RUSSIAN-BRAZILIAN SLR AND GNSS MONITORING STATIONS: OPERATION AND RECENT RESEARCH ACTIVITIES

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Summary

- Russian-Brazilian GNSS Cooperation
  - Overview
- Russian-Brazilian SLR Station
  - Operation
  - Recent Results
- Russian-Brazilian One-Way-Station
  - Operation
  - **Recent Results**
- Conclusions and future works.

Russian-Brazilian GNSS Cooperation

Summarized timeline overview:

- (Feb. 19th 2013): GLONASS OWS in Brazil starts its operation;
- (Jul. 14th 2014): GLONASS SLR station in Brazil starts its operation;
- (May 18th 2015): ICTP and UnB representatives first talk during the Workshop on Applications of GNSS at Krasnoyarsk, Russia;
- (Sept. 15th 2015): Official Letter in support of the cooperation enters into force;
- (Sep. 22nd 2015): CPD/UnB FTP server for data transfer set up;
- (Sep. 25th 2015): Measurement data transfer protocol signed;
- (Oct. 01st 2015): UnB regular data transfer started;
- (Jan. 08th 2016): MoU formalizes the scientific research cooperation between the UnB and the ICTP in the field of GNSS in the region of Brasilia;
- (Feb. 16th 2016): ITEP regular data transfer started;
- (Apr. 20th 2016): UFSM regular data transfer started.

Russian-Brazilian SLR Station

- Operation
  - Research and Production Corporation - Precision Systems and Instruments methods (software and hardware);
  - Compact laser-optical system for SLR, angular measurements and photometry;
  - Measurement cycle: calibration, operation, data processing.

- Recent results
  - Contribution for the LARGE-4 mission of the ILRS;
  - High amount and quality of GLONASS satellites laser tracking.

Fig. 1: SLR (a) and technical room (b) in detail.

Russian-Brazilian One-Way-Station

- Operation
  - Research and Production Corporation - Precision Systems and Instruments methods (receiver);
  - GLONASS reference station;
  - Measurement: 24/7 operation.

- Recent results
  - Use of Artificial Neural Networks (ANN) to estimate TEC values based on GNSS;
  - vTEC short-term forecasting.

Artificial Neural Networks

- Definition
  - A set of massively interconnected simple computing units, called neurons, interconnected by plastic links, usually modified by a training algorithm.

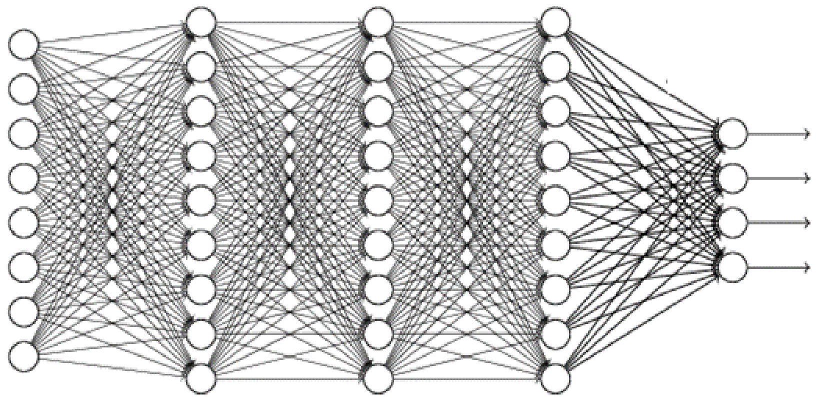

Fig. 2: Artificial neural networks schematic

- Inspired by biological neural networks
  - Each structure connect to each other by synapses
  - The main components of a biological neuron are:
    - Dendrites – which receive stimuli from other neurons;
    - The cell body – which stores and combine information from
    - other neurons;
    - Axon – transmits stimuli to other nerve cells.

