National Technical University of Athens

Spatio-temporal Graph Neural Networks for Ionospheric TEC Prediction Using Global Navigation Satellite System Observables

Maria Kaselimi, Vassilis Gikas, Nikolaos Doulamis, Anastasios Doulamis and Demitris Delikaraoglou

National Technical University of Athens, Department of Surveying Engineering, 9 Iroon Polytechniou Str., Zografou Campus, 15780 Athens, Greece

(mkaselimi@mail.ntua.gr, vgikas@central.ntua.gr, ndoulam@cs.ntua.gr, adoulam@cs.ntua.gr, ddeli@mail.ntua.gr)

27 May 2022

CC BY

1st Approach: Temporal Ionospheric TEC modelling

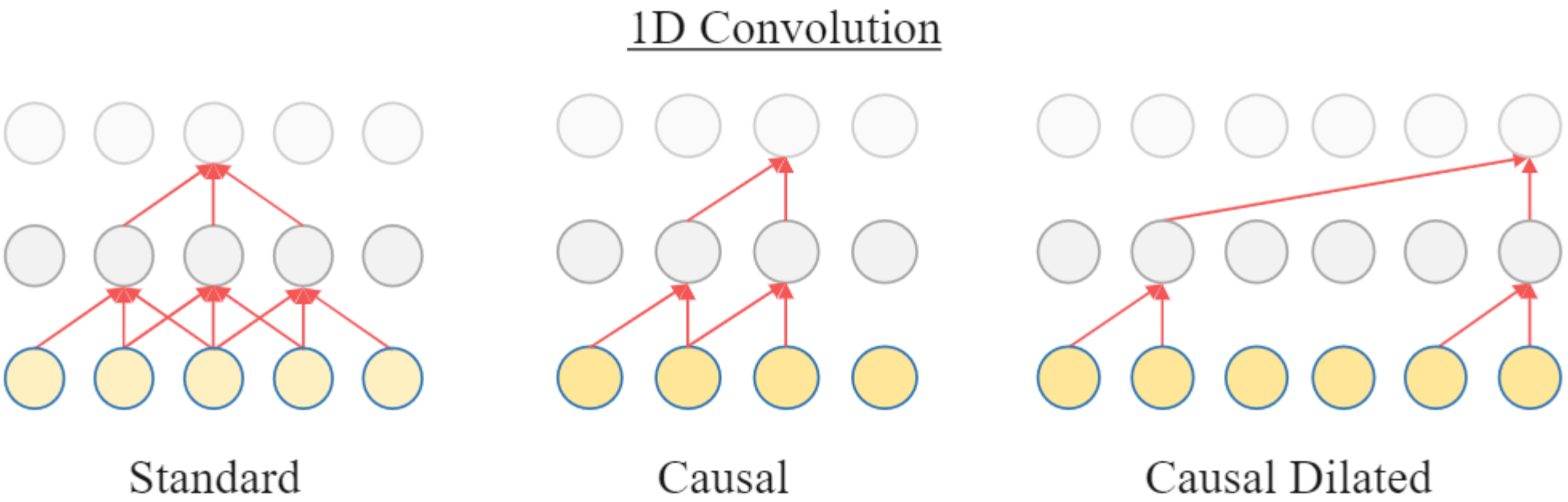
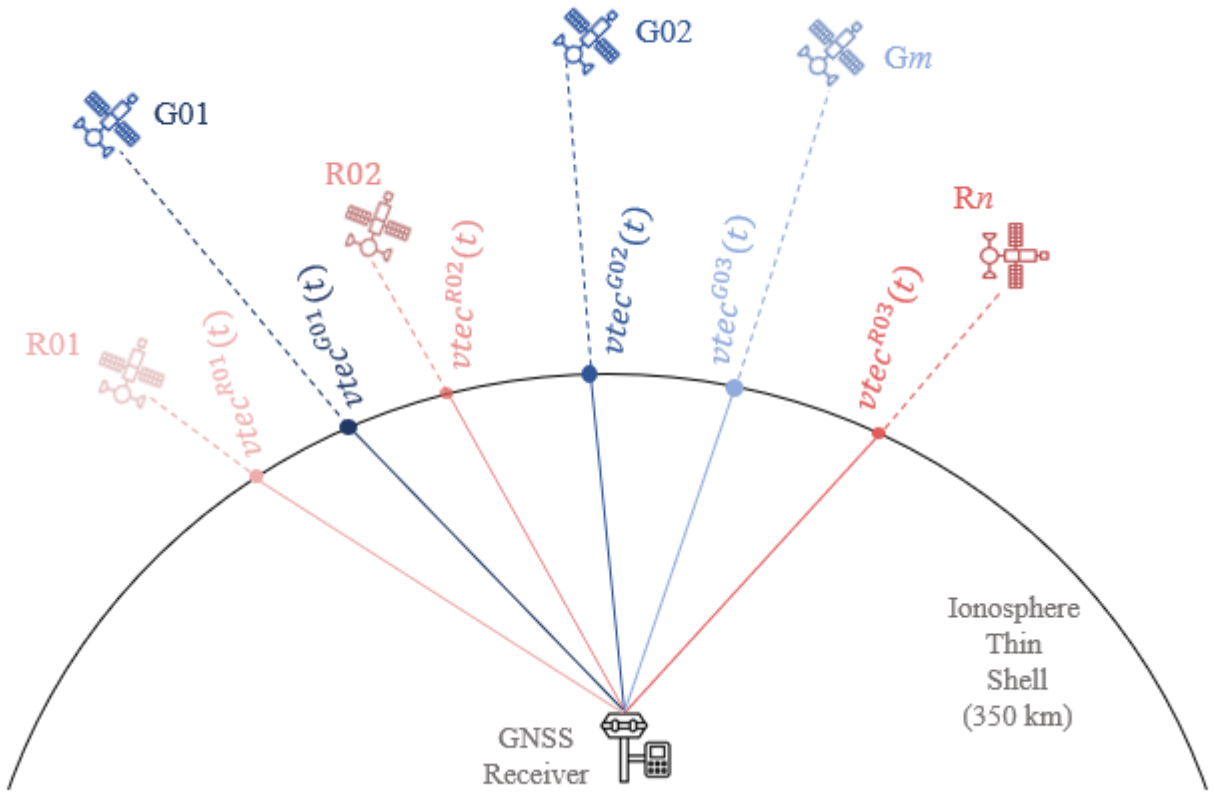


