XVIII World Water Congress
International Water Resources Association (IWRA)

A geoelectrical recognition model of seawater/freshwater interface types based on convolutional neural network

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XVIII WORLD WATER CONGRESS Water for All Harmony between Humans and Nature
第18届 世界水资源大会 水与万物：人与自然和谐共生

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Background

Groundwater :

Largest distributed store of freshwater

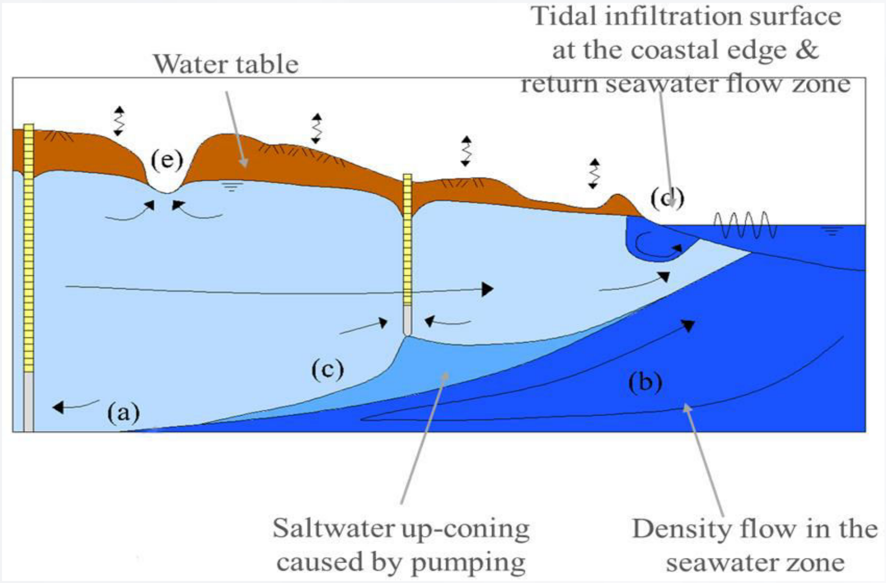
Coastal aquifers

Primary source of drinking water for up to one billion people worldwide

Seawater intrusion: a global issue

e.g., USA, UK, Italy, Greece, Australia, China and Japan.

- Exacerbated by excessive extraction of groundwater within coastal aquifers.
- Predisposed to the influences of rising sea levels and changing climates.



Methodology

Electrical Resistivity Tomography (ERT)

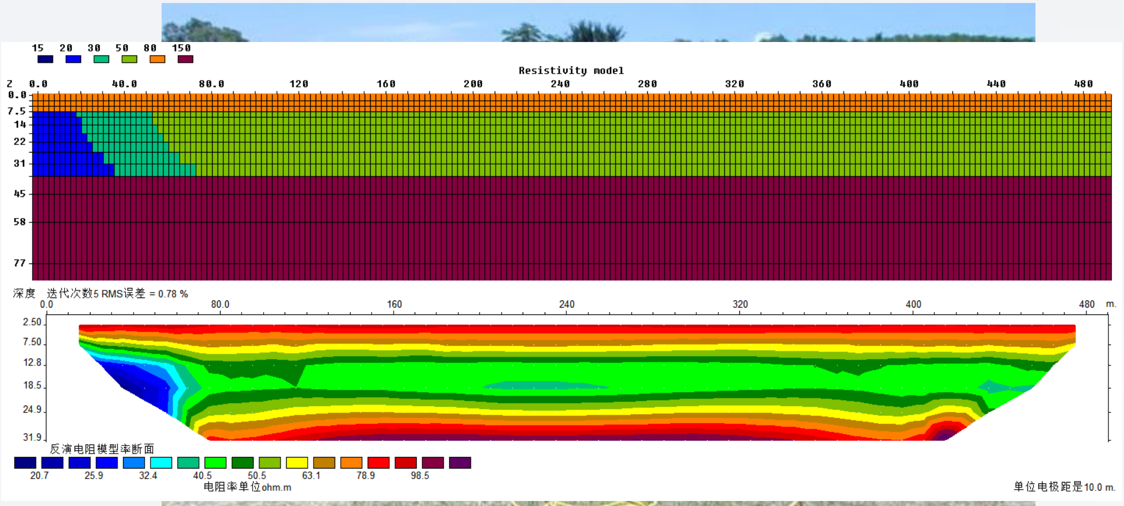
or High-density electrical resistivity method:

- Visualization of the subsurface resistivity distribution in 2D or 3D
- Non-destructive testing equipment
- Highly efficient