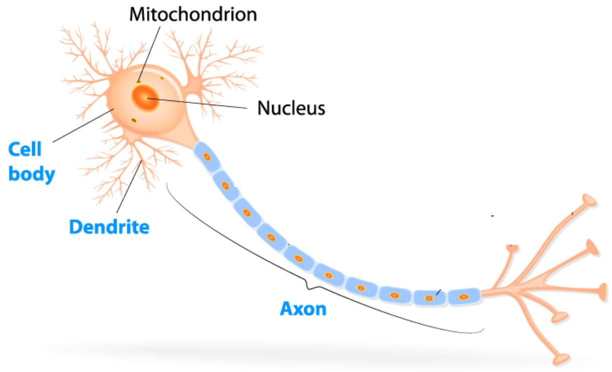

Fig. 3: Anatomy of a neuron

The ANN model

- The ANN input parameters
  - Geographic location;
  - Seasonal variation;
  - Daily variation;
  - Solar radio flux;
  - Dst-index;
  - Geomagnetic Kp-index;

- Calibration Techniques
  - Dr. Gopi Seemala calibration technique;
  - ICTP calibration technique.

- Training procedure
  - Levenberg-Marquardt backpropagation

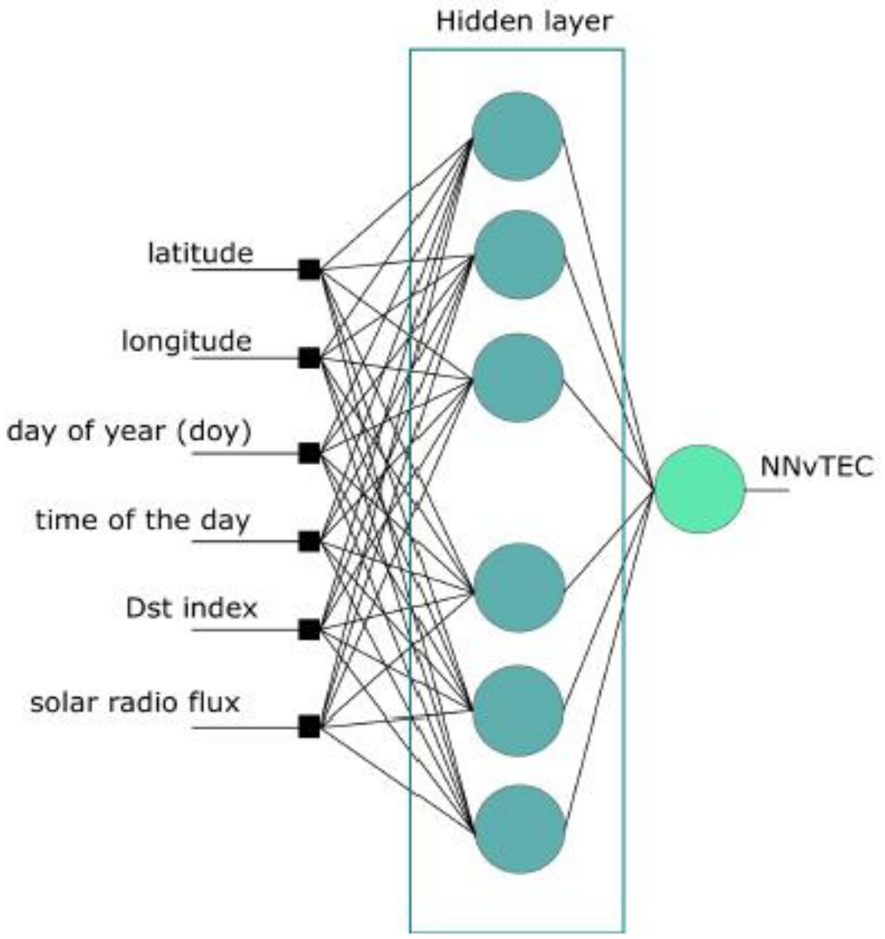

Fig. 4: Example of ANN structure.

Results and Analysis – ANN performance indexes

- Average error

$$\alpha = \frac{1}{N}\sum_{i=1}^{N} NNvTEC_i - vTEC_i,$$

- Root Mean Squared Error (RMSE)

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(vTEC_i - NNvTEC_i)^2}$$

- Normalized Root Mean Squared Error (NRMSE)

$$NRMSE = \frac{\sqrt{\sum_{i=1}^{N}(vTEC_i - NNvTEC_i)^2}}{\sqrt{\sum_{i=1}^{N}(vTEC_i - \overline{vTEC_i})^2}}$$

Results and Analysis – Case study 1

- South Region

Table 1: Summarized information of the stations under investigation in the South region - Case study 1.

