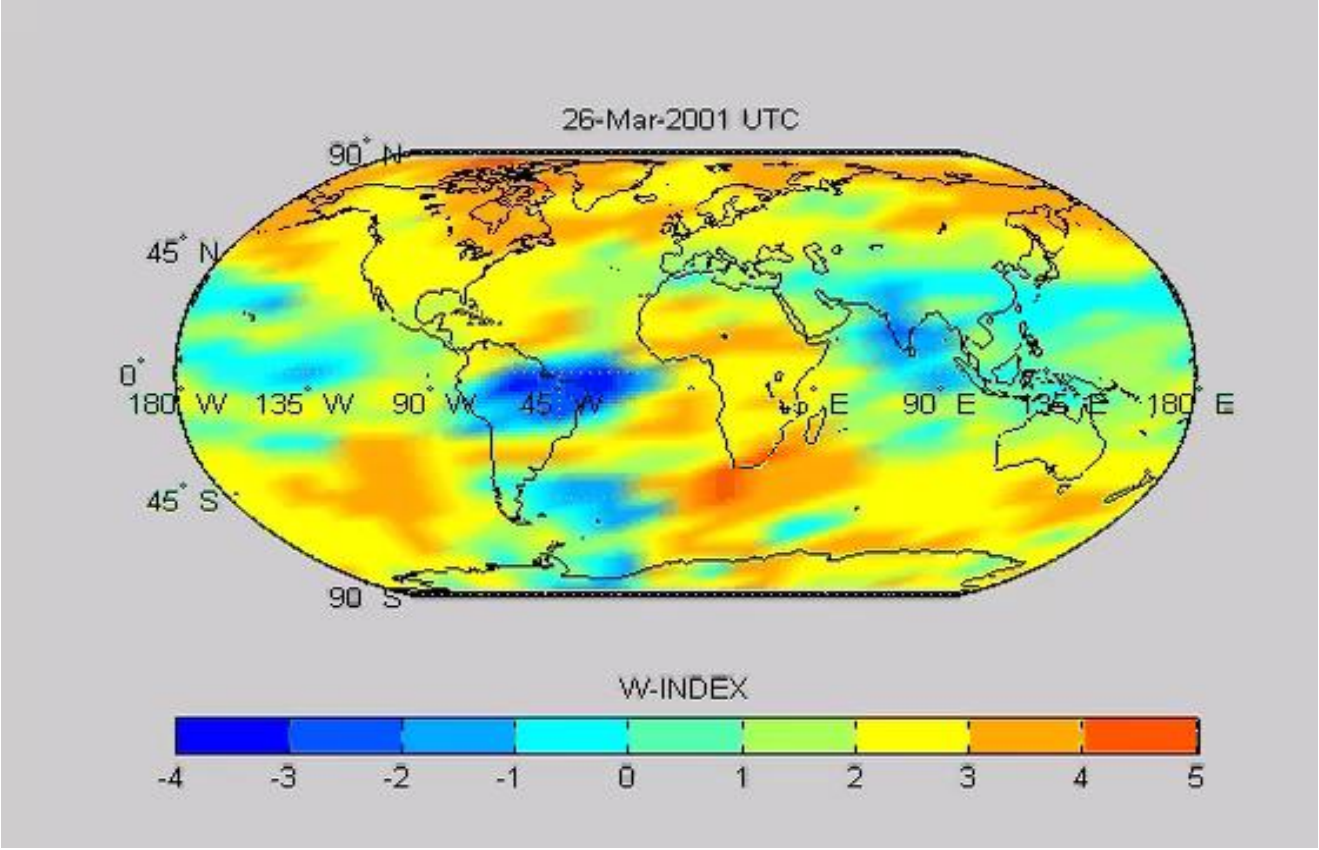
W and Wp Indices (2)

- **DTEC=log(TEC/MTEC(15 d median)) Deviation from the quiet median**

W-index	DTEC	Ionosphere state
4	DTEC > 0.301	Intense positive W^+ storm
3	0.155 < DTEC< 0.301	Moderate W^+ storm or substorm
2	0.046 < DTEC< 0.155	Moderate W^+ disturbance
1	0.0 < DTEC< 0.046	Quiet W^+ state
0	DTEC = 0.0	Reference Quiet state
-1	-0.046< DTEC < 0.0	Quiet W^- state
-2	-0.155<DTEC< -0.046	Moderate W^- disturbance
-3	-0.301<DTEC< -0.155	Moderate W^- storm or substorm
-4	DTEC< -0.301	Intense negative W^- storm