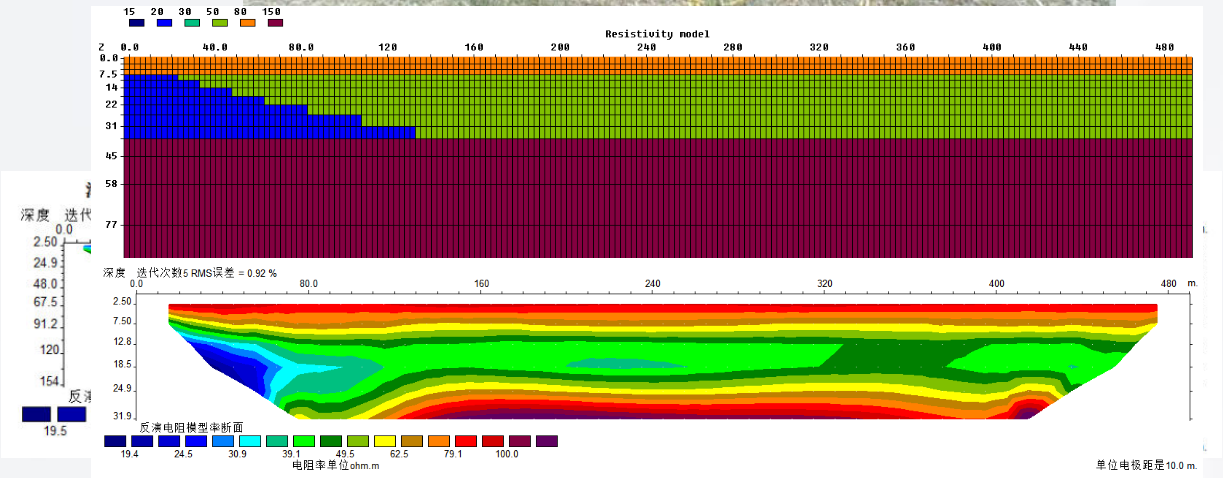
Application:

- Mineral, oil and gas exploration,
- Groundwater detection,
- Soil pollution investigation,
- Archaeology,
- Seawater intrusion mapping, etc.

Seawater intrusion process and ERT inversion results

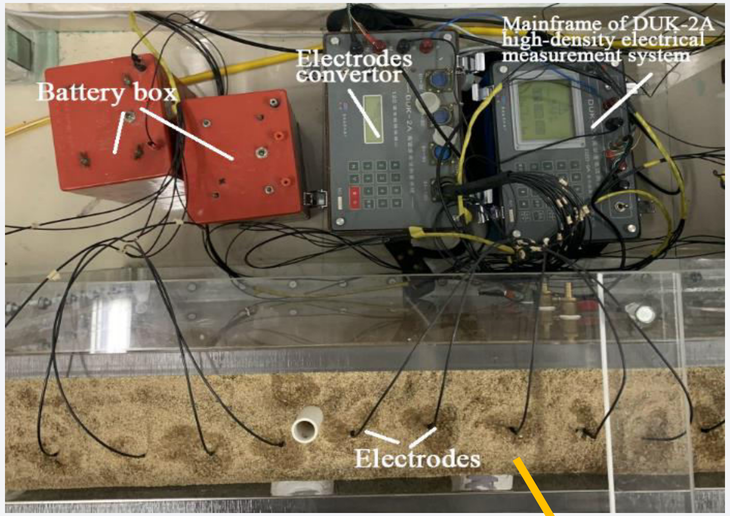


(a) Wedge-shaped interface model



(b) Abrupt interface model

Application

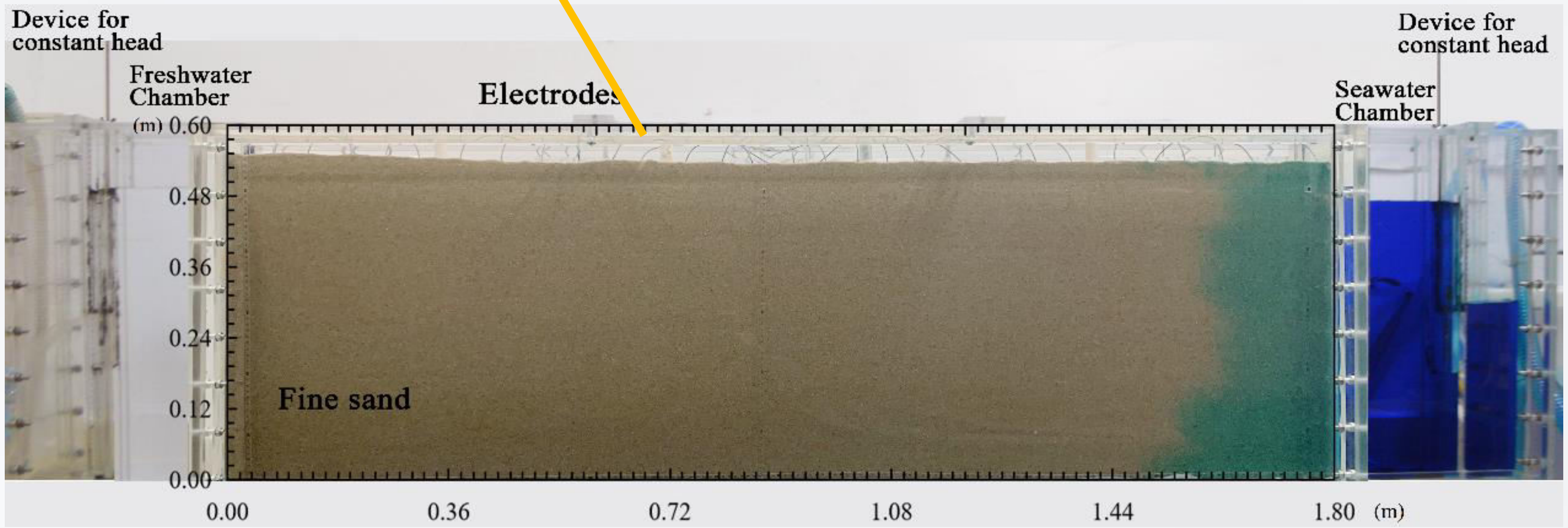


Laboratory tests

- Main body of the sand tank: fine sand (1.80m×0.55m).
- The seawater is configured by deionized water, sodium chloride (NaCl).
- Bright Blue ($C_{37}H_{34}N_2Na_2O_9S_3$): trace the saltwater transport.

