

Forecasting ionospheric Total Electron Content maps with deep neural networks

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DeLTA : Deep Learning for Aerospace Applications

Electromagnetism

Remote sensing

Robotics

Optics



Materials and structures

Fluid mechanics

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TEC

Approach for TEC prediction

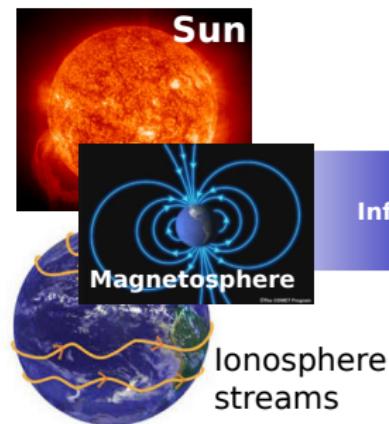
Experiments

Conclusion and future work

Ionosphere

Ionosphere

Highly ionized region in upper atmosphere.



Ionosphere state

Influence

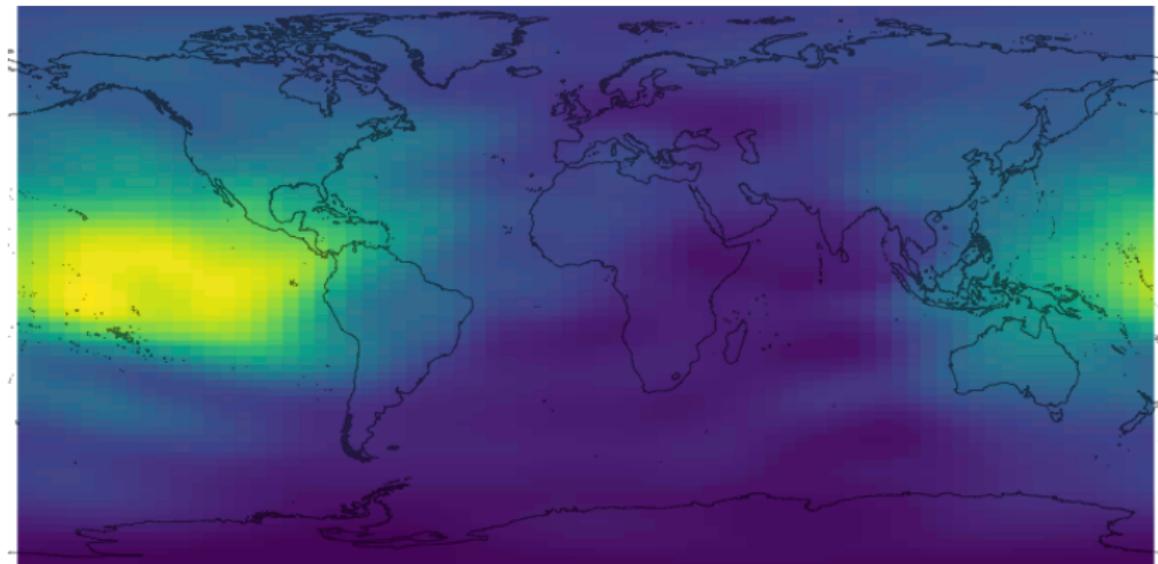


Affects trans-ionospheric
radiowaves



GPS / space
based telecoms

TEC Map



Total Electron Content (TEC) measures ionospheric activity.

TEC = Integration of electron density along a $1m^2$ sect. tube between GNSS station and GNSS satellite

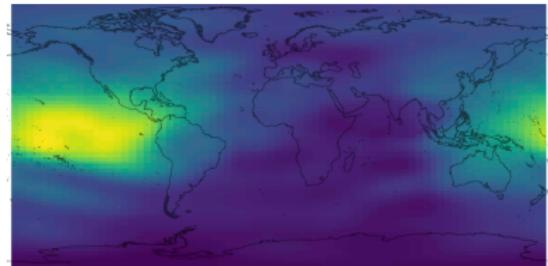
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Code TEC data