W and Wp Indices (3)

- W-index computed from GIM for 26 March-3 April 2001



T.L. Gulyaeva, F. Arikan, M. Hernandez-Pajares, I. Stanislawska, GIM-TEC adaptive ionospheric weather assessment and forecast system, Journal of Atmospheric and Solar-Terrestrial Physics, Vol 102, 2013, 329-340, https://doi.org/10.1016/j.jastp.2013.06.011

W and Wp Indices (4)

- The planetary Wp index depicts contributions of perturbation at a global scale:

The difference (span) between the maximum of positive index, $W\max j$, and the minimum of negative index, $W\min j$, at the j-th latitude, serves as a latitudinal measure of the storm if there are values corresponding to the storm at the particular latitude:

$\delta Wj = W\max j - W\min j$ for $W\max j \geq 3$ and/or $W\min j \leq -3$

$\delta Wj = \max(W\max j, |W\min j|)$ for $W\max j \leq 2$ and $W\min j \geq -2$

The planetary W_p index depicts contributions of perturbation at a global scale:

$$W_p = (1 + kn^{-1}m^{-1})n^{-1}\Sigma\delta Wj, (j = 1, ..., n) \qquad (2)$$

- Wp is the latitude averaged span between extremes δWj at each latitude. The weight

$$(1 + kn^{-1}m^{-1}).$$

explains the latitude-longitude extent of the areas of the greatest positive index

$W\max=\max(W\max j)$,

and the least negative value

$W\min=\min(W\min j)$.

- Count k represents the number of the extreme positive and negative index values on a map.

W and Wp Indices (5)

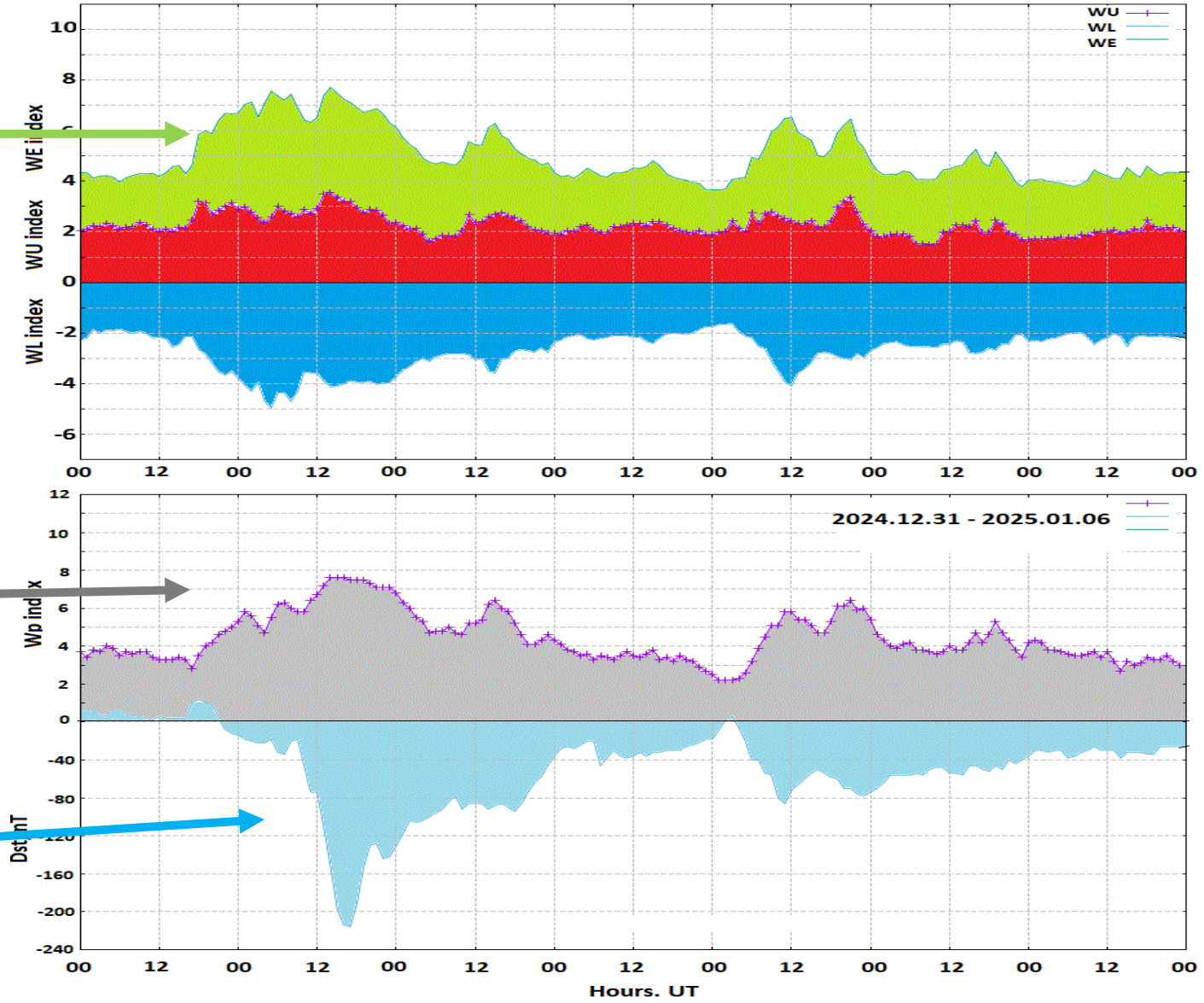
- WU index-- global intensity of TEC enhancement,
- WL index - global intensity of TEC depletion,
- global **WE** = **WU** - **WL**.

