IONOSPHERIC TOTAL FREE-ELECTRON CONTENT(TEC) ANOMALY

–EARTHQUAKE PRECURSOR

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TEC CHARACTERS

The amount of TEC varies with the amount of radiation received from the Sun.

Seasonal variations, less radiation received from the Sun in winter, more in summer.

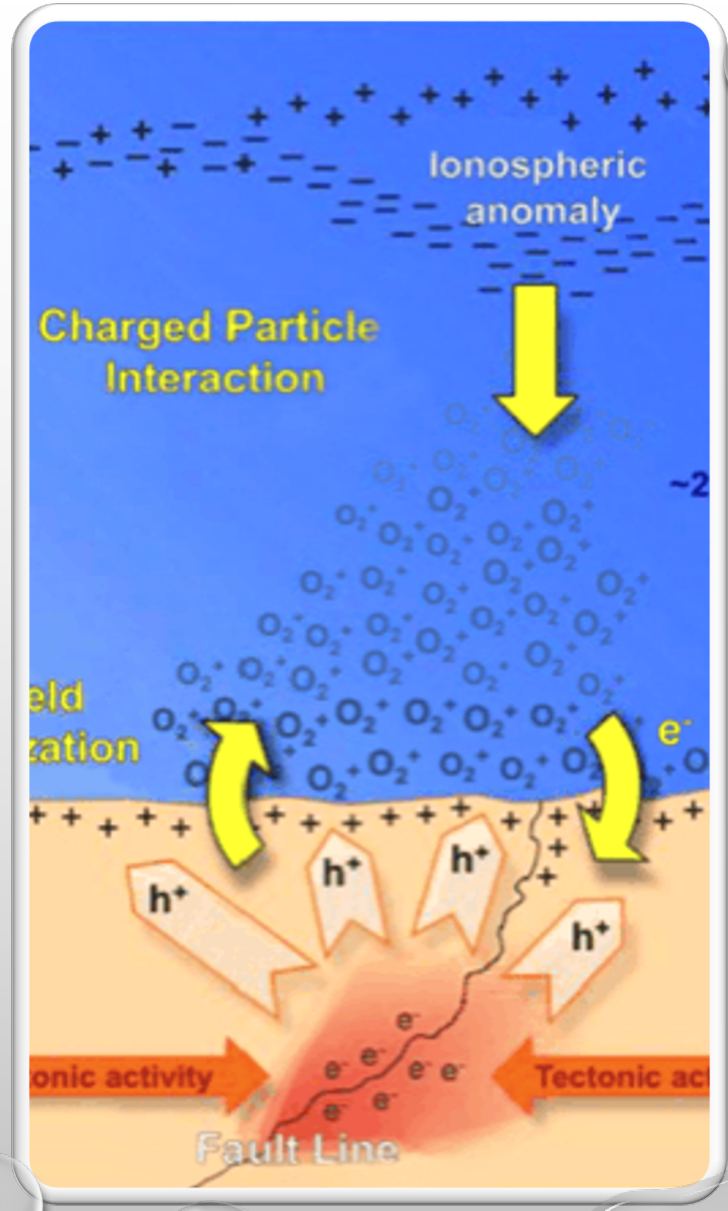
Strong Daily fluctuations, high tec value during daytime and near-zero tec at night-time

imposes a dispersive delay on the GPS satellite ranging signals broadcasting

Affection on signals varies with TEC values

RELATIONSHIP BETWEEN EARTHQUAKE AND TEC

- DURING EARTHQUAKE PREPARATION, FREE-ELECTRONS ARE RELEASED AND CHANGE THE LOCAL IONOSPHERIC TEC
- TEC ANOMALY TIME REMAIN CONTROVERSIAL, BETWEEN 3 DAYS AND 2 WEEKS BEFORE AND AFTER THE EARTHQUAKE ARE DISCUSSED IN DIFFERENT RESEARCHES



GOALS

- BUILD A PROGRAM FOR PRE-EARTHQUAKE TEC ANOMALY (PETA) VISUALIZATION ANALYSIS BY USING GPS TOOLKIT (GPSTK).
- EMPLOY DEEP LEARNING METHOD, TO RECOGNIZE THE UNDERLYING RELATIONSHIPS BETWEEN IONOSPHERIC TEC ANOMALY AND EARTHQUAKES.

RAW DATA

Receiver Independent Exchange Format (RINEX)

enable users to post-process the GPS stations received data and generating more accurate results.

Observation data from Geonet

e.g. yald2430.19o, contains all the related physical quantity observations in a 30 seconds intervals.

e.g. yald2430.19d, Hatanaka compressed file, 35% file size compression capability.

Navigation data from Scripps Orbit and Permanent Array Center(SOPAC)

Eeg. auto2430.19n, broadcast ephemeris data for the GPS constellation

DATA ETHICS

GEONET

- GEONET PROJECT SPONSORS REQUEST TO BE ACKNOWLEDGED FOR ALL USERS THAT ARE USING THE DATA.
- GEONET PROJECT SPONSORS ARE NOT LIABLE FOR ANY LOSS AND DAMAGE RESULTING FROM THE USE OF THE DATA DIRECTLY OR INDIRECTLY.
- GEONET PROJECT SPONSORS CAN'T GUARANTEE DATA ACCURACY, COMPLETENESS, AND FITNESS FOR ALL-PURPOSE USE ("GEONET").