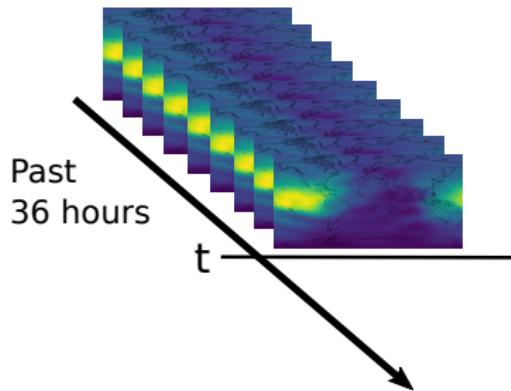
aiuws.unibe.ch/ionosphere/
based 200 stations
1 TEC map every 2 hours since
2003

- ▶ 72×80
- ▶ Resolution : $5^\circ \times 2.5^\circ$

Approach

Preprocessing

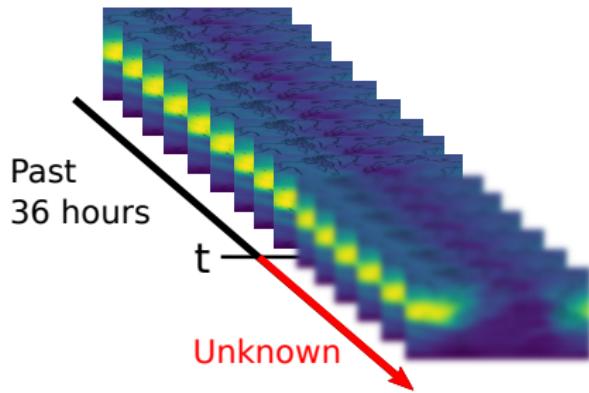
Heliocentric coordinates : remove rotation effect.



Approach

Preprocessing

Heliocentric coordinates : remove rotation effect.