Data Network	Station Name	City in Brazil	Lat. (°S)	Lon. (°W)	Type of Use (vTEC Data)
RBMC	RSPE	Pelotas (RS)	31.802	52.418	NN training
	RSCL	Cerro Largo (RS)	28.141	54.755	NN training
	RSAL	Alegrete (RS)	29.789	55.769	NN training
	SCLA	Lages (SC)	27.792	50.304	NN training
	SMAR	Santa Maria (RS)	29.718	53.716	NN testing
	POAL	Porto Alegre (RS)	30.659	51.120	NN testing

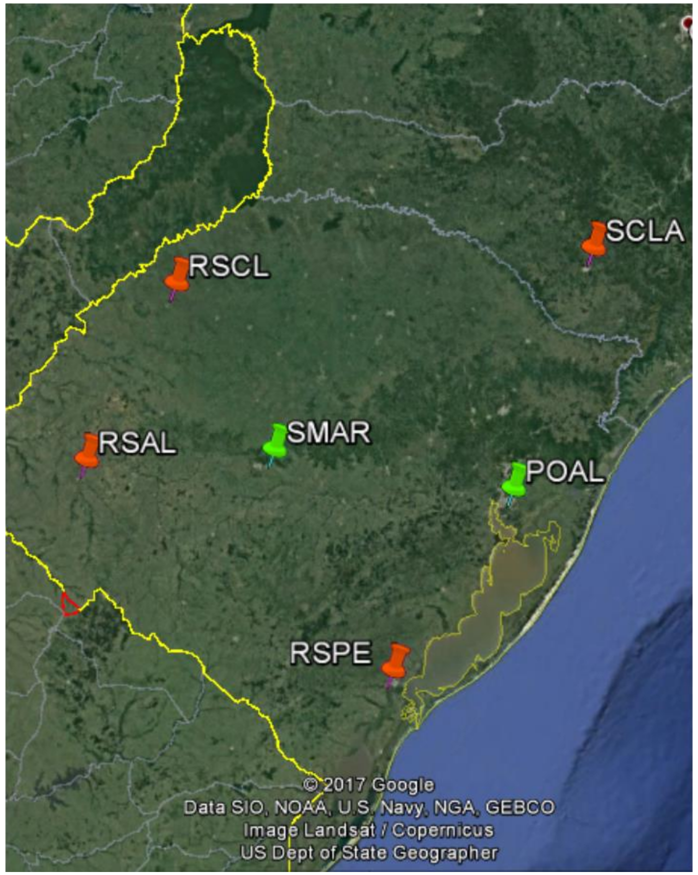

Fig. 5: Location of the stations - South region.

Results and Analysis – Case study 1

- The ANN input parameters

Table 2: ANN structures under investigation - Case study 1.

Structure	Input Parameters	Activation Function
A	Kp-index, $F_{10.7}$	$logsig$
B	Dst-index, $F_{10.7}$	
C	Dst-index	
D	Kp-index, $F_{10.7}$	$tansig$
E	Dst-index, $F_{10.7}$	
F	Dst-index	

- Common inputs:
  - lat, lon, doy, time of the day.
- vTEC calibration
  - GPS-TEC Analysis Application (Dr. Gopi Seemala)
- Period of Training
  - From doy 264 to 268