SOPAC

"PLEASE ACKNOWLEDGE USAGE OF SOPAC DATA AND/OR DATA PRODUCTS IN YOUR PUBLICATIONS, APPLICATIONS AND PRODUCTS. ACCESS TO THE SOPAC ARCHIVE IS INTENDED FOR NON-COMMERCIAL USERS BUT THERE ARE NO USER FEES AND THERE IS SIGNIFICANT USAGE BY THE PRIVATE SECTOR ("SOPAC")."

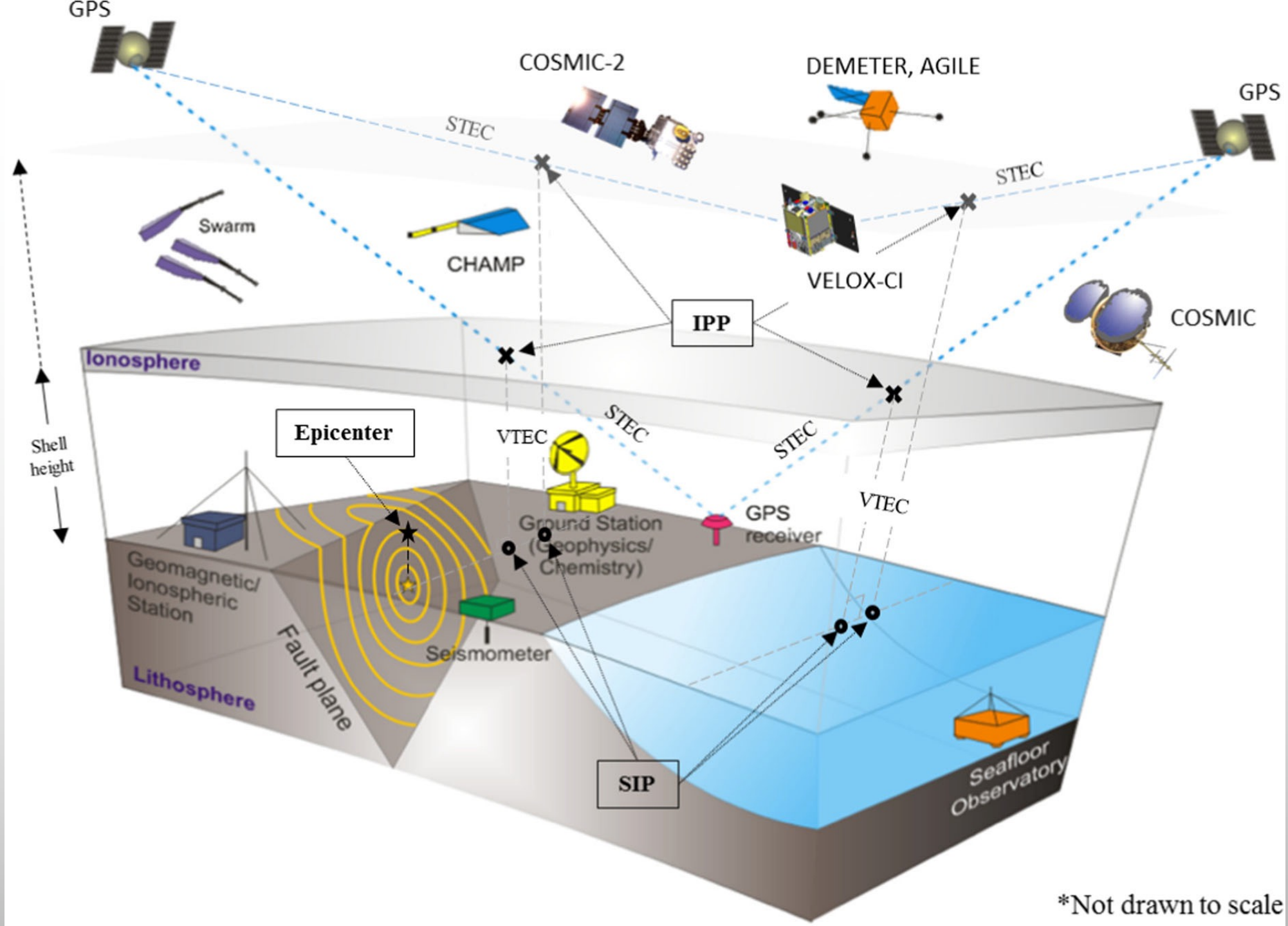
GPS TOOLKIT (GPSTK)

an open-source computing suite to the satellite navigation community produced by Space and Geophysics Laboratory within the Applied Research Laboratories of the University of Texas at Austin, to process GPS associated satellite navigation system data.

All applications are created by using ISO-standard C++ programming language, to ensure that the code is modular, extensible, and maintainable

enable us to compute TECU in the ionosphere by following programs.