- **Wp** and **WE** indices

follow the geomagnetic disturbance very well.

- High Correlation with **Dst** index

December 31, 2024- January 06, 2025
Superstorm



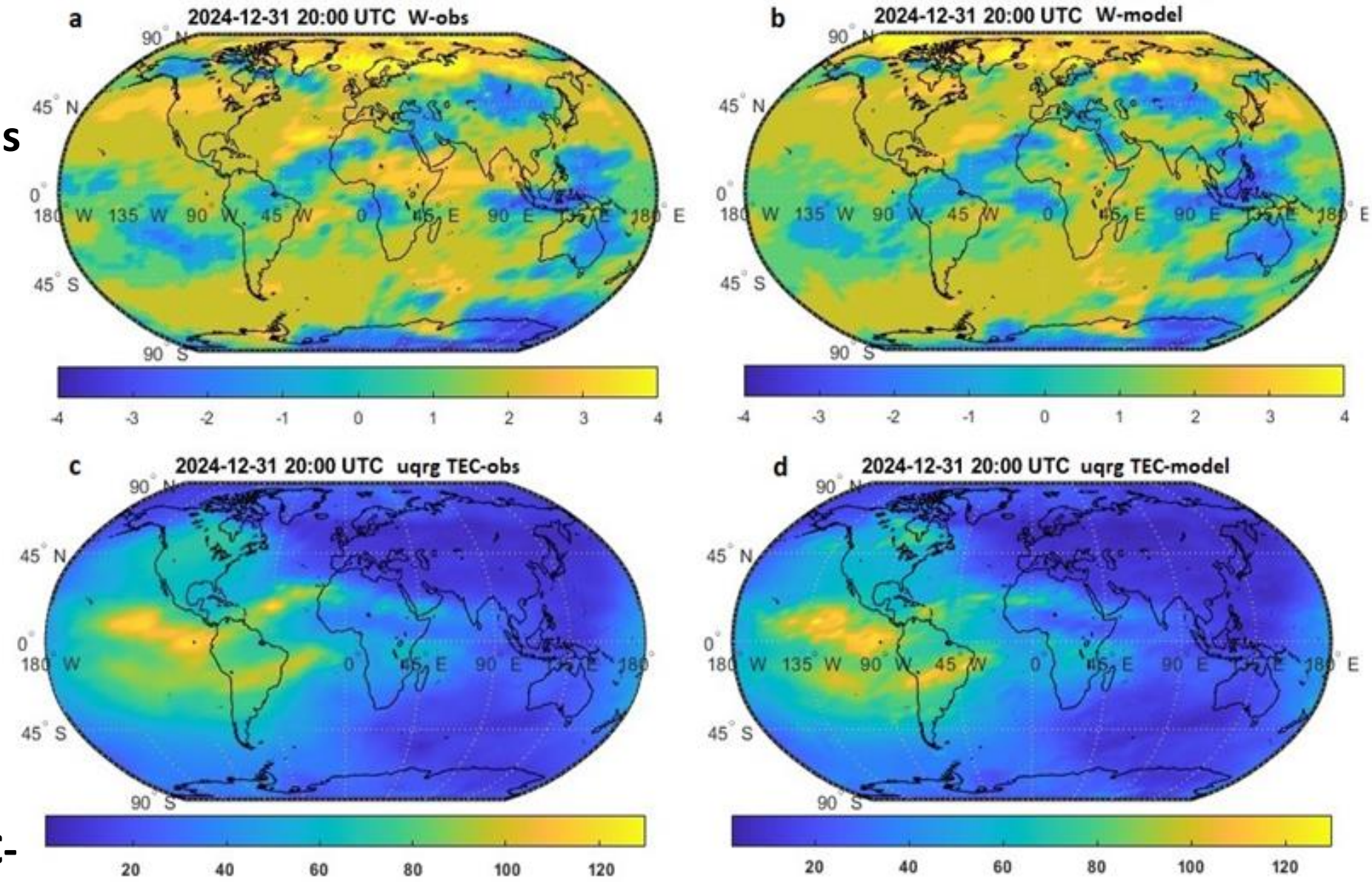
W-model

- **W-model is produced hour by hour by the rotation of the W-index map from the preceding hour UT by 15 degrees westward.**