ERT measurement

DUK-2A high-density electrical method measurement system

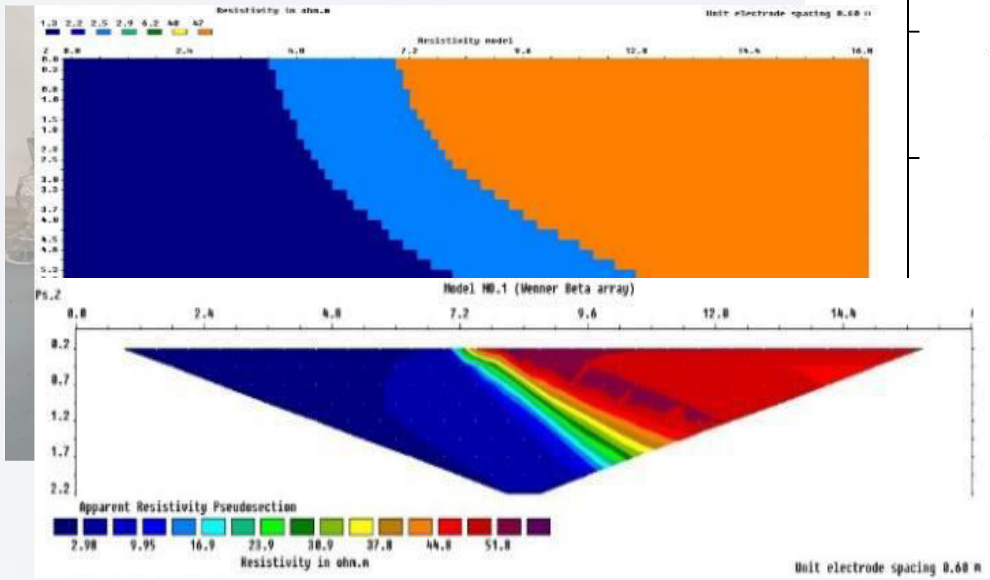


Layout of high density electrical measurement system on the sand tank

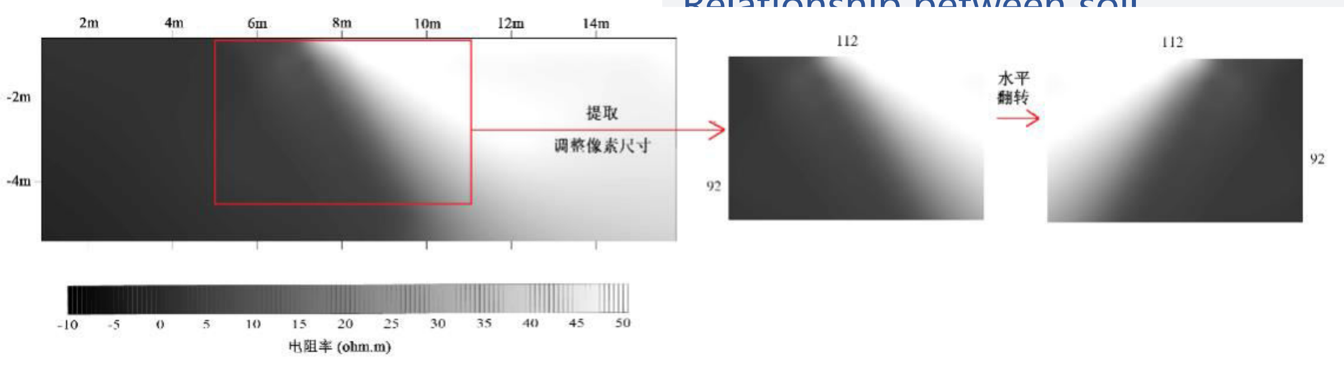
- Wenner-α configuration
- 30 electrodes
- Spacing factor: n=9
- Electrode spacing: 0.06m

Application

Training set:



Relationship between soil



686 samples

4 6 8 10 12 14 16 18 20

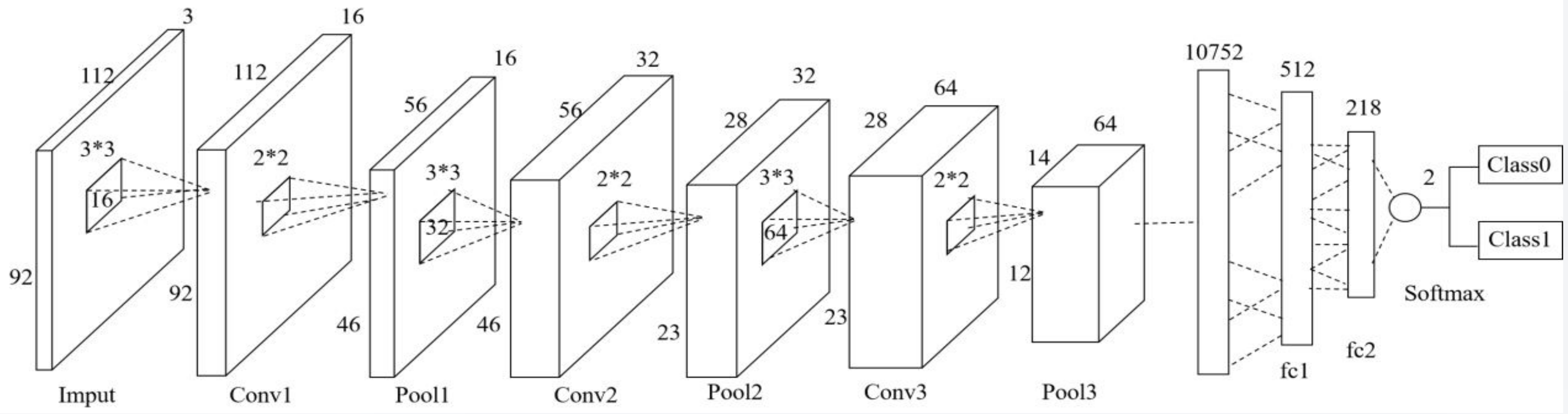
Cl- concentration (g/L)