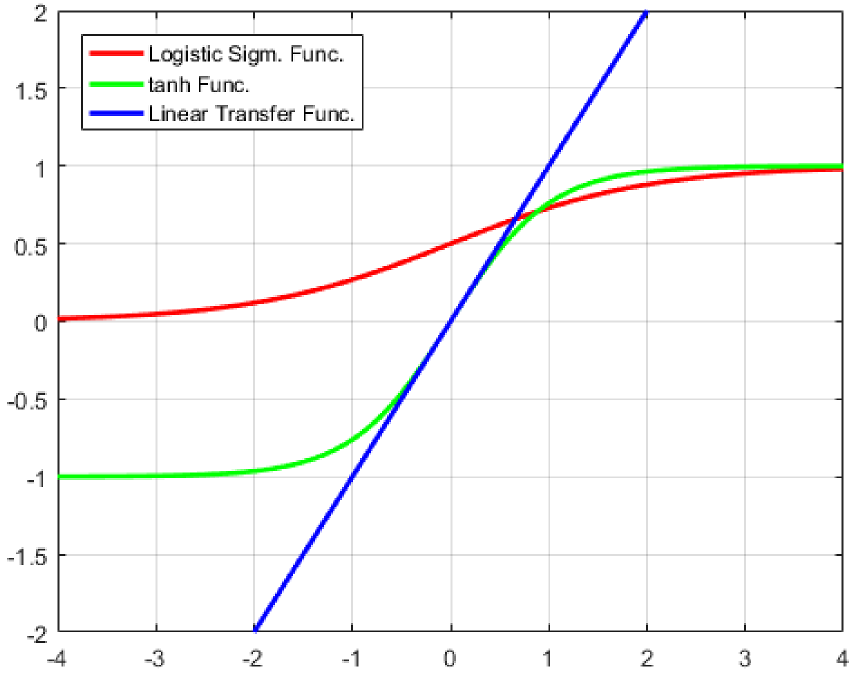

Fig. 6: Transfer functions.

Results and Analysis – Case study 1

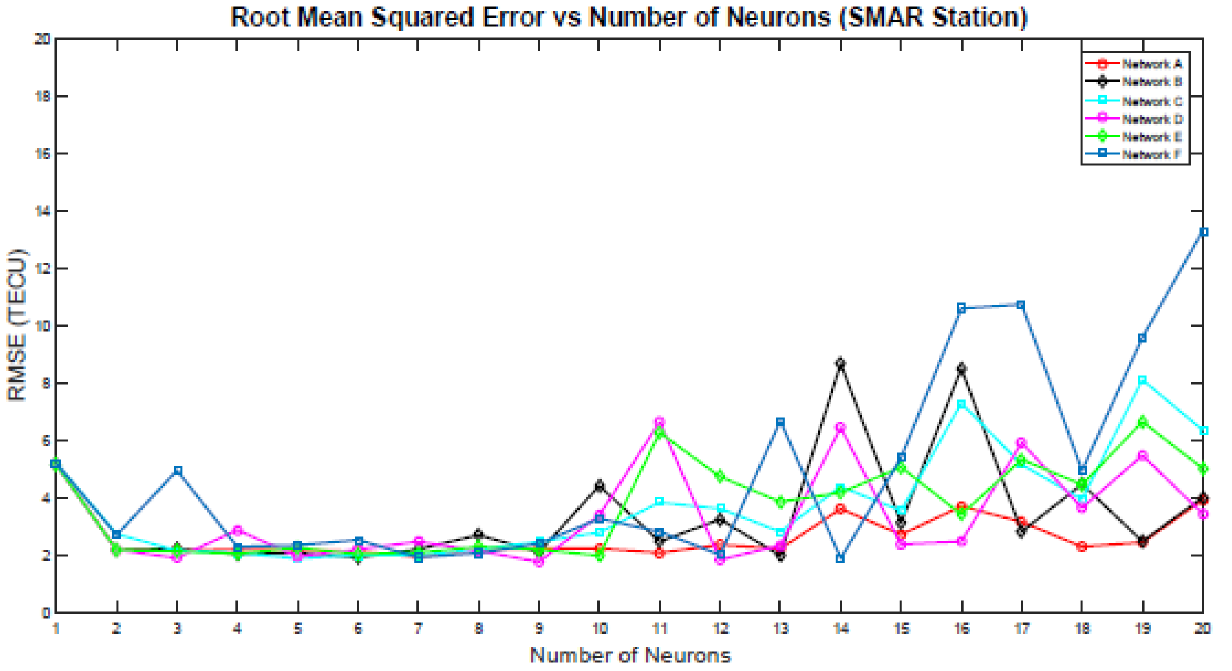

Fig. 7: RMSE values for each ANN structure tested - Case study 1.