- **GIM-MTEC : -15 day running median produced for 0, 1,…, 23 UT from GIMs observed on 15 preceding days.**
- **GIM-W-TEC at each grid point** $= \mathrm{MTEC} \times 10^{\mathrm{DTEC}}$
- **Coefficients for the W-model values:**

W	−4	−3	−2	−1	0	1	2	3	4
10^{DTEC}	0.50	0.59	0.79	0.95	1.00	1.05	1.26	1.69	2.00

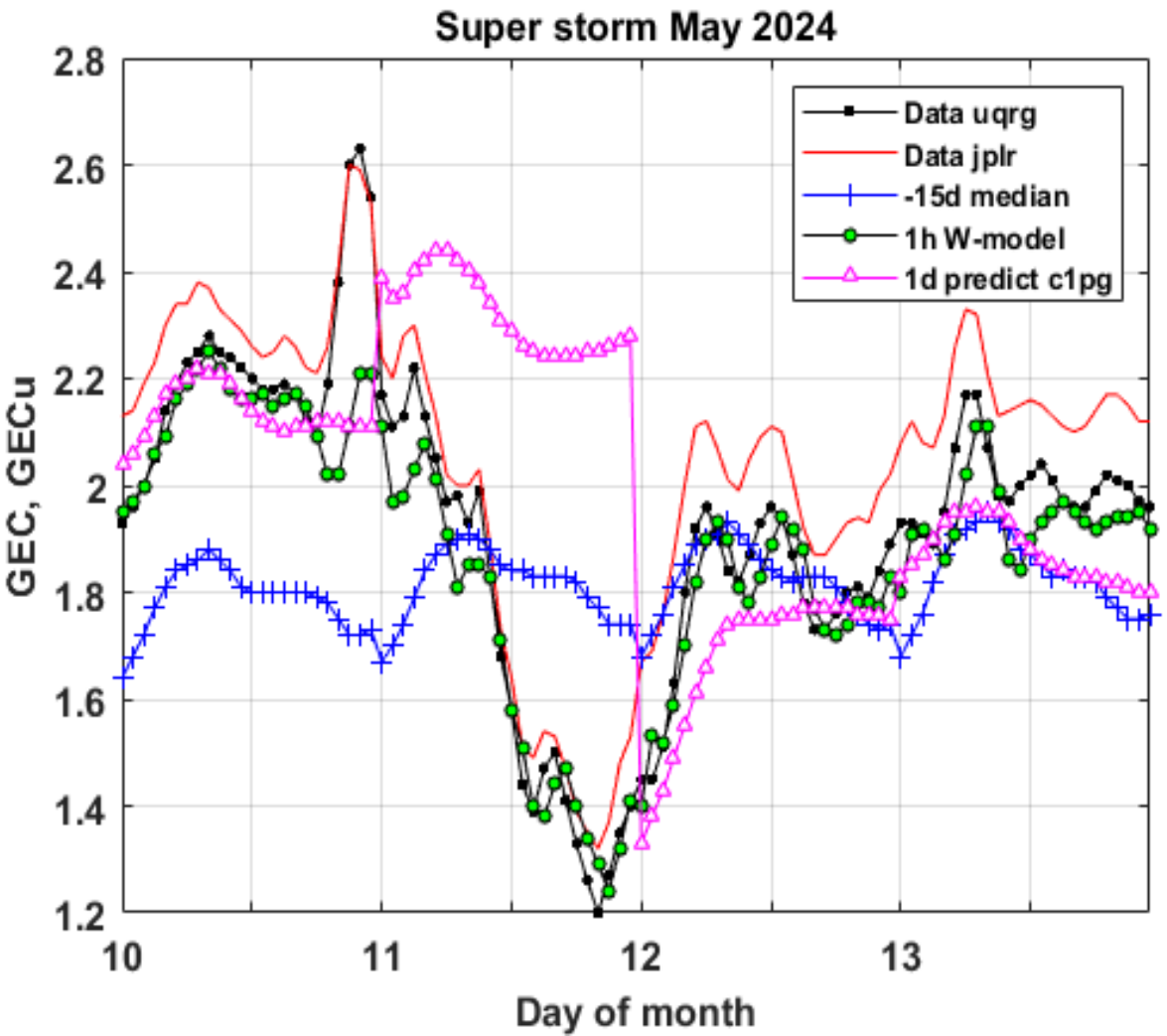
RESULTS (1)