Training set: 80% Test set: 20%

Layer	Size	Number	Weights exponent
Input	92×112	3	0
Conv1	92×112	16	1483792
Pool1	46×56	16	41216
Conv2	46×56	32	741920
Pool2	23×28	32	21504
Conv3	23×28	64	371008
Pool3	12×14	64	10752
fc1	1×512	1	5505536
fc2	1×128	1	65664
Softmax	1×2	1	0

Model set:

Convolutional Neural Network (**CNN**) Model: **TensorFlow**



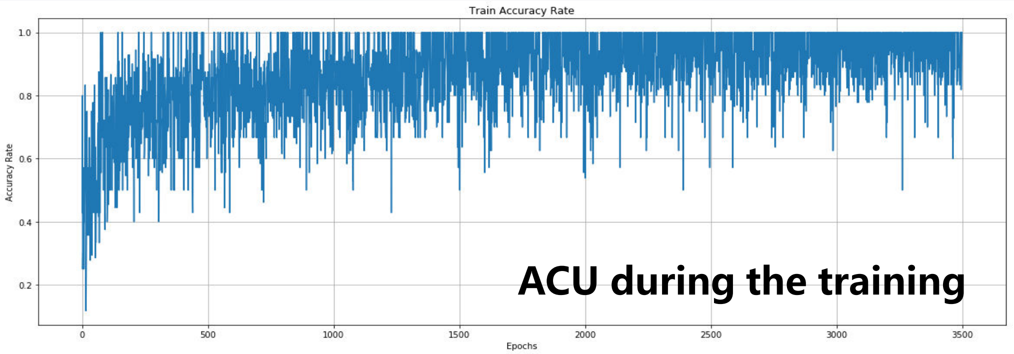
Application

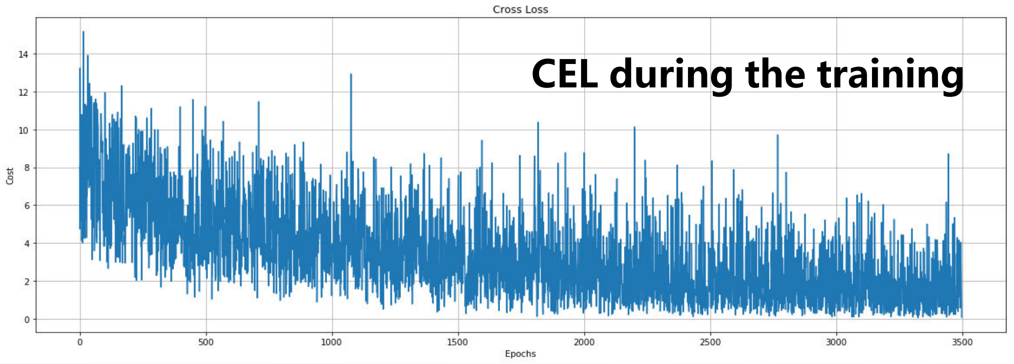
Model Training:

- Number of training steps (Epochs) : 3500
- Dropout rate: 0.2
- Learning rate: 0.00001
- Batch size: 50

Recognition Network Training Results for Seawater Intrusion Interface Resistivity Models (5 Trials)

Training times	1	2	3	4	5	Average
ACU	1.0000	0.9444	0.9231	1.0000	0.9231	0.9581
CEL	0.5283	2.3847	1.5001	0.0923	2.2435	1.3500





Training parameters:

Training efficiency under different batch sizes

Batch size	10	20	30	40	50	60	80	100
ACU	0.9071	0.9427	0.9345	0.9032	0.9581	0.9586	0.9167	0.9445
CEL	1.8261	1.7659	1.5377	1.4502	1.35	1.9181	2.8208	1.0693
Time(s)	873.74	869.38	871.06	868.39	866.67	883.05	883.46	885.04

Analysis of Results with different dropout rates

Dropout	0.1	0.2	0.3	0.4	0.5	0.6	0.7
ACU	0.9309	0.9581	0.934	0.9446	0.9511	0.8632	0.8051
CEL	1.1312	1.35	2.2556	1.4502	1.9108	2.6754	5.265
Time(s)	867.57	866.67	878.06	872.01	873.83	879.09	877.73