- Data from the training stations were used to estimate vTEC from doy 264 to 268 on SMAR station;
- By the analysis, it was possible to verify that the structure D with tansig activation function, 9 neuron on the hidden layer and the inputs lat, lon, doy, time of the day, kp-index and solar radio flux presented the best RMSE error, equals to 1.795 TECU.
- This structure was used to estimated the vTEC on South (SMAR and POAL) and Center-West (GOGY and MTNX) regions during the September equinox of 2016 (doy 266).

Results and Analysis – Case study 1

- South Region

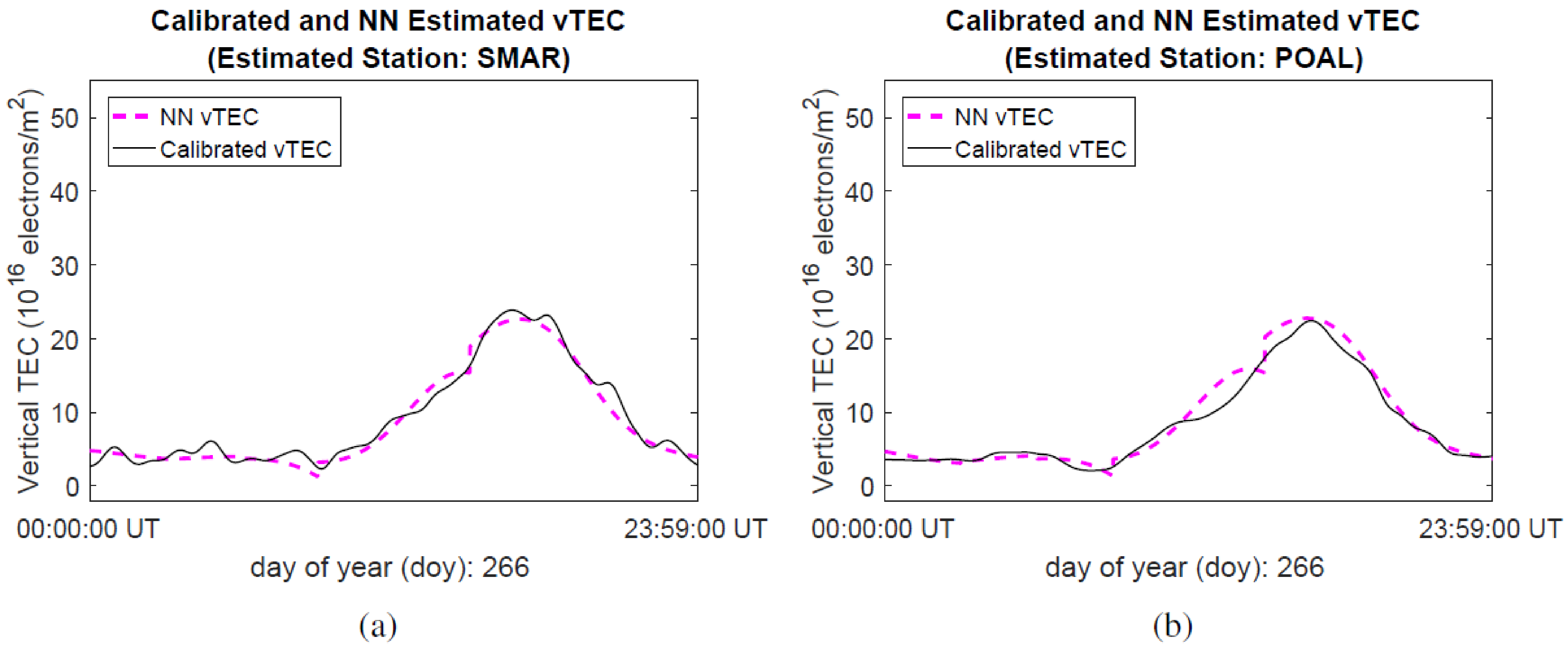

Fig. 8: Calibrated vTEC and NN vTEC on the September equinox of 2016 for the South region - Case study 1. (a) SMAR station, (b) POAL station.

Results and Analysis – Case study 1

- Central-West Region

Table 3: Summarized information of the stations under investigation in the Central-West region - Case study 1.