“ResCor”	“IonoBias”	“TECMaps”


GPS
COSMIC-2
DEMETER, AGILE
GPS
STEC
STEC
Swarm
CHAMP
VELOX-CI
IPP
COSMIC
Ionosphere
Shell height
Epicenter
VTEC
STEC
STEC
VTEC
GPS receiver
Ground Station (Geophysics/ Chemistry)
Geomagnetic/ Ionospheric Station
Fault plane
Seismometer
Lithosphere
SIP
Seafloor Observatory
*Not drawn to scale

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-52.122 150.562 1.948
-50.361 151.292 2.176
-48.574 151.978 2.373
-46.764 152.624 2.528
-44.934 153.233 2.649
-43.089 153.808 2.746
-41.234 154.352 2.829
-39.372 154.866 2.903
-37.507 155.354 2.969
-35.645 155.817 3.029
-33.790 156.257 3.081
-31.945 156.676 3.125
-30.115 157.075 3.162
-28.303 157.455 3.190
-26.513 157.818 3.211

-52.385 151.923 1.863
-50.612 152.617 2.129
-48.812 153.268 2.350
-46.989 153.881 2.517
-45.147 154.458 2.644
-43.290 155.002 2.745
-41.422 155.517 2.832
-39.548 156.003 2.908
-37.672 156.464 2.978
-35.799 156.901 3.040
-33.932 157.317 3.095
-32.077 157.712 3.141
-30.236 158.088 3.179
-28.414 158.446 3.207
```

"TECMAPS"

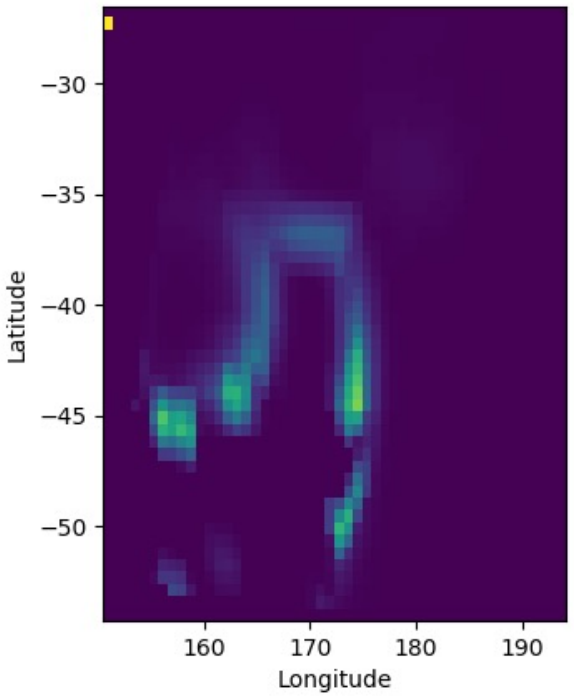
- ALL OUTPUTS FROM "RESCOR" AND 'IONOBIAS' ARE FED IN, TO ESTIMATE THE IONOSPHERIC TEC ON EACH POINT OF A HORIZON GRID AT A FIXED HEIGHT OF 350 KILOMETRES.