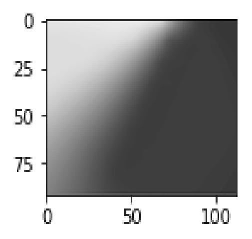
Application

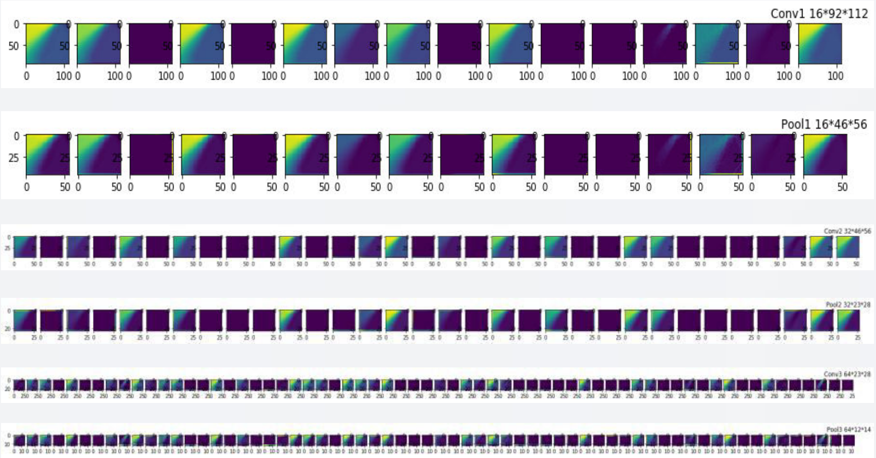
Model Testing:

Test number	Test 1	Test 2
Wedge-shaped interface probability	1.21%	84.73%
Abrupt interface probability	98.79%	15.27%
Result	Abrupt interface	Wedge-shaped interface

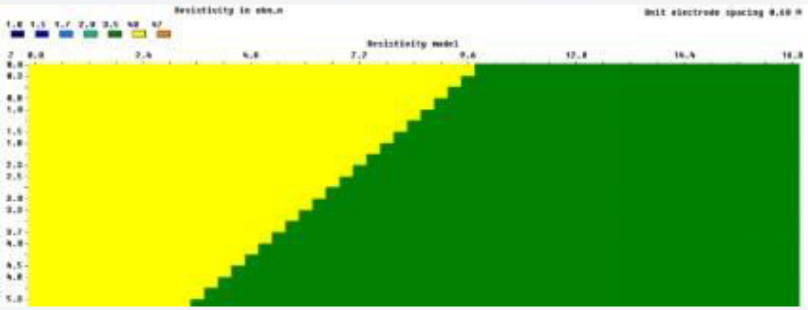
Test 1

读取图像 C118(2)



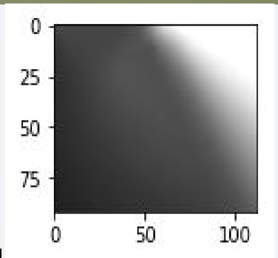


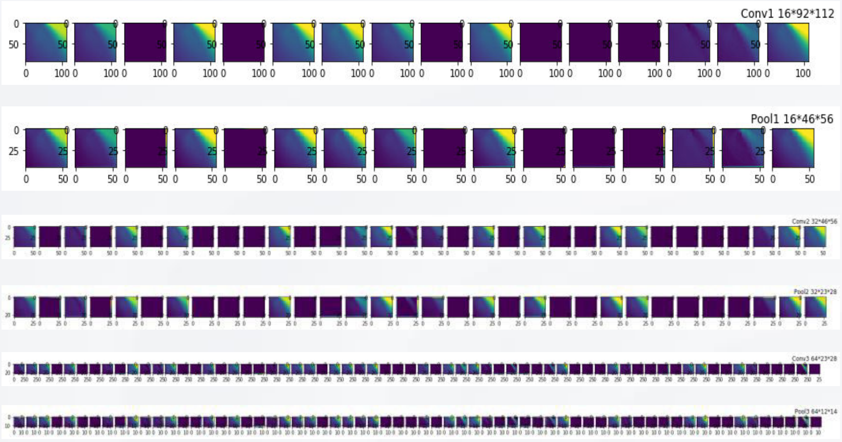
[[0.0121261 0.98787385]]