Data Network	Station Name	City in Brazil	Lat. (°S)	Lon. (°W)	Type of Use (vTEC Data)
GLONASS R&D	BRAJ	Brasília (DF)	15.772	47.866	NN training
RBMC	GOJA	Jataí (GO)	17.883	51.726	NN training
	GOUR	Uruaçu (GO)	14.509	49.144	NN training
	MGUB	Uberlândia (MG)	18.919	48.257	NN training
	MTNX	N. Xavantina (MT)	14.697	52.349	NN testing
	GOGY	Goiânia (GO)	16.664	49.255	NN testing

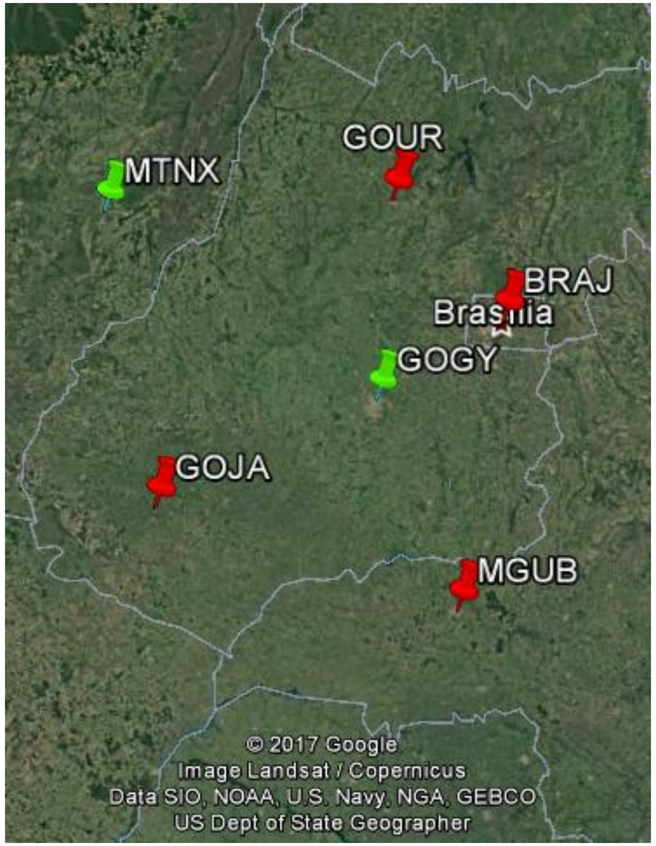

Fig. 9: Stations location – Center West region.

