

**Machine learning emulator for physics-based prediction of ionospheric response to solar wind variations**

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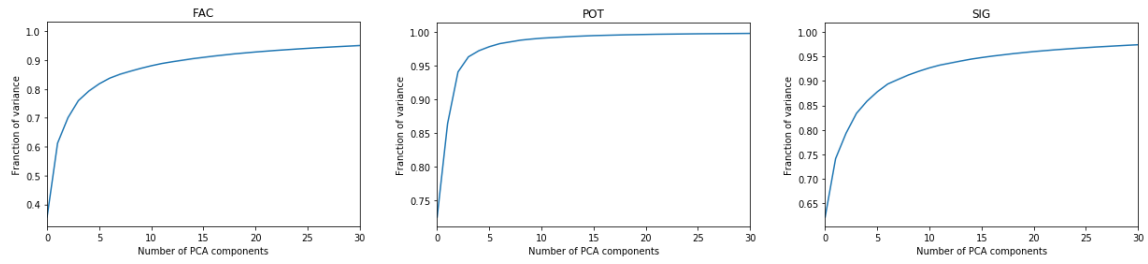
Figures S1 to S8

**Additional Supporting Information (Files uploaded separately)**

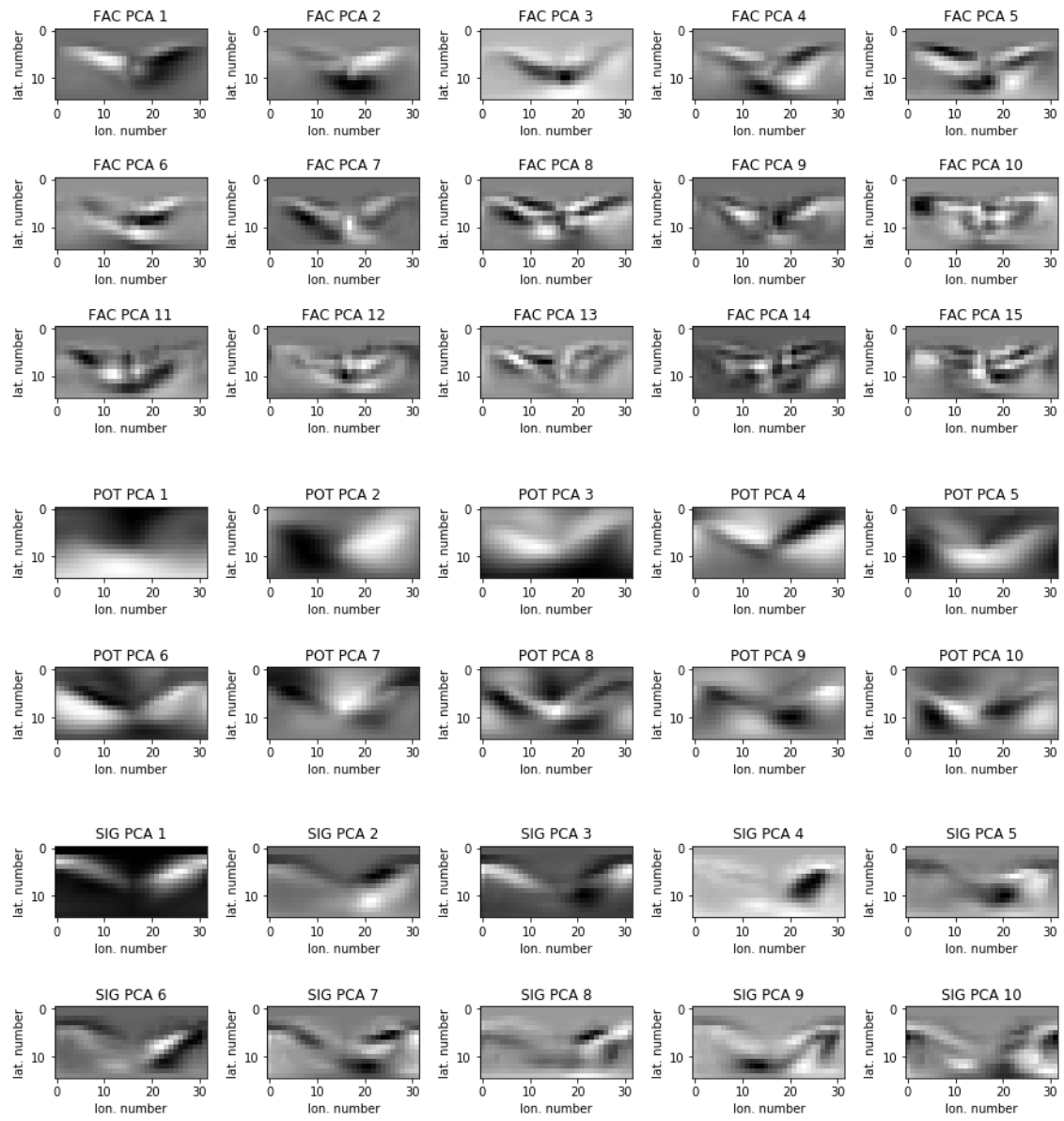
Captions for Movies S1 to S3

**Introduction**

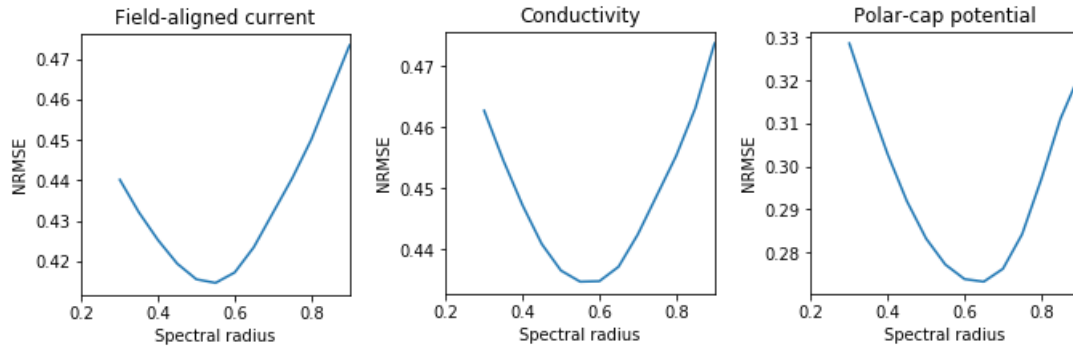
We provide additional information for the principal component analysis (PCA) results (Figures S1-S2), optimization of spectral radius for the Echo State Network (ESN) model (Figure S3), training and testing of ESN models for ionospheric potential and conductivity (Figures S4-S5), and further synthetic solar wind experiment (Figures S6-8). All-step comparison between the REPPU simulation results and ESN-based emulator results are also shown for FAC (field-aligned currents), potential, and conductivity (Movies S1-S3).