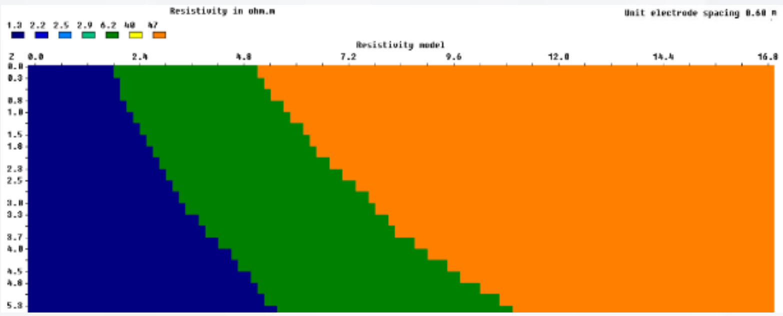
Test 2

读取图像 X93-1





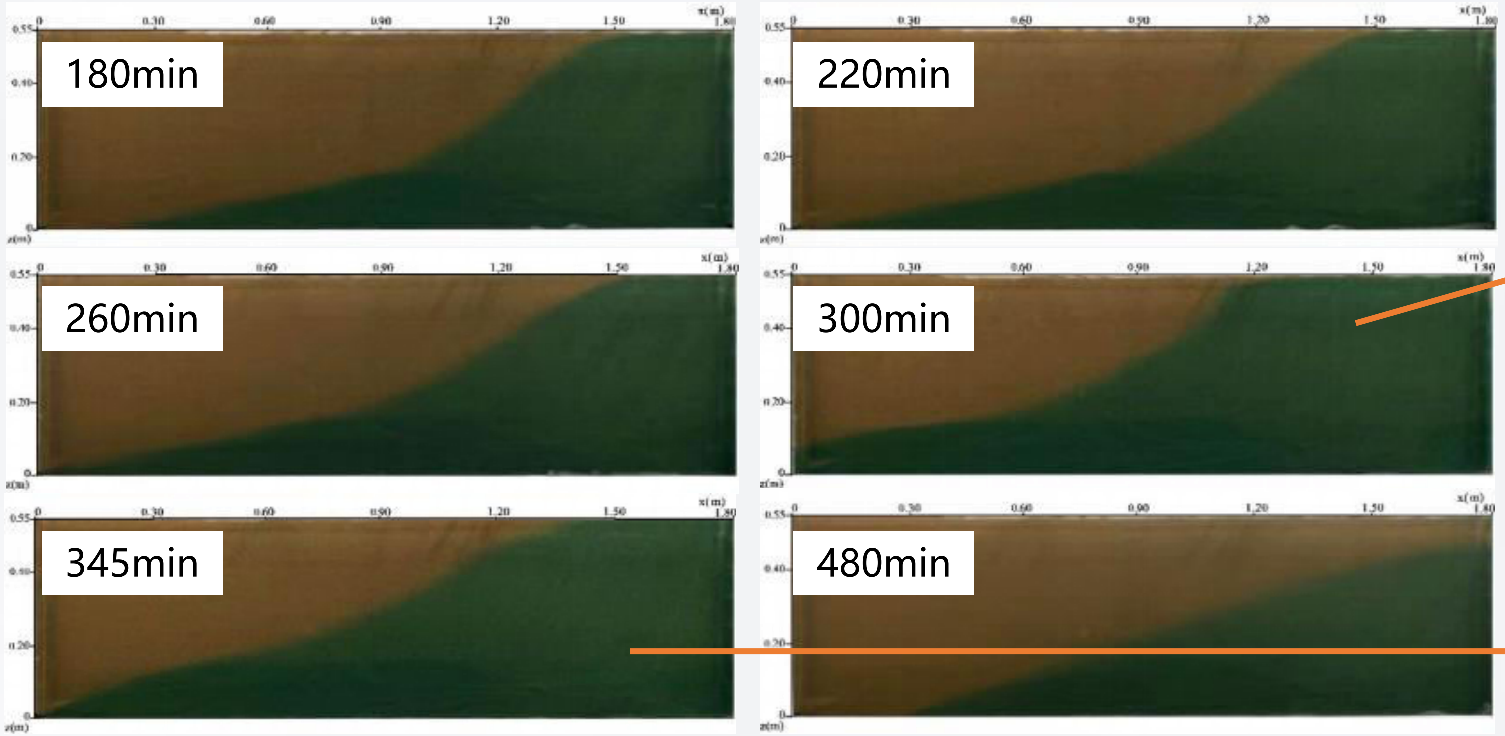
[[0.8473316 0.15266845]]



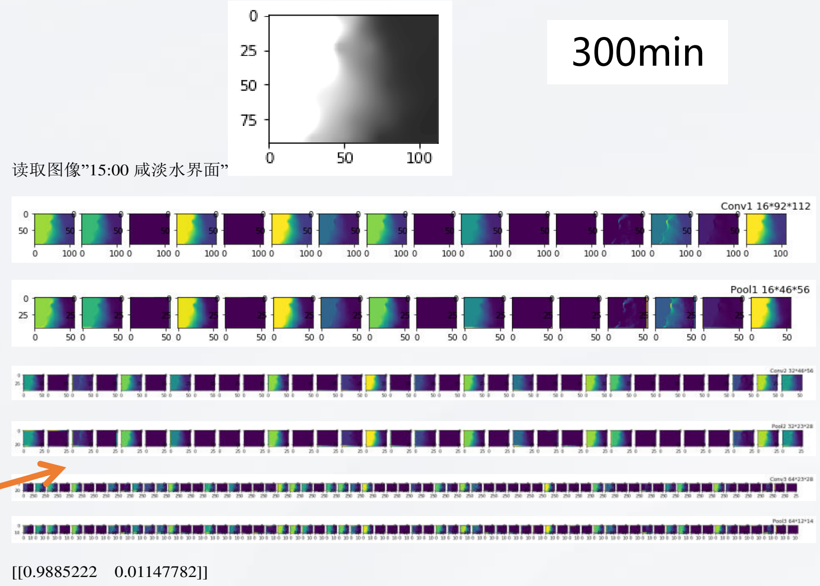
Application

Experimental Data of Homogeneous Seawater Intrusion:

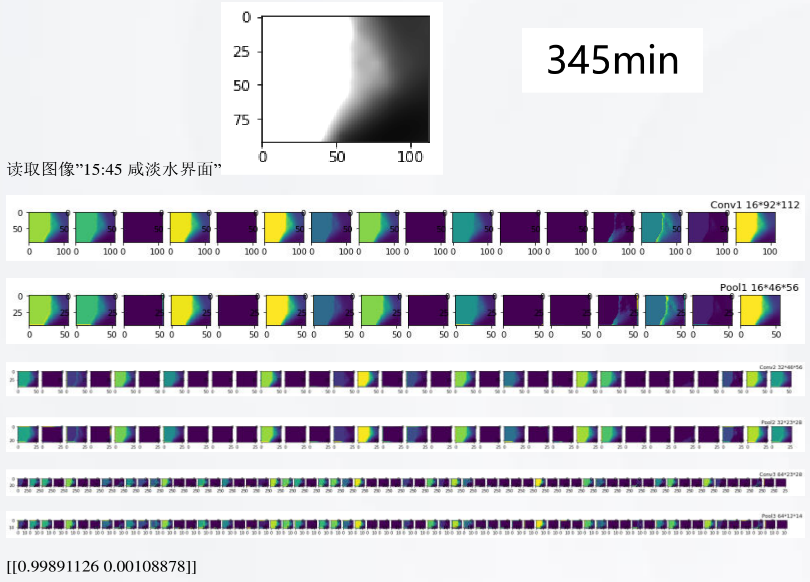
Seawater intrusion simulation:
High tide, rising sea levels and groundwater level decreases.