Results and Analysis – Case study 1

- Central-West Region

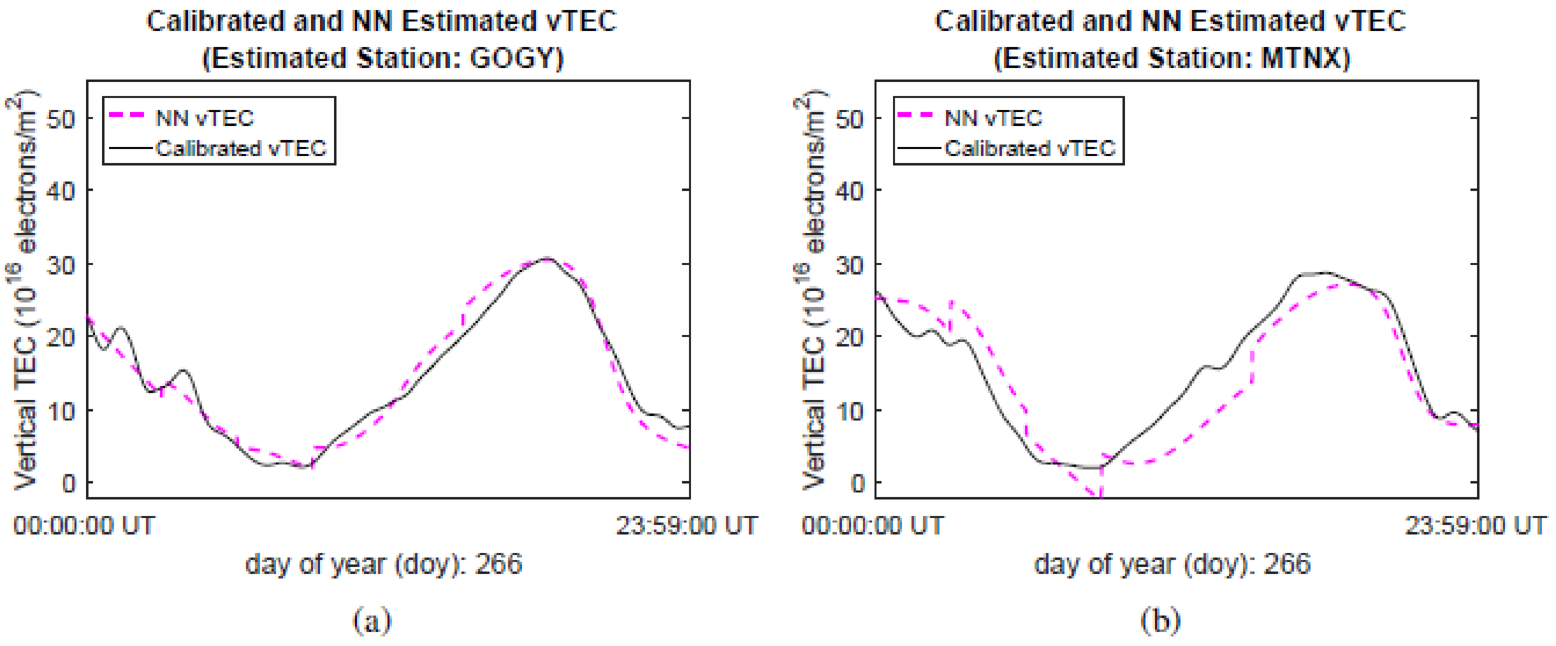

Fig. 10: Calibrated vTEC and ANN vTEC on the September equinox of 2016 for the Central-West region - Case study 1. (a) GOGY station. (b) MTNX station.

Results and Analysis – Case study 1

Table 4: Spatial performance of the ANN model - Case Study 1.

Station (region)	Analysis period (doy)	NRMSE	RMSE (TECU)	α (TECU)	Std. dev. of the error (TECU)
POAL (S)	266	0.2057	1.253	0.544	1.129
SMAR (S)	266	0.1769	1.187	-0.365	1.130
GOGY (CW)	266	0.2126	1.791	0.062	1.791
MTNX (CW)	266	0.4311	3.730	-1.049	3.580

Results and Analysis – Case study 2 (Spatial performance and forecasting)

- The ANN input parameters
  - Geographic location (latitude and longitude);
  - doy;
  - Time of the day;
  - Kp-index;
  - Solar radio-flux.

- vTEC calibration
  - ICTP TEC calibration.

- Period of Analysis
  - Period A: from doy 154 to 163 (Average $F_{10.7}$: 84.7 sfu);
  - Period B: from doy 282 to 291 (Average $F_{10.7}$: 94.33 sfu).

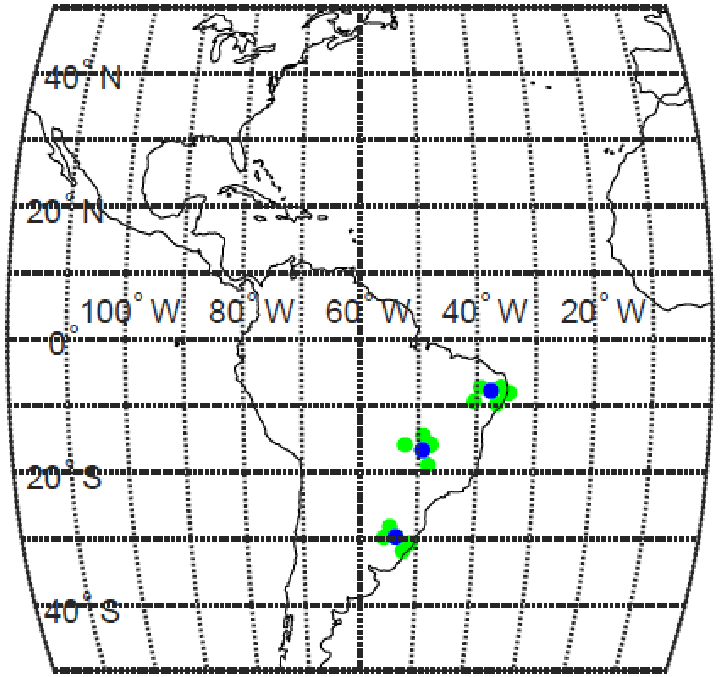

Fig 11: Positions in the world map of the stations under investigation - Case study 2. Green and blue dots represent training and testing stations, respectively.