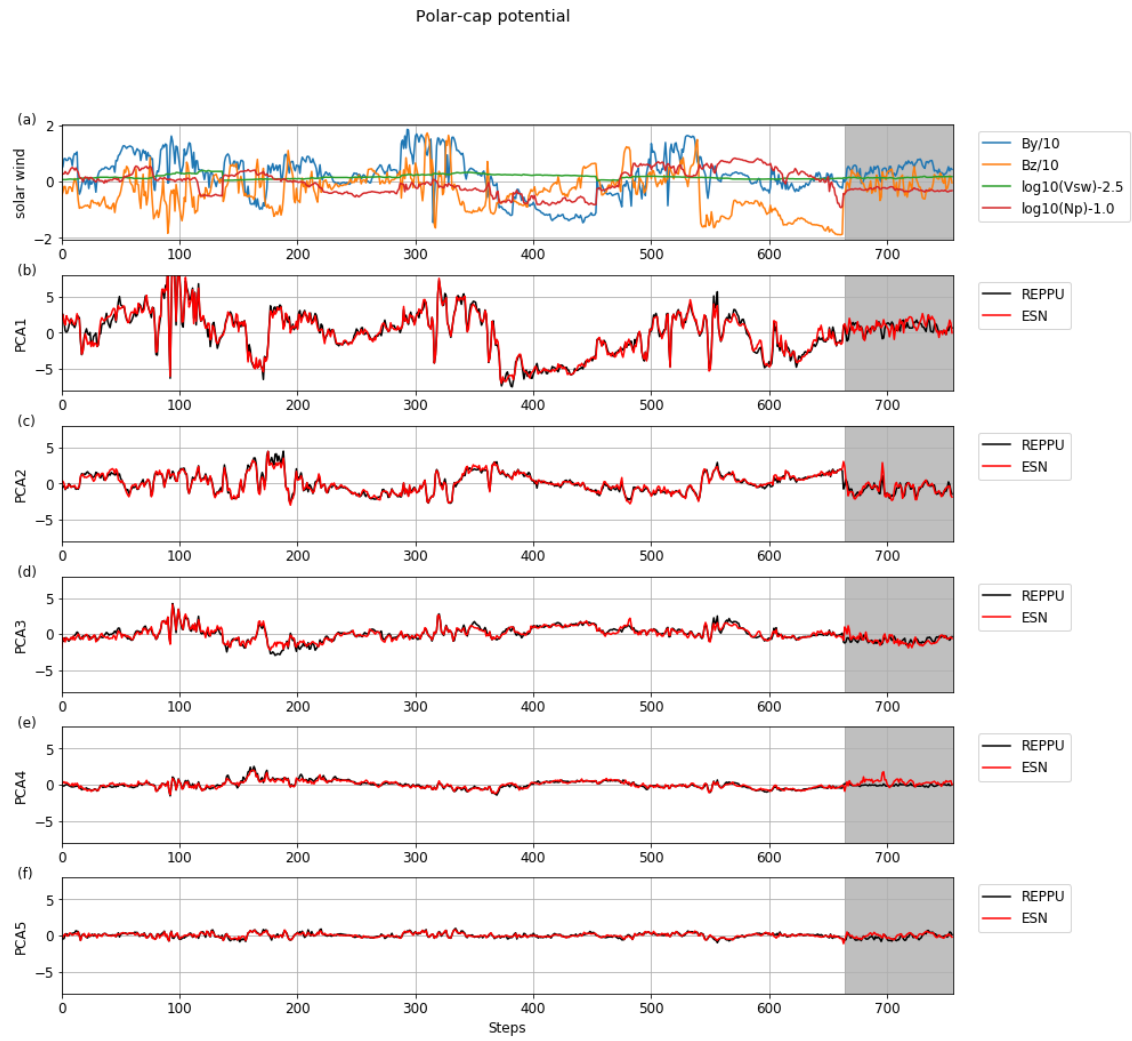
**Figure S1.** Explained variance ratio of the principal component analysis (PCA) for field-aligned current (left), ionospheric potential (middle), and conductivity (right).