300min



345min



	Wedge-shaped interface probability	Abrupt interface probability	Result
300 min	98.85%	1.15%	Wedge-shaped interface
345 min	99.89%	0.11%	Wedge-shaped interface

Further research

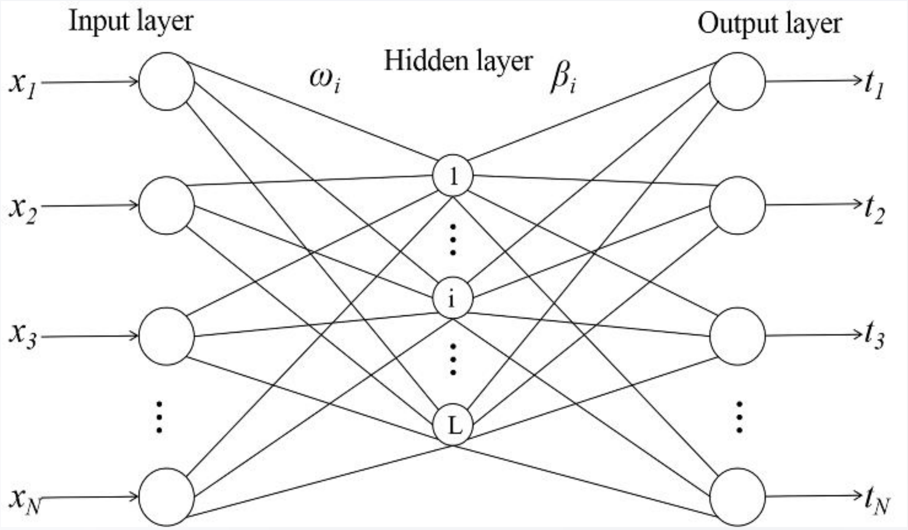
The inversion method:

Extreme Learning Machine, ELM
(Huang et al., 2006)

Regularized Extreme Learning Machine (RELM)
(Huang et al., 2011):

$$\min E = \min_{\beta} \left\| H\beta - T \right\| + C \left\| \beta \right\|$$

Where, *C* is the regularization parameter.

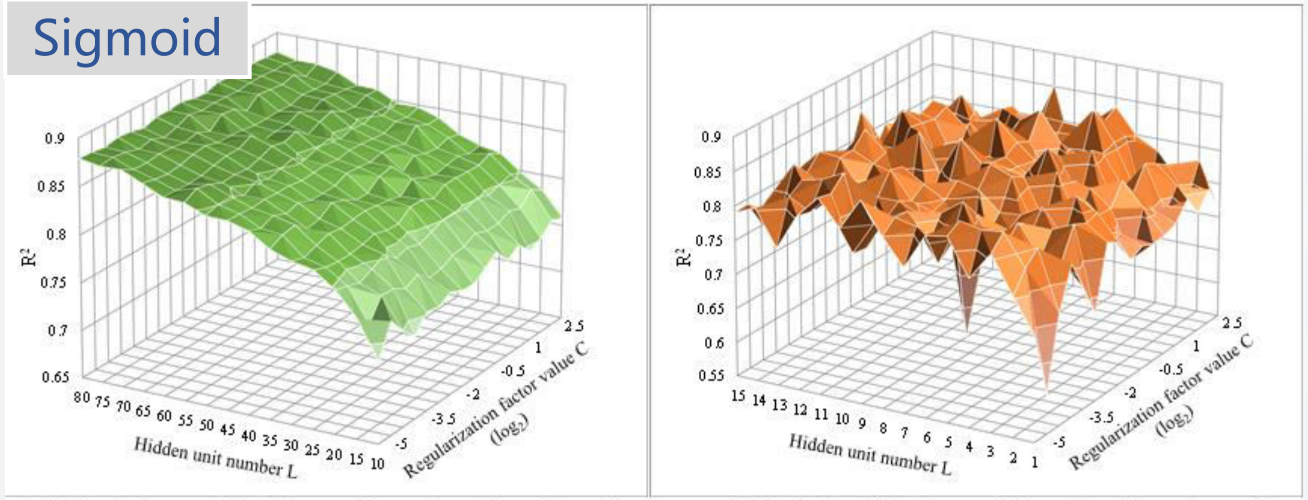


Extreme Learning Machine Structure Diagram

Training samples:

- Forward geoelectrical models: Wenner-α
- Res2mod software
- 402 samples with the noise of 0.2

Parameters selecting: Cross Validation (CV):



(a) Training with Sigmoid activation function (b) Test with Sigmoid activation function