- **Model-data comparisons of global maps of W-index (top panel) and**
- **GIM-TEC (bottom) for quiet day (24 Dec 2024, 20:00 UT, Kp = 1.7):**
- **(a) W-obs;**
- **(b) W-model, obtained by rotation W-obs at 19:00 UT.**
- **(c) uqrg TEC-obs;**
- **(d) W-TEC (TEC-model), obtained from -15 d TEC-median at 20:00 UT and W-model (b).**



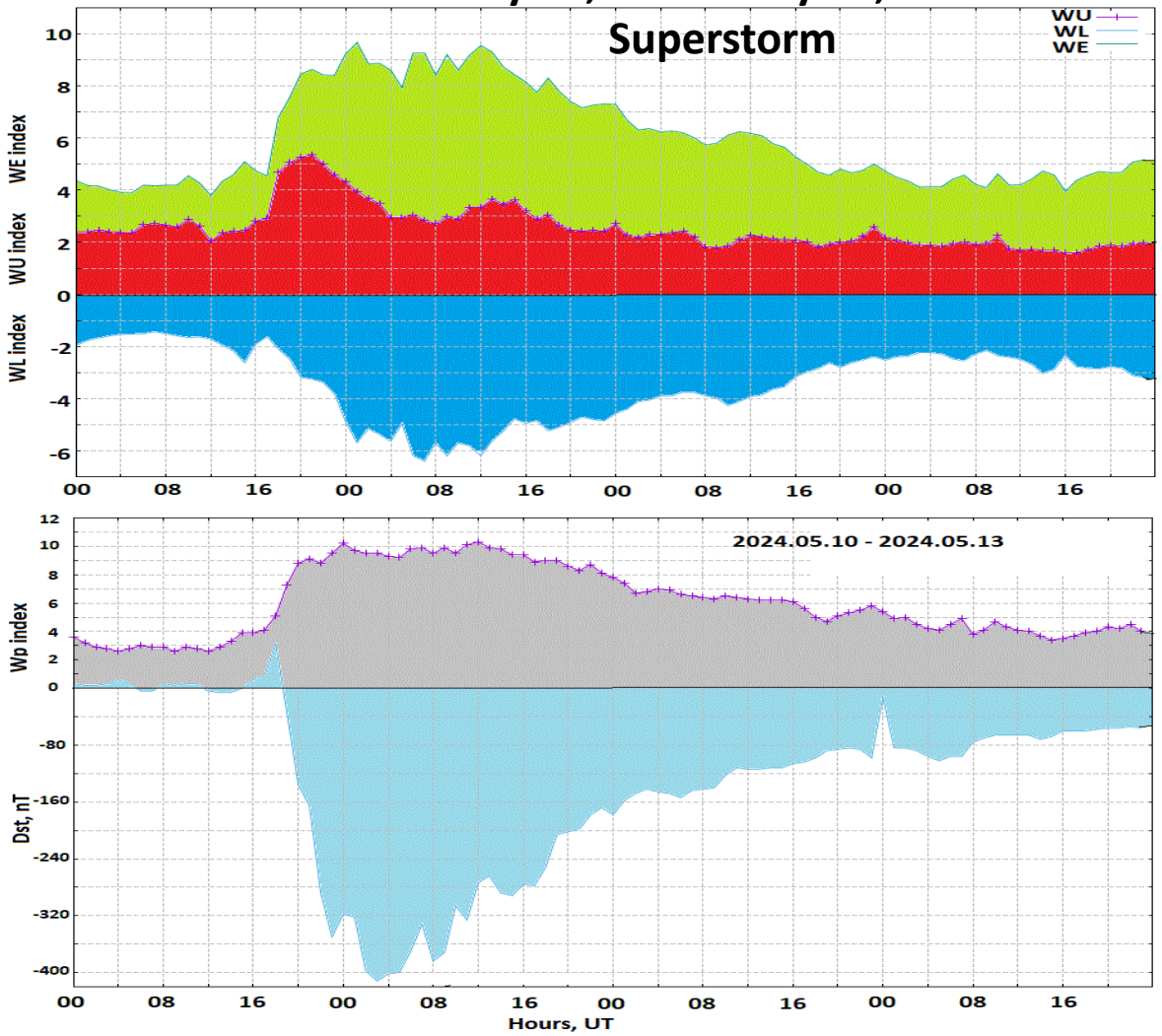
RESULTS (2)