- IT COMPUTES THE AVERAGE VTEC VALUE AT EACH TIME POINT FIRST, THEN EXECUTES A DOUBLE LOOP, OVER ALL GRID POINTS AND ALL DATA VALUES, TO COMPUTE EACH GRID VALUE.
- THE OUTPUT FROM "TECMAPS" IS 2881 FILES, 2880 ARE THE ESTIMATED TEC VALUES OF EACH GRID WITH CORRESPONDING LATITUDES AND LONGITUDES. EACH OF THE 2880 FILES IS ONE OF THE 30 SECONDS TIME INTERVALS TEC VALUES THROUGHOUT THE 24 HOURS RANGE.

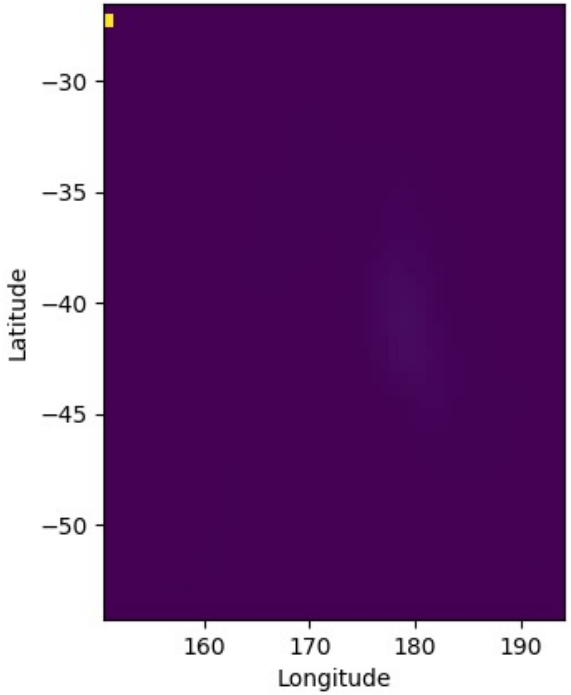
ıat	lon	corr_k	nd_k
-52.122002	150.561996	NaN	4
-50.361	151.292007	NaN	6
-48.574001	151.977997	NaN	6
-46.764	152.623993	NaN	6
-44.933998	153.233002	NaN	6
-43.089001	153.807999	0.91372406	6
-41.234001	154.352005	0.97785163	6
-39.372002	154.865997	0.98638111	6
-37.507	155.354004	0.98656416	6
-35.645	155.817001	0.97686702	6
-33.790001	156.257004	0.98372561	6
-31.945	156.675995	0.99544036	6
-30.115	157.074997	0.99810314	6
-28.302999	157.455002	0.99915373	6
-26.513	157.817993	0.99862462	4

ANOMALY CORRELATION

- THERE IS 1 CORRELATION FILE PER DAY.
- IT COMPARES EACH GRID'S TECU VALUES TO NEIGHBOUR GRIDS SPATIALLY AND TEMPORALLY.
- IF ONE OR FEWER GRIDS' TECU ARE DIFFERENT FROM NEIGHBOURS, THERE IS MORE LIKELY TO BE A PETA.
- IF TECU ARE STANDING OUT FROM THEIR NEIGHBOUR GRIDS IN A LARGE AREA, THIS IS MORE LIKELY CAUSED BY SOLAR ACTIVITIES OR OTHER GEOMAGNETIC EFFECTS.