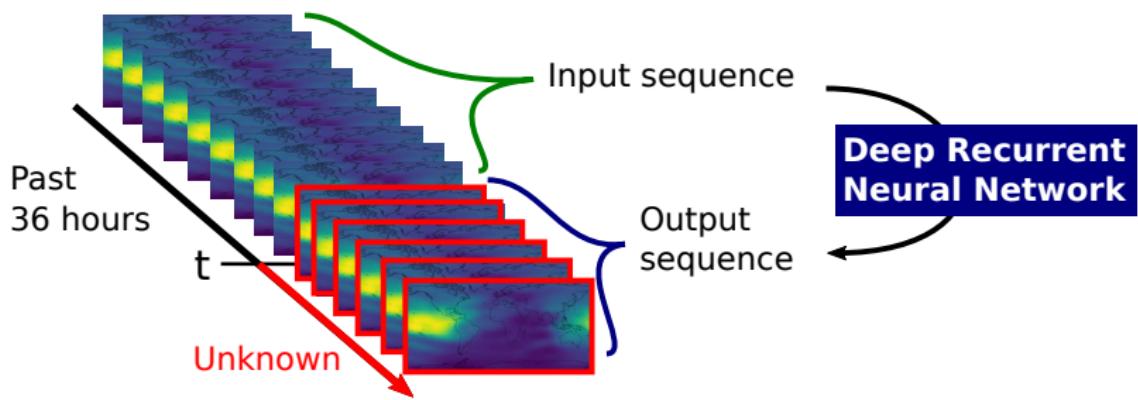
Prediction based on previous states

- No physical model
- No additional inputs
- No prediction of perturbations

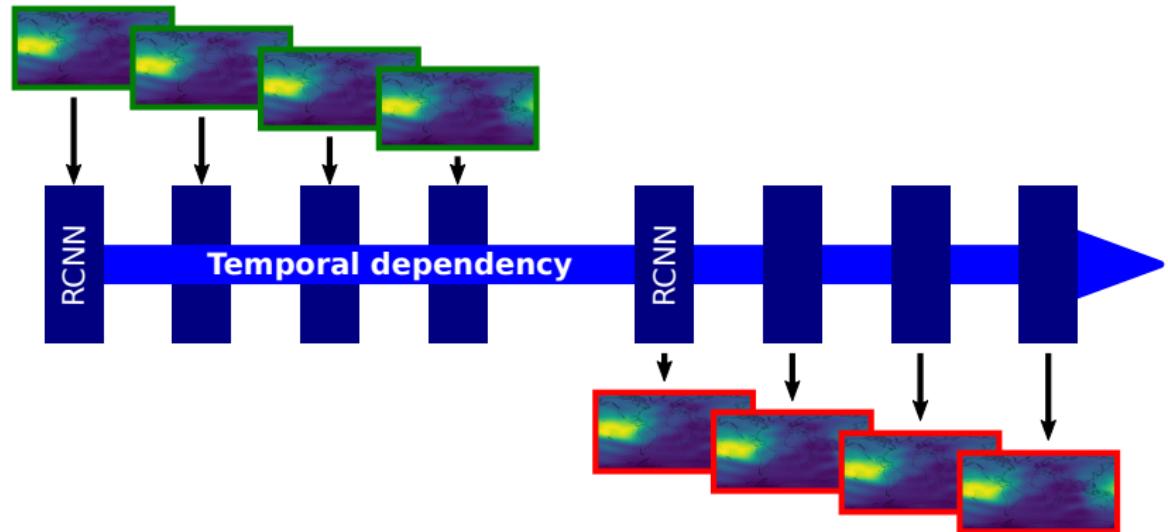
Approach

Preprocessing

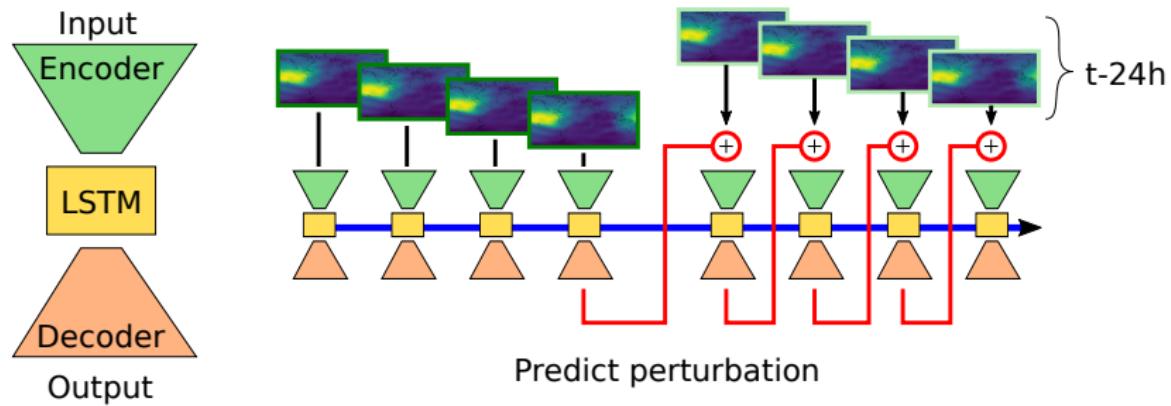
Heliocentric coordinates : remove rotation effect.



Network architecture



Encoder - Decoder architecture¹



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1. Work presented at ICONIP : *Deep sequence-to-sequence neural networks for ionospheric activity map prediction* [1]