- **Global Electron Content (GEC) produced from global maps on 10-13 May 2024**



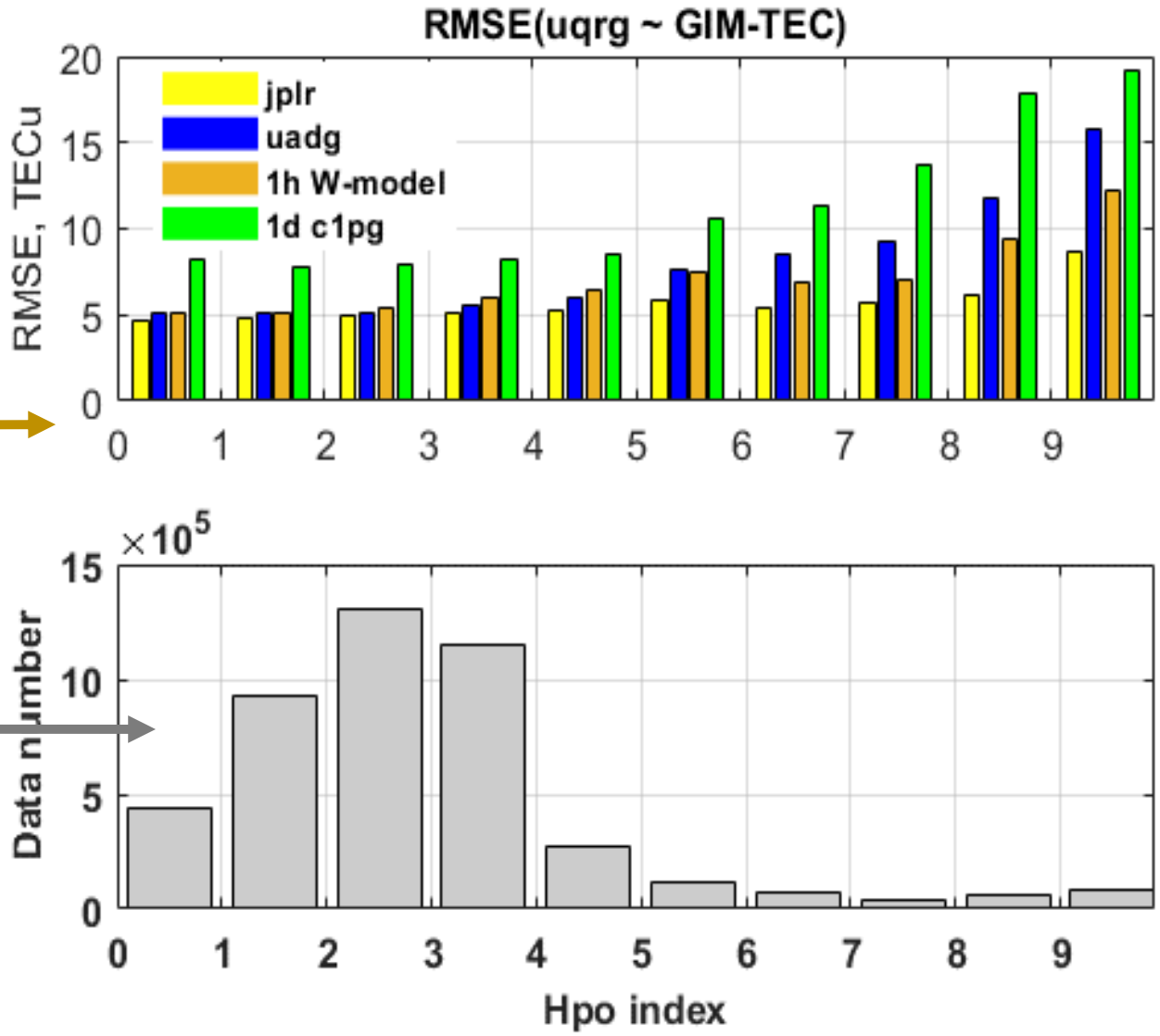
- **Temporal variation of ionospheric WU, WL, WE and Wp indices and Dst**
- **Dst = -412 nT, Hpo = 10.7**