- CLOSER TO 0 SHOWING A STRONG CORRELATION.

CORRELATION IMAGES





DEEP LEARNING

- LEARNING METHOD: CONVLSTM2D FROM ‘TENSORFLOW’.
- LEARNING DATA: NEW ZEALAND 29 MAJOR EARTHQUAKES FROM 2003 (EXCLUDE AFTERSHOCKS WITHIN 3 DAYS).
- OUTPUT DATA: PERCENTAGE TO BE AN EARTHQUAKE EVENT.

DATA

- DAILY CORRELATION IMAGES (50, 50, 1) SHAPED NUMPY ARRAY DATA.
- CENTRE AND SCALED SUNSPOT NUMBERS.
- CENTRE AND SCALED DAY OF THE YEAR.
- 24 IMAGES EACH EVENT. 21 DAYS BEFORE THE EVENT, 2 DAYS AFTER.

DATA PREPARATION

- 26 EVENTS AND 3 EVENTS DATA SPLITTING
- A TIME SEQUENCE LENGTH OF 10 DAYS IS APPLIED, 15 SEQUENCES EACH EVENT.
- DATA LABEL LIST FOR EACH EVENT IS [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0.05, 0.25, 0.4, 0.25, 0.05]
- TRAINING DATA RESAMPLING
- TRAINING DATA SHUFFLING

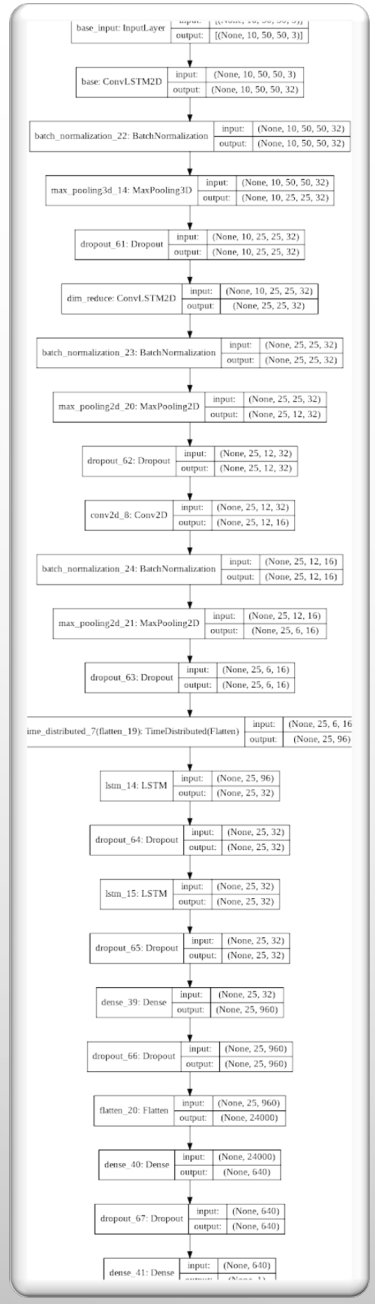
	kernels	layers	neurons	shrinkage	target
trial 1	2.498	3.803	36.87	0.197	0.054
trial 2	1.624	0.624	3.846	0.732	0.05415
trial 3	3.404	2.832	2.009	0.94	0.05431
trial 4	4.33	0.8494	9.909	0.367	0.5449
trial 5	2.217	2.099	22.17	0.582	0.05437
trial 6	3.447	0.558	15.32	0.733	0.05441
trial 7	2.824	3.141	10.78	0.028	0.05448
trial 8	3.37	0.1858	30.77	0.341	0.05481
trial 9	1.26	3.796	48.32	0.617	0.05492
trial 10	2.218	0.3907	34.53	0.88	0.05482
trial 11	1.488	1.981	2.685	0.819	0.05474