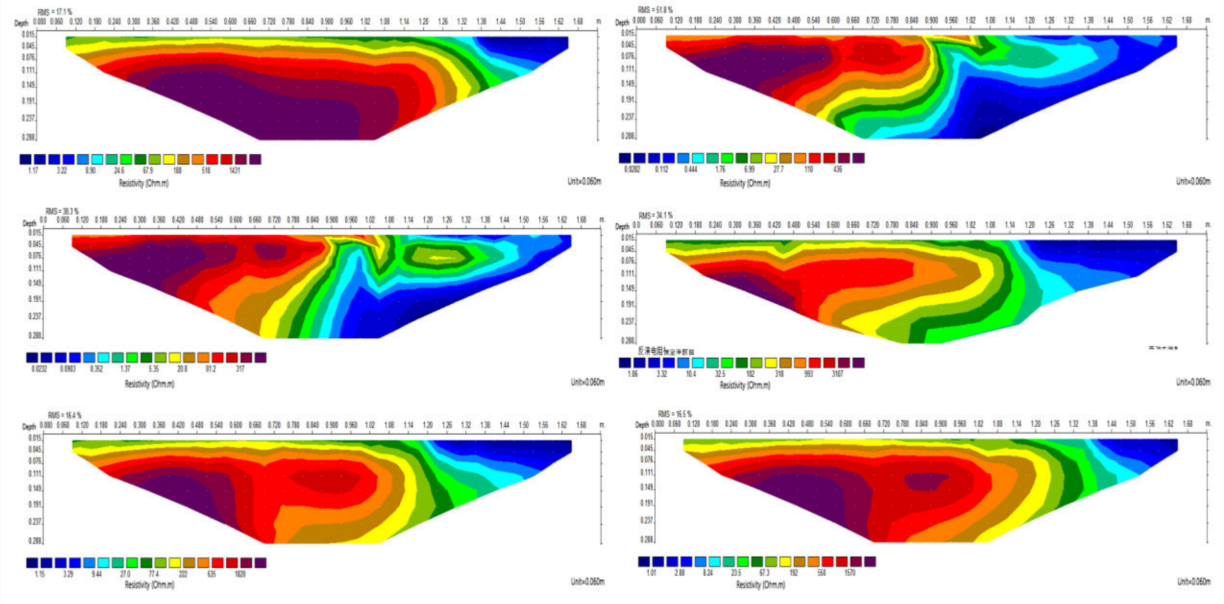
R^2 surface of training and test with different hidden nodes and regularization parameters

- Activation function: **Sigmoid function**
- Hidden layer nodes *L*: **75**
- Regularization parameters *C*: **$2^{-3.5}$**

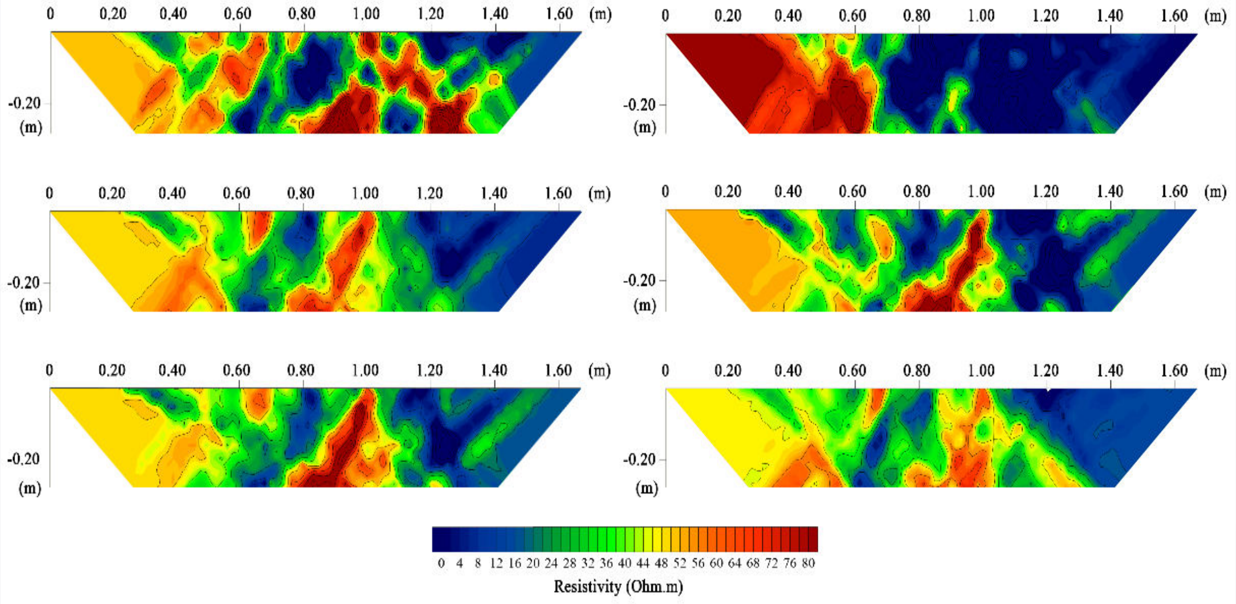
Further research

Inversion results

The least square inversion results:



RELM inversion results:



- RELM inversion method is more effective than the traditional inversion method.
- The imaging results can reflect the changing trend of the morphology and resistivity of the seawater/freshwater interface.
- The imaging effect of the inversion method is slightly inferior in homogeneous region, and the continuity of the image is poor.

Conclusion

1. ERT method is effective to map the freshwater/seawater interface and reflect the advancing process of seawater intrusion.
2. The well trained CNN recognition model was introduced to classify the interface types which presented accurate results that the interface types can be identified.
3. Compared with the inversion results of the least square method, RELM inversion method has advantages for the accuracy and effect of the inversion at the bottom of the interface with fewer measurement data.

Acknowledgement:

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Thanks!