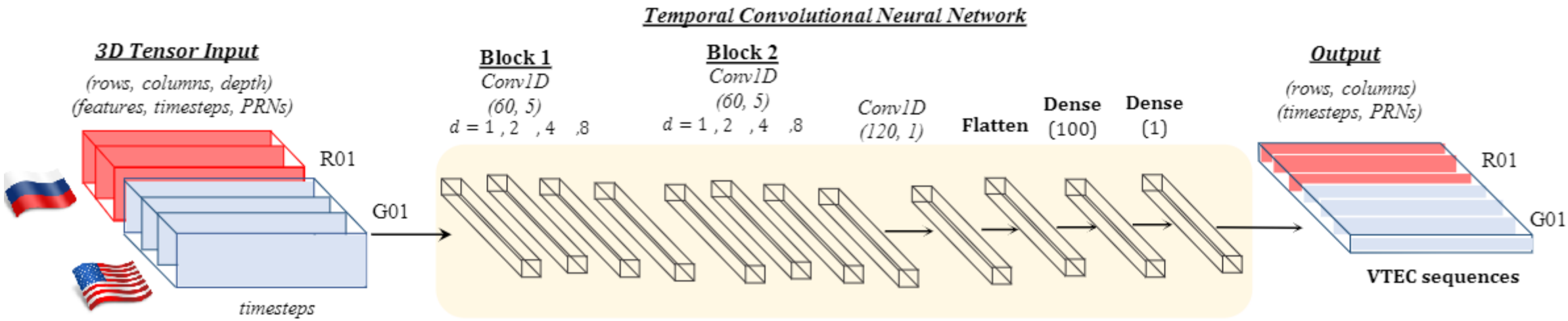
Fig. 1. Schematic representation of standard versus causal versus dilated convolutions.