Results and Analysis – Case study 2 (Forecasting performance)

- In this case, data from from doy 282 to 291 were used in the training procedure.
- The ANN was used to estimate the vTEC values on doy 292.

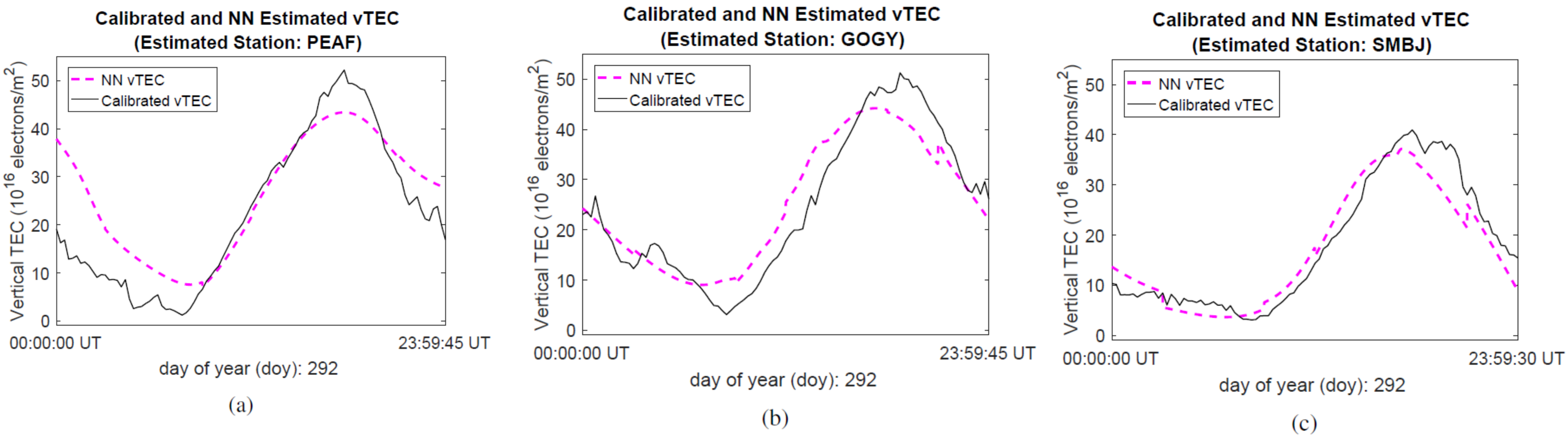

Fig. 12: Calibrated vTEC and NN vTEC for short-term forescasting of doy 292 – Case study 2. (a) PEAF station. (b) GOGY station. (c) SMBJ station.

Results and Analysis – Case study 2 (Forecasting performance)

Table 5: Short-term forecasting performance of the ANN model - Case study 2.

Station (region)	NRMSE	RMSE (TECU)	α (TECU)	Std. dev. of the error (TECU)
PEAF (NE)	0.502	7.84	3.544	6.999
GOGY (CW)	0.355	5.18	0.577	5.153
SMBJ (S)	0.320	4.05	-0.813	3.972

Conclusions and future works

- The proposed ANN model presented good estimates for the Brazilian region;
- A large number of neurons does not lead necessarily to a performance improvement for the investigated ANNs.
- Performance analysis of ANN model results is also under investigation when compared with CODE GIMs.
- The applicability in **short-term forecasting in a near real-time scenario** will also be investigated.
- The **performance analysis of low-cost single-frequency receivers** using the vTEC values from the proposed ANN to mitigate the ionospheric range error in positioning systems.
- Improvements in the SLR station are constantly in progress and **preventive maintenance** is on focus now.
- Future investigations also include combination of **GNSS and SLR observations using GNSS satellites co-location.**

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THANK YOU FOR YOUR ATTENTION

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