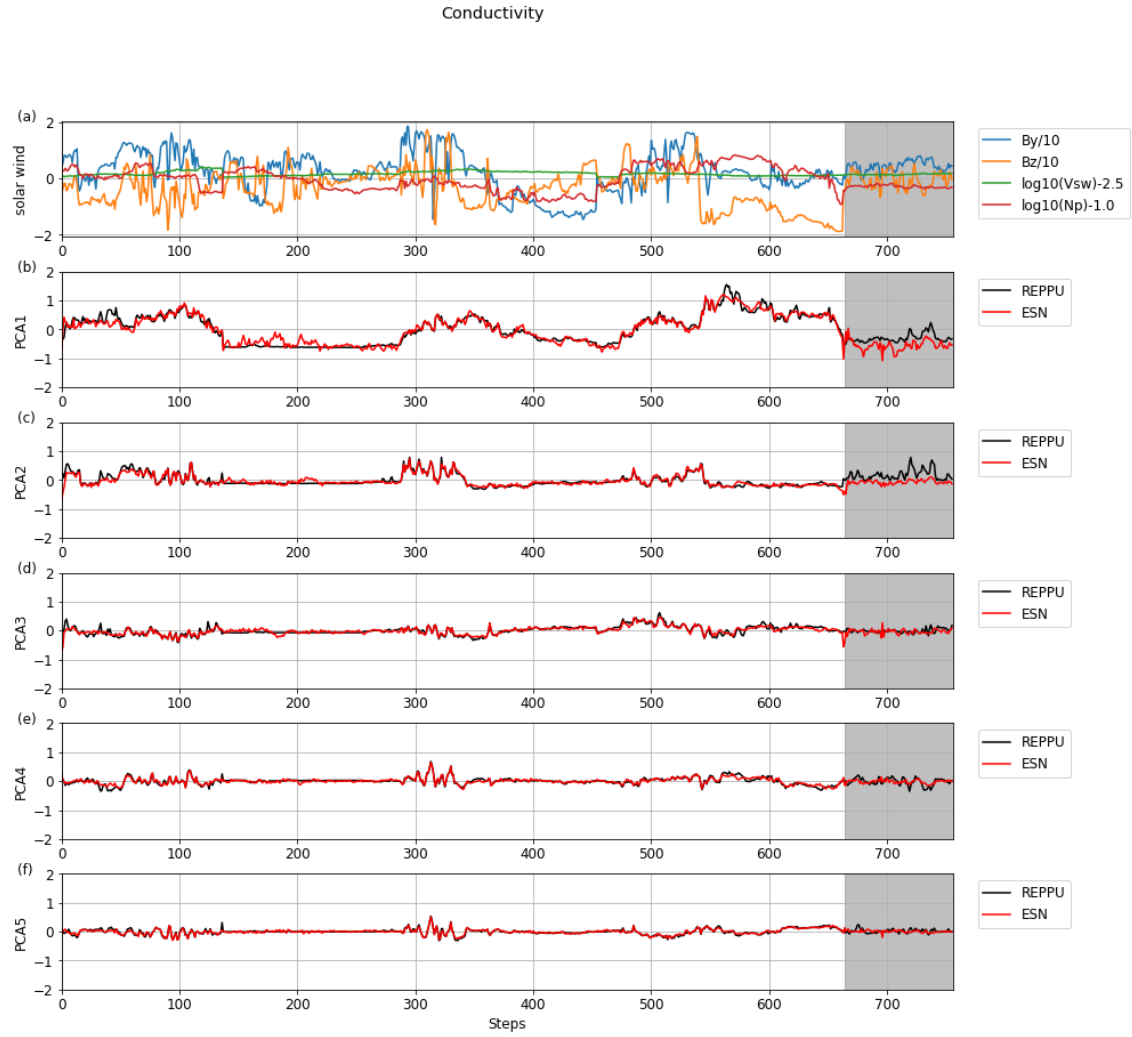
**Figure S2.** PCA longitude-latitude patterns for field-aligned current (top 3 rows), ionospheric potential (middle rows), and ionospheric conductivity (bottom rows).