EGU General Assembly
CC BY

IONOSPHERE PIERCE POINT (IPP)



Temporal Modelling: WAVETEC ARCHITECTURE



METRICS

$$bias_r^s(t) = vtec_{r,CNN}^s(t) - vtec_{r,GROUND\ TRUTH}^s(t)$$

- *s is the GPS satellite in view (G01, G02, …, G32),*
- *r is the receiver station (MGEX experiment STATIONS: bor1, ganp, graz, leij, pots, wtzz),*
- $vtec_{r,CNN}^s(t)$ the predicted TEC value from the CNN model
- $vtec_{r,GROUND\ TRUTH}^s(t)$ the ground truth value (GAMP software)

$$MAE_r^s = \sqrt{\frac{1}{T}\sum_{i=1}^{T}\left|vtec_{r,CNN}^s(t) - vtec_{r,GROUND\ TRUTH}^s(t)\right|}$$

EGU General Assembly
CC BY

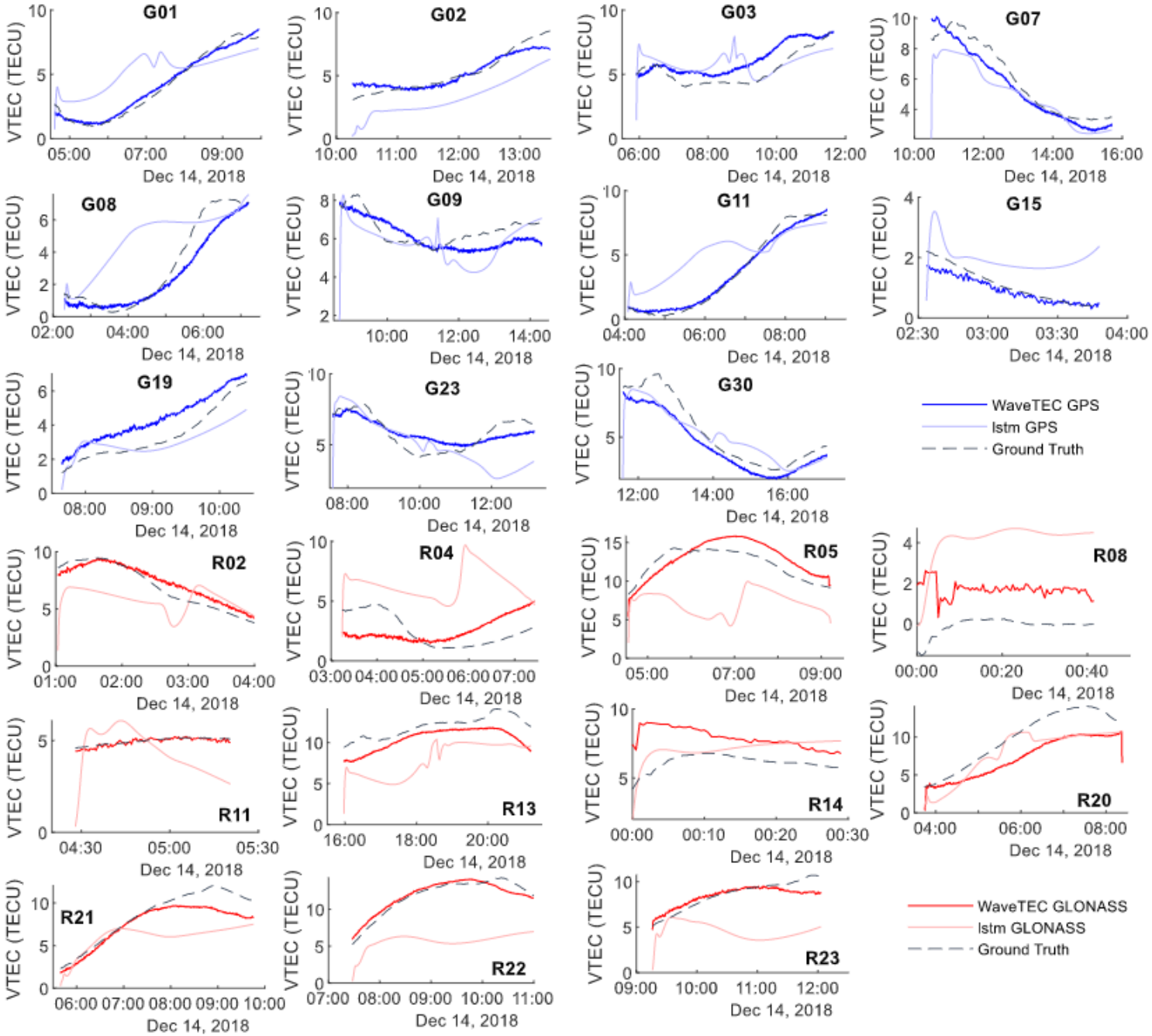
COMPARISONS

TABLE I
PERFORMANCE METRICS (AVERAGE MAE, MSE AND RMSE VALUES) FOR VTEC (TECU) PREDICTION FOR SIX SELECTED STATIONS (BOR1, GANP, GRAZ, LEIJ, POTS AND WTZZ) ON 14 DECEMBER 2018.