trial 12	2.035	2.65	16.27	0.04	0.05484
trial 13	2.453	0.2091	34.59	0.872	0.05498
trial 14	2.942	0	34.44	0.245	0.05506
trial 15	3.573	0.1856	35.23	0.639	0.05526
trial 16	3.672	0	34.32	1	0.05534
trial 17	4.987	0.0214	34.07	0.956	0.05536
trial 18	4.646	1.431	34.25	0.038	0.05537
trial 19	5	0.9348	32.69	1	0.05561
trial 20	4.943	2.558	32.3	0.955	0.05565

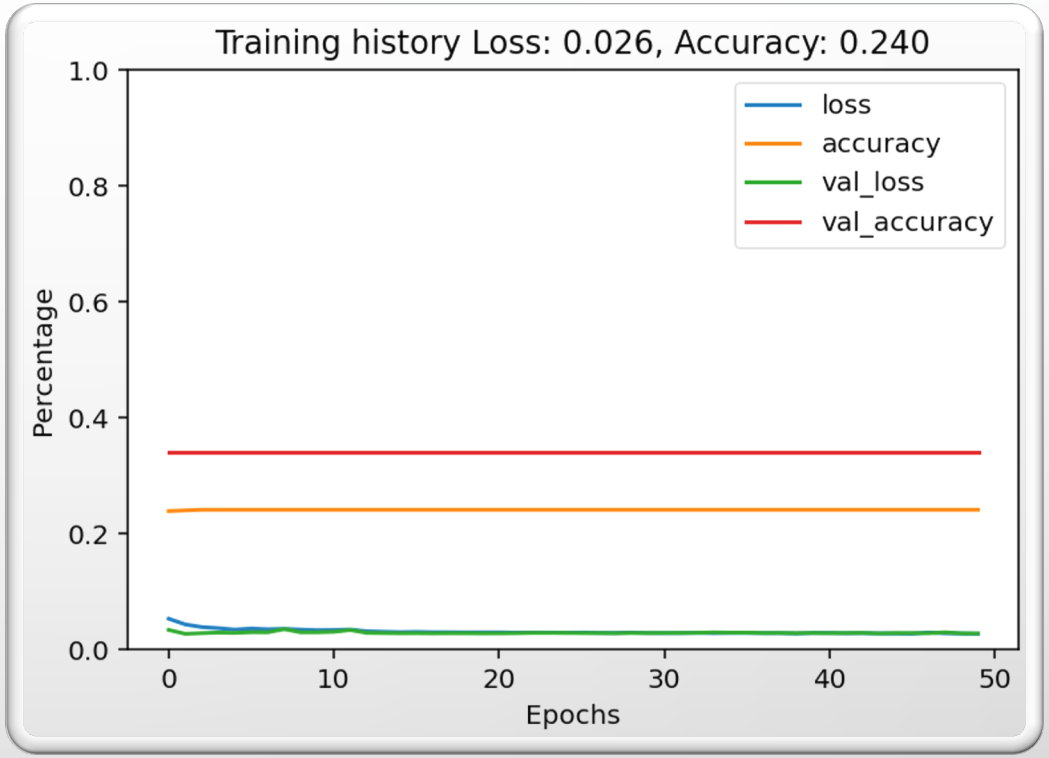
TRAINING

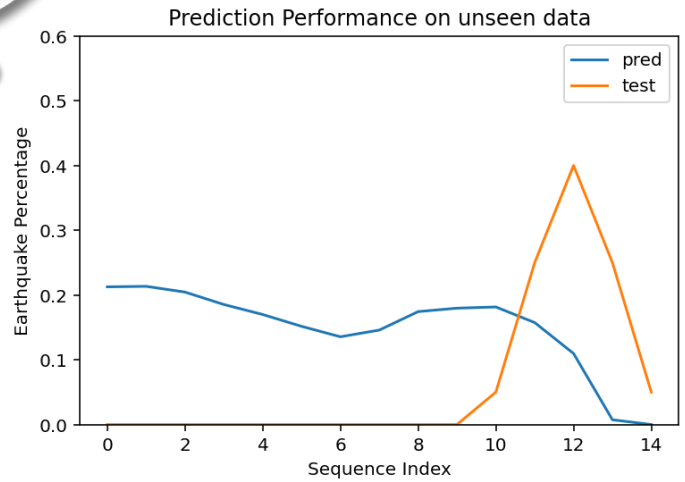
BAYESIAN OPTIMIZER

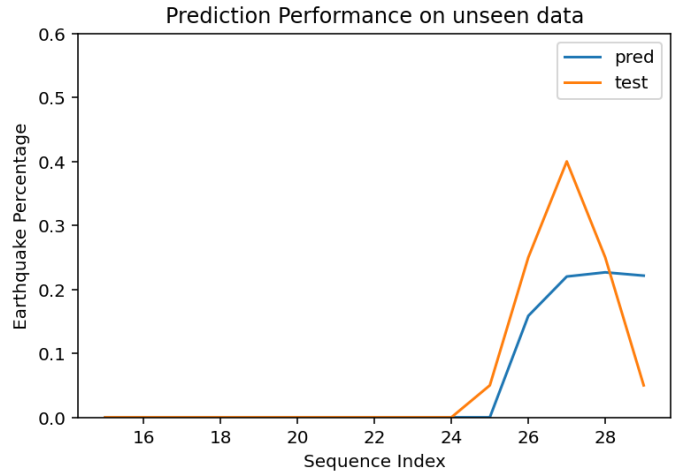
12 POINTS GRID SEARCH

8 ITERATIONS


base_input: InputLayer
input:
output: [(None, 10, 50, 50, 3)]
base: ConvLSTM2D
input: (None, 10, 50, 50, 3)
output: (None, 10, 50, 50, 32)
batch_normalization_22: BatchNormalization
input: (None, 10, 50, 50, 32)
output: (None, 10, 50, 50, 32)
max_pooling3d_14: MaxPooling3D
input: (None, 10, 50, 50, 32)
output: (None, 10, 25, 25, 32)
dropout_61: Dropout
input: (None, 10, 25, 25, 32)
output: (None, 10, 25, 25, 32)
dim_reduce: ConvLSTM2D
input: (None, 10, 25, 25, 32)
output: (None, 25, 25, 32)
batch_normalization_23: BatchNormalization
input: (None, 25, 25, 32)
output: (None, 25, 25, 32)
max_pooling2d_20: MaxPooling2D
input: (None, 25, 25, 32)
output: (None, 25, 12, 32)
dropout_62: Dropout
input: (None, 25, 12, 32)
output: (None, 25, 12, 32)