Recurrent U-net

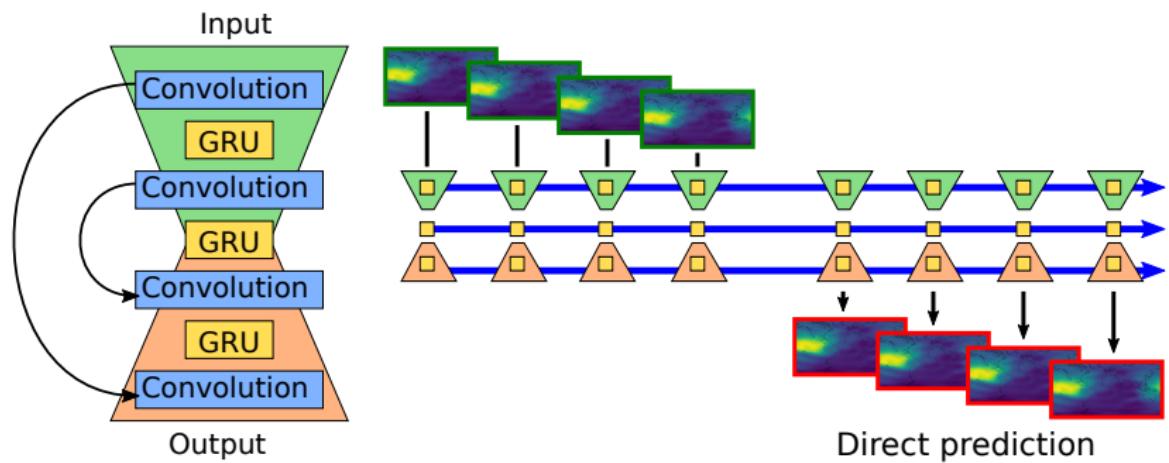


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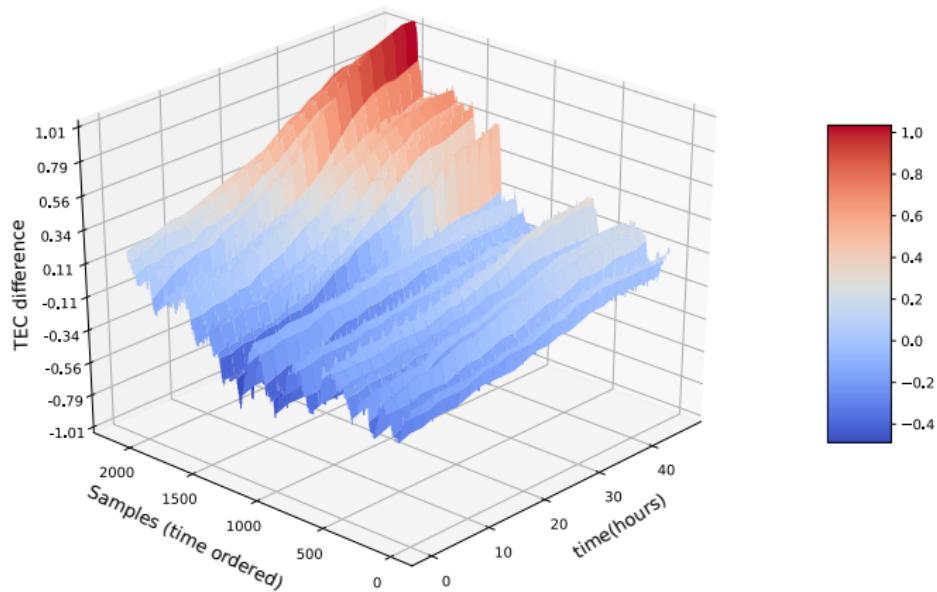
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Comparison with Encoder-Decoder method



Prediction difference between [1] and Rec-Unet.

Quantitative results

Whole test set

Method	RMS 48h	First 24h	Last 24h
Priodic	2.74	2.88	2.53
ICONIP	2.65	2.65	2.65
Ugru	2.66	2.46	2.85

First half of test set

Method	RMS 48h	First 24h	Last 24h
Priodic	2.88	2.87	2.89
ICONIP	2.75	2.74	2.76
Ugru	2.60	2.46	2.74

Note : mean over 6 runs, numbers updated compared to paper. Different test set.

Comparison with other approaches

	Reference	RMS (ref)	RMS (best run)
[2]	Chunli D., Jinsong P.	1.45	2.1
[3]	Huang, Z., Yuan, H.	≤ 2	1.53
[4]	Niu, R. <i>et al.</i>	3.1	0.73

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2. Erratum : in paper numbers from [1]. Replaced at aboulch.github.

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Conclusion

Our method

- ▶ Global TEC prediction
- ▶ Recurrent Unet

Perspectives

- ▶ Improve prediction from 24h to 48h
- ▶ Improve convergence (may diverge)
- ▶ Reduce time dependency to training set (train on more data)
- ▶ Involve other sources (e.g. sun imagery)

Thanks for your attention

Slides and updated paper at : aboulch.github.io

Implementation

- ▶ PyTorch framework
- ▶ Code to be released

References

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