May 10, 2024- May 13, 2024



RESULTS (3)

- **RMSE calculated between uqrg and GIM-TEC (jplr, uadg, 1h W-model and 1 day c1pg forecast) during 36 quiet and storm days: 10-13.05.2024, 31.12.2024, 1-31.01.2025.**
- **RMSE increases with magnitude of geomagnetic disturbance and Hpo index (1h equivalent to Kp).**
- **W-model results outperform**
  - **uadg at high Hpo and**
  - **c1pg in all cases.**
- **Number of data points used for RMSE calculation.**



CONCLUSIONS AND FUTURE DIRECTIONS

- **A novel method, W-model, is proposed for artificially updating GIM-TEC maps hour by hour, based on the rotation of the W-index map from the preceding hour by a westward rotation of 15 degrees.**
- **The performance of the method is demonstrated by comparisons of Global Electron Content (GEC) from observed GIM-TEC with model results during superstorm in May 2024 and intense storm in January 2025.**
- **RMSE of GIM-W-TEC relative to those of uqrg**
  - **outperform uadg at high geomagnetic activity and**
  - **it is less than those of c1pg results in all cases.**
- **1 h W-model in this presentation is produced with uqrg.**
- **In the future, it would be best to apply W-model to quasi-real time uadg hour by hour since uadg has 15-minute cadence and a 2-hour UT delay.**

Thank you

Acknowledgements

- Jet Propulsion Laboratory (JPL) database: https://sideshow.jpl.nasa.gov/pub/iono_daily/IONEX_rapid/
- The Universitat Politècnica de Catalunya (UPC-ionSAT) GIM: http://cabrera.upc.es/upc_ionex_GPSonly-RINEXv3/
- The Earth Data NASA GIM: https://cddis.nasa.gov/archive/gnss/products/ionex/
- W-index maps are routinely produced from 1h JPL GIM, jplr, and 15-min UPC maps uqrg and uadg GIM-TEC: https://www.izmiran.ru/ionosphere/weather/grif/Maps/.
- W-index maps are provided online by IONOLAB : https://www.ionolab.org/index.php?page=index&language=en
- W-index is published in
  - Gulyaeva, T.L.,, I. Stanislawska, Derivation of a planetary ionospheric storm index. Annales Geophysicae, 26, N.9, 2645-2648, www.ann-geophys.net/26/2645/2008/, 2008. DOI:10.5194/angeo-26-2645-2008.
  - Gulyaeva, T., & Arikan, F. (2017). Statistical discrimination of global post-seismic ionosphere effects under geomagnetic quiet and storm conditions. Geomatics, Natural Hazards and Risk, 8(2), 509-524. http://dx.doi.org/10.1080/19475705.2016.1246483.
- Hpo index is published in
  - Yamazaki, Y., Matzka, J., Stolle, C., Kervalishvili, G., Rauberg, J., Bronkalla, O., Morschhauser, A., Bruinsma, S., Shprits, Y.Y., and Jackson, D.R., Geomagnetic activity index Hpo, Geophys. Res. Lett., 2022, vol. 49, no. 10. https://doi.org/10.1029/2022GL098860