conv2d_8: Conv2D
input: (None, 25, 12, 32)
output: (None, 25, 12, 16)
batch_normalization_24: BatchNormalization
input: (None, 25, 12, 16)
output: (None, 25, 12, 16)
max_pooling2d_21: MaxPooling2D
input: (None, 25, 12, 16)
output: (None, 25, 6, 16)
dropout_63: Dropout
input: (None, 25, 6, 16)
output: (None, 25, 6, 16)
ime_distributed_7(flatten_19): TimeDistributed(Flatten)
input: (None, 25, 6, 16
output: (None, 25, 96)
lstm_14: LSTM
input: (None, 25, 96)
output: (None, 25, 32)
dropout_64: Dropout
input: (None, 25, 32)
output: (None, 25, 32)
lstm_15: LSTM
input: (None, 25, 32)
output: (None, 25, 32)
dropout_65: Dropout
input: (None, 25, 32)
output: (None, 25, 32)
dense_39: Dense
input: (None, 25, 32)
output: (None, 25, 960)
dropout_66: Dropout
input: (None, 25, 960)
output: (None, 25, 960)
flatten_20: Flatten
input: (None, 25, 960)
output: (None, 24000)
dense_40: Dense
input: (None, 24000)
output: (None, 640)
dropout_67: Dropout
input: (None, 640)
output: (None, 640)
dense_41: Dense
input: (None, 640)


Training history Loss: 0.026, Accuracy: 0.240
loss
accuracy
val_loss
val_accuracy
Percentage
Epochs
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50


Prediction Performance on unseen data
pred
test
Earthquake Percentage
Sequence Index