**Figure S3.** Normalized root-mean-square error against the spectral radius for the ESN prediction of FAC (left), ionospheric conductivity (middle), and ionospheric potential (right).

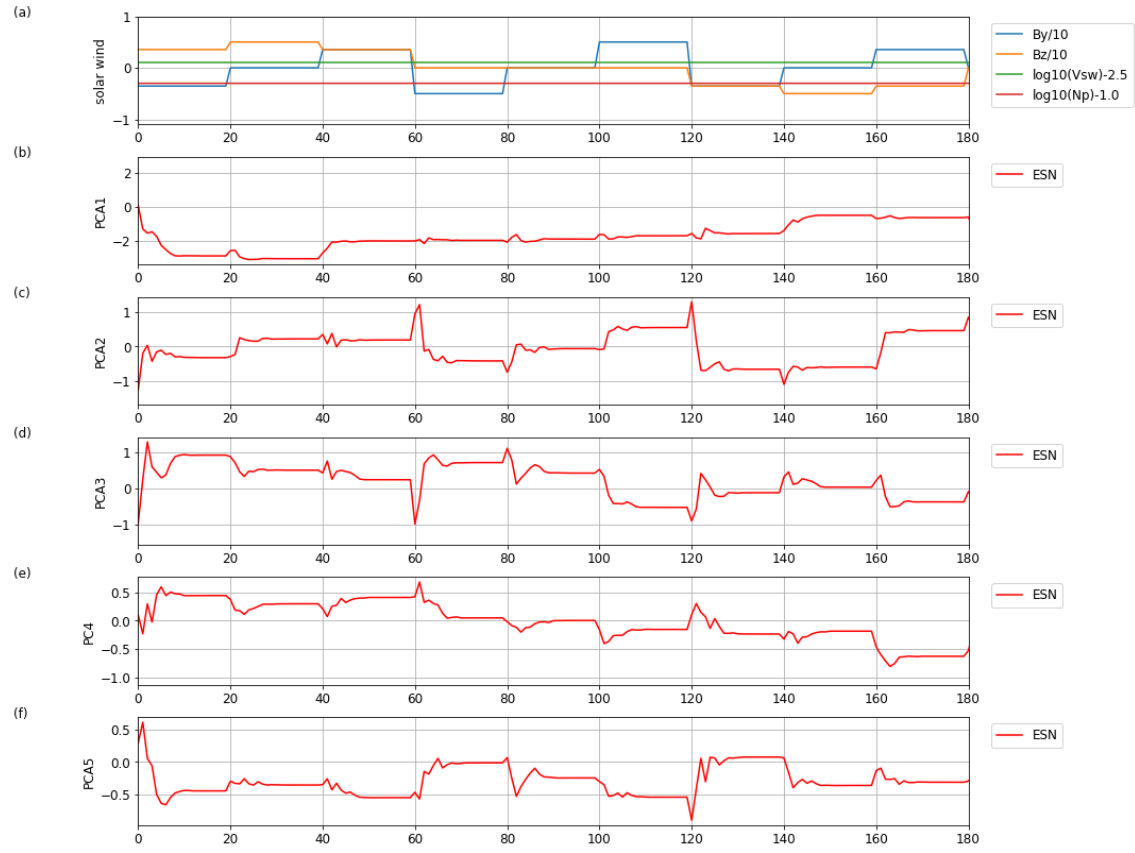


**Figure S4.** Solar wind parameters (a) and top five PCA components (b-f) for ionospheric potential. Black curves are from the REPPU simulation results, while red curves are from the Echo State Network (ESN) model. The testing time interval is shown by gray hatched region. The number of nodes is 300 and the spectral radius is 0.65.



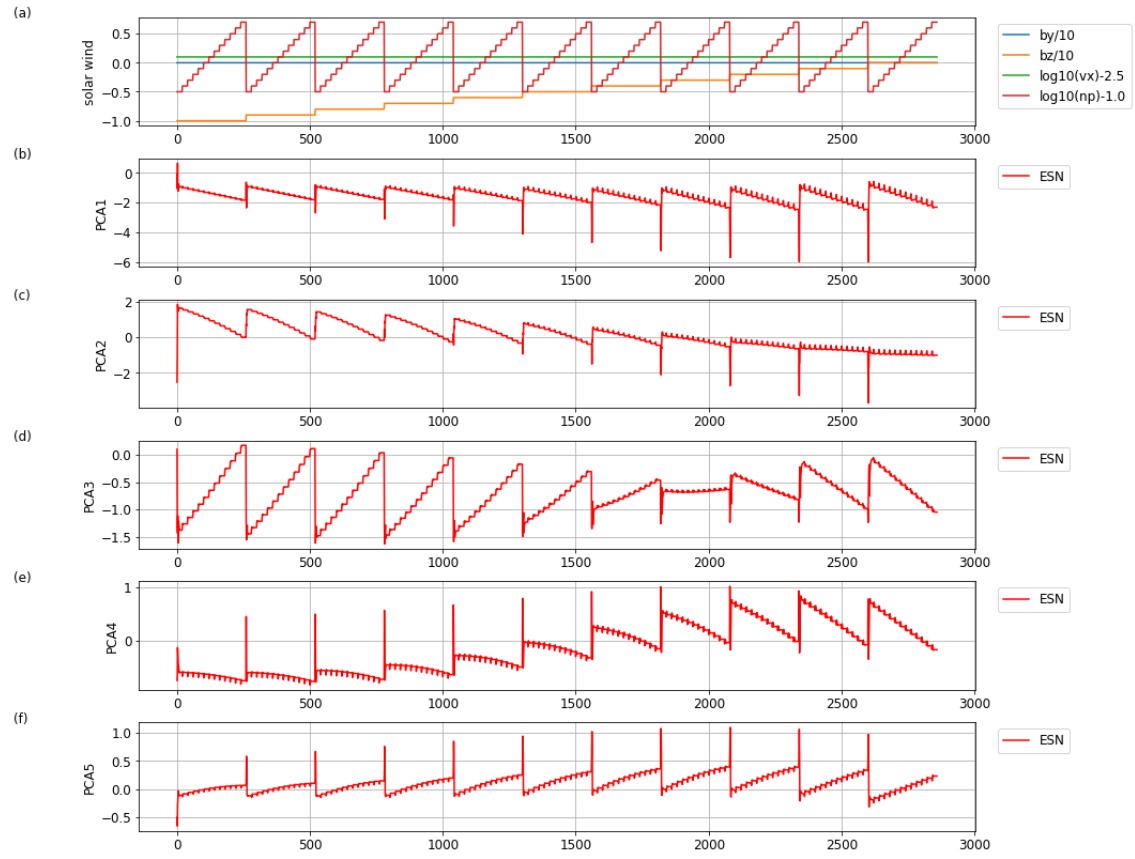
**Figure S5.** Solar wind parameters (a) and top five PCA components (b-f) for ionospheric conductivity. Black curves are from the REPPU simulation results, while red curves are from the ESN model. The testing time interval is shown by gray hatched region. The number of nodes is 300 and the spectral radius is 0.60.

field-aligned current



**Figure S6.** Synthetic solar wind variations (top) and the predictions of PCA components from the ESN-based emulator, to confirm the IMF (interplanetary magnetic field) clock angle dependence.