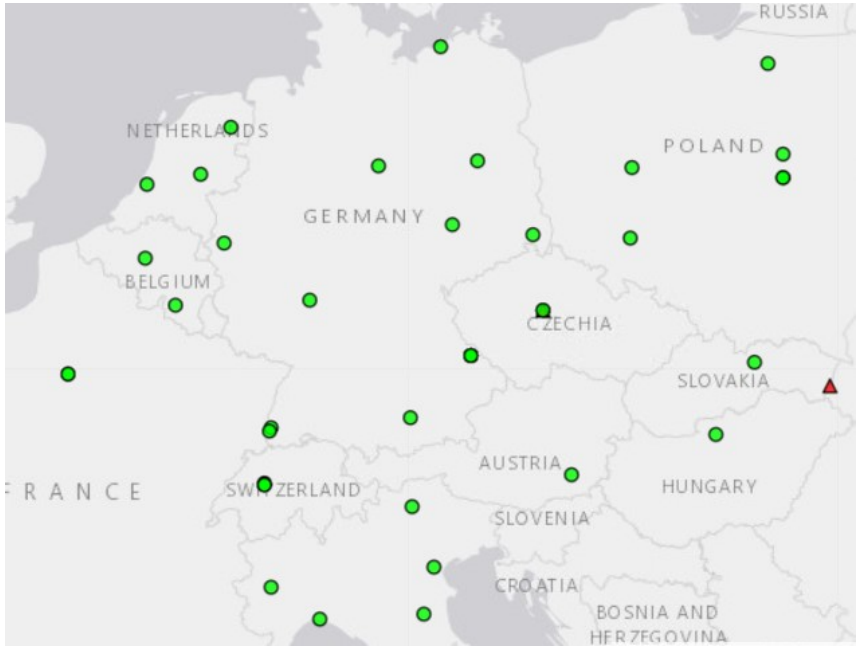
	bor1			**ganp**			**graz**		
	μ_{MAE}	μ_{MSE}	μ_{RMSE}	μ_{MAE}	μ_{MSE}	μ_{RMSE}	μ_{MAE}	μ_{MSE}	μ_{RMSE}
WAVETEC	0.858	1.280	1.072	0.984	1.552	1.198	1.044	1.627	1.228
LSTM	1.112	1.929	1.369	1.037	1.691	1.267	1.088	1.861	1.327
RNN	1.118	2.104	1.300	1.176	2.250	1.360	1.190	2.298	1.389
ARMA	1.302	2.535	1.510	1.217	2.301	1.412	1.204	2.300	1.389
AR	1.870	4.395	2.130	1.534	3.265	1.807	2.941	12.243	3.499
	leij			**pots**			**wtzz**		
	μ_{MAE}	μ_{MSE}	μ_{RMSE}	μ_{MAE}	μ_{MSE}	μ_{RMSE}	μ_{MAE}	μ_{MSE}	μ_{RMSE}
WAVETEC	0.884	1.411	1.128	0.766	1.073	0.977	0.955	1.393	1.141
LSTM	1.124	1.931	1.381	1.153	2.237	1.462	1.226	2.331	1.507
RNN	1.211	2.260	1.371	1.197	2.412	1.372	1.207	2.275	1.377
ARMA	1.402	5.037	1.672	1.323	2.597	1.517	1.201	2.262	1.396
AR	1.919	4.704	2.169	2.695	9.848	3.138	2.007	5.193	2.279

EGU General Assembly
CC BY

COMPARISONS



Future Steps: Spatial-Temporal Graphs for ionospheric TEC modelling



$$G^{(t)} = (V, E, X^{(t)})$$

V = IGS permanent stations network

E = elements of the adjacent matrix, Euclidean distances between the stations

X = solar and geo-magnetic indices that affect the ionosphere at time t

$$G^{(1)} \dots G^{(t)} \rightarrow G^{(t+1)}$$

Deep Learning Architecture

A graph convolutional layer is followed by a CNN-based structure. The graph convolutional layer operates on A and X(t) to capture the spatial dependence, while the temporal CNN layer slides over X along the time axis to capture the temporal dependence. The output layer generates a prediction for each node, such as its future value at the next time step.

EGU General Assembly
CC BY

Thank you !

EGU General Assembly
CC BY