Prediction Performance on unseen data
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Earthquake Percentage
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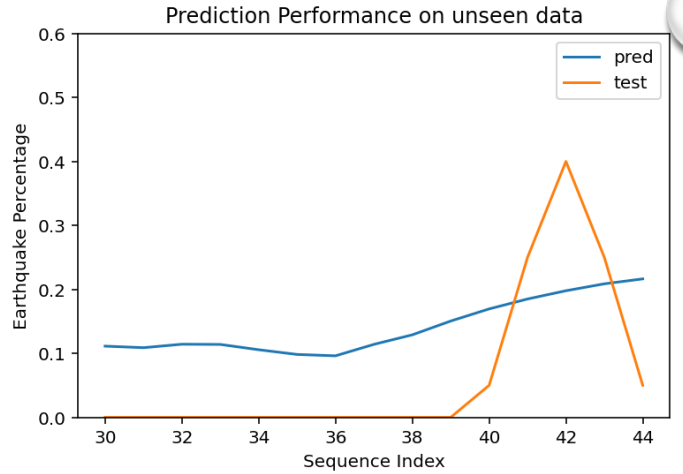
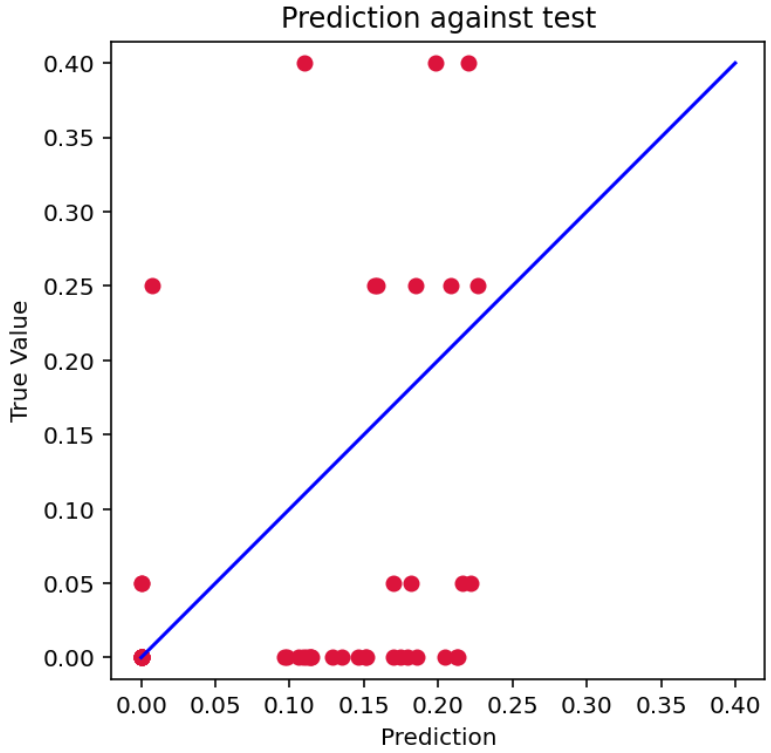
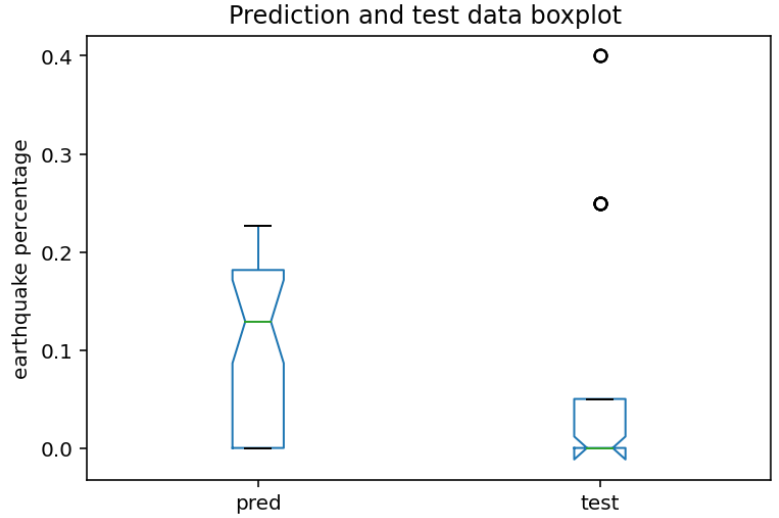
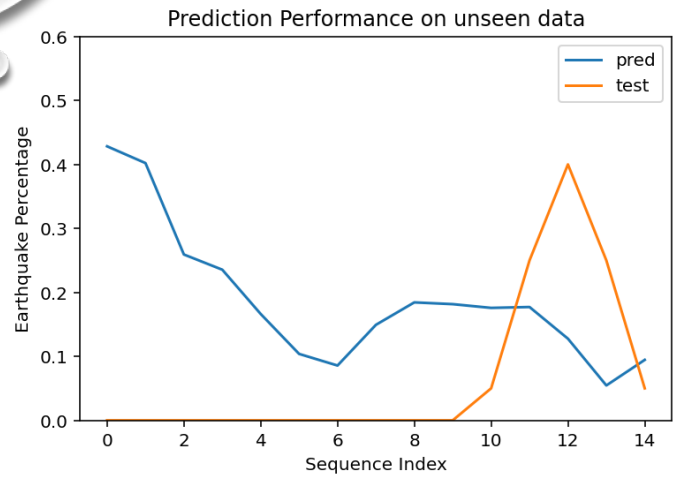
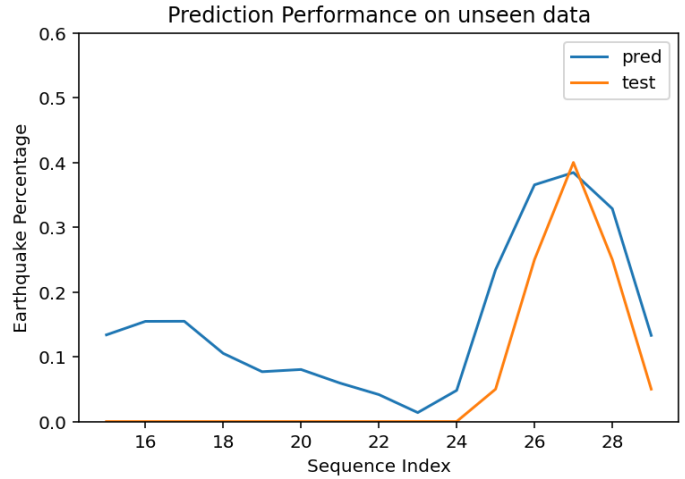

Prediction Performance on unseen data
pred
test
Earthquake Percentage
Sequence Index


Prediction against test
True Value
Prediction


Prediction and test data boxplot
earthquake percentage
pred
test


Prediction Performance on unseen data
pred
test
Earthquake Percentage
Sequence Index


Prediction Performance on unseen data
pred
test
Earthquake Percentage
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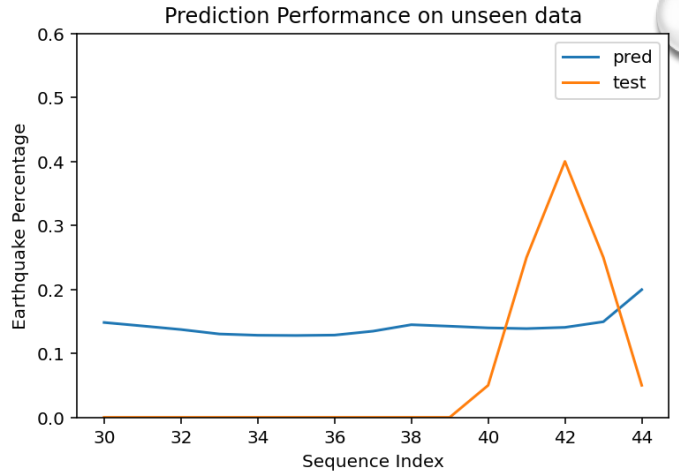
Prediction Performance on unseen data
pred
test
Earthquake Percentage
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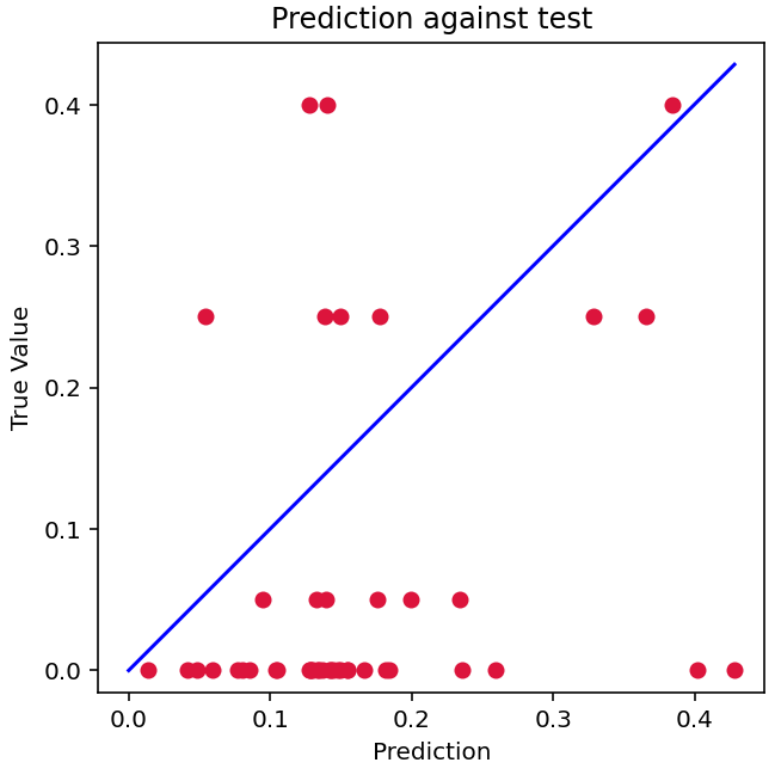
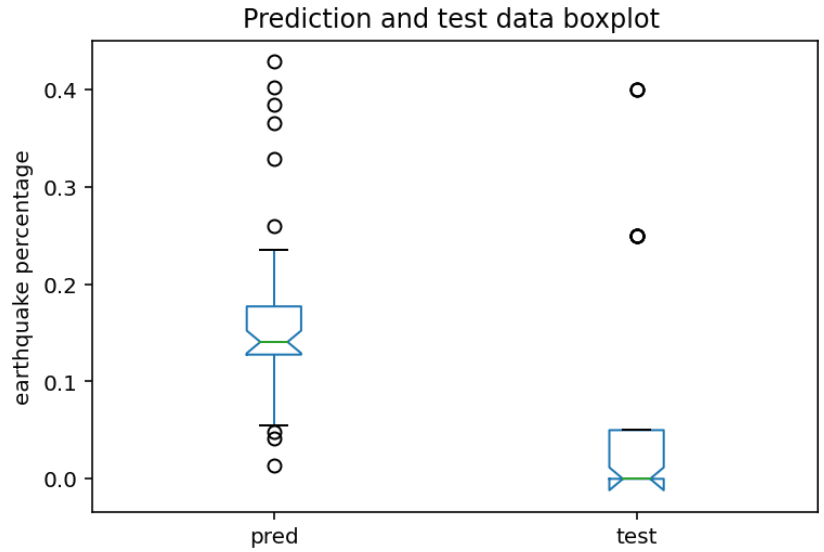

Prediction against test
True Value
Prediction


Prediction and test data boxplot
earthquake percentage
pred
test

“NO ONE DOES WHEN THEY BEGIN. IDEAS DON’T COME OUT FULLY FORMED. THEY ONLY BECOME CLEAR AS YOU WORK ON THEM. YOU JUST HAVE TO GET STARTED (MARK ZUCKERBERG).”