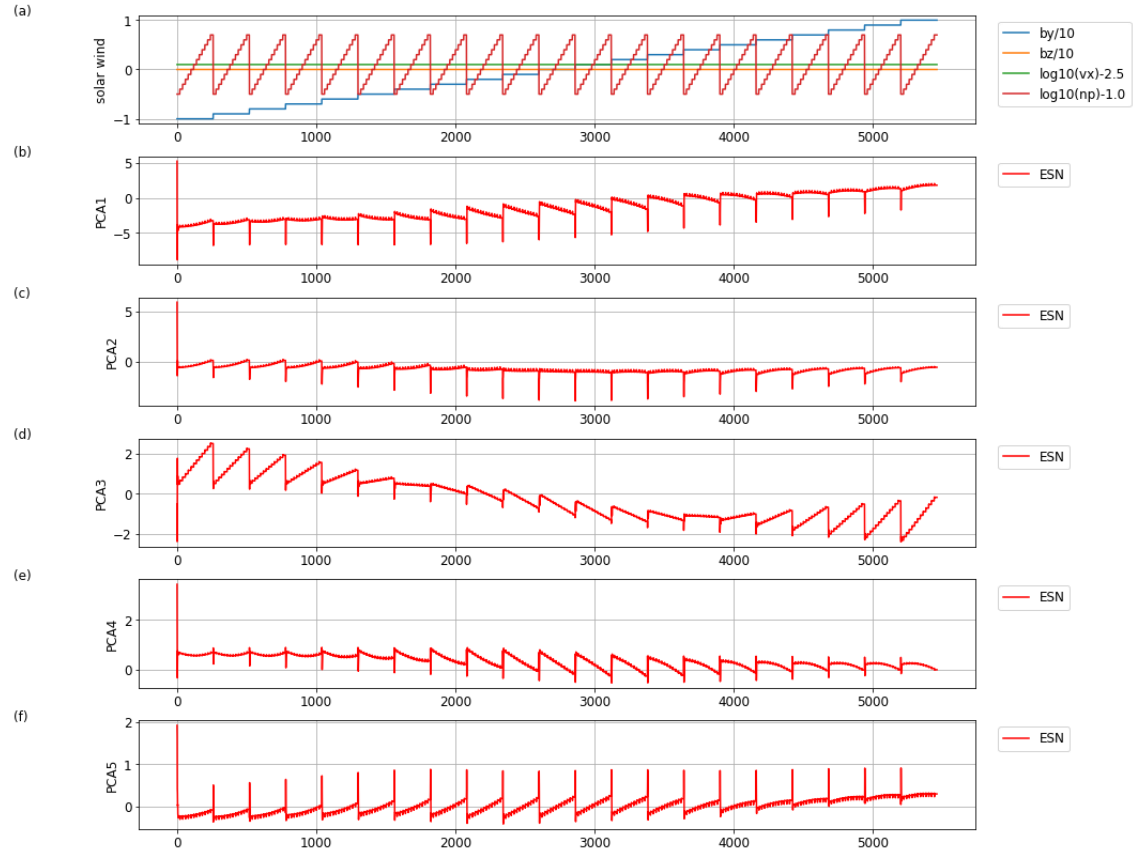
# Polar-cap potential



**Figure S7.** Synthetic solar wind variations (top) and the predictions of PCA components from the ESN-based emulator, to create the southward IMF (SBZ)-density heat map of cross-polar cap potential (CPCP).



# Polar-cap potential



**Figure S8.** Synthetic solar wind variations (top) and the predictions of PCA components from the ESN-based emulator, to create the IMF By-density heat map of CPCP.

**Movie S1.** Comparison of REPPU simulation results and ESN-based emulator results for FAC.

**Movie S2.** Comparison of REPPU simulation results and ESN-based emulator results for ionospheric potential.

**Movie S3.** Comparison of REPPU simulation results and ESN-based emulator results for ionospheric conductivity.