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2021 EAGE ANNUAL
82ND CONFERENCE & EXHIBITION
AMSTERDAM | THE NETHERLANDS

Subsurface Temperature Measurement Using Electromagnetic Waves and Machine Learning for Enhanced Oil Recovery

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Outline

- Background and motivation
- EM and borehole field measurements
- Machine learning approach
- Results
- Discussion

Background and motivation

Enhanced Oil Recovery (EOR)

- Allows more (~60%) oil to be extracted from reservoir
  - Viscosity
  - Mobility ratio
- Various methods in use
  - Gas injection
  - Thermal methods ← this application
- Steam injection
  - Need to monitor subsurface temperature profile
  - Use temperature observation wells (TOW)
  - Measure 3-4 times a year, expensive
    - Cost of drilling
    - $5000,- typical cost per well for measurement
    - No production during measurement

Virtual TOW wish list

- No drilling
- Using surface data
- Measure without well downtime
- Faster acquisition
- More frequent monitoring
- Low cost per measurement
- Easy data processing

EM and borehole field measurements

EM data/TOW data

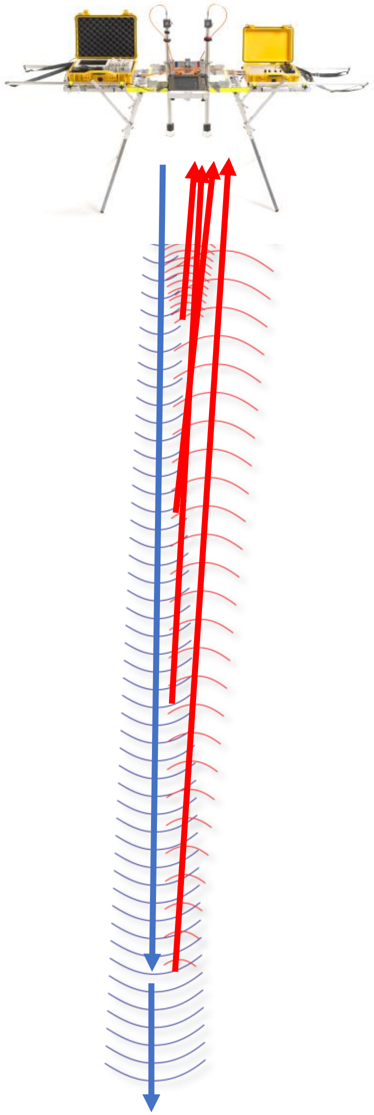
- Pulsed radar subsurface imaging
  - Low frequency (1-3MHz) for deeper penetration
  - Bistatic data acquisition
  - Stacking 100,000 shots
  - Measurement takes a few minutes per well
- Data acquired on 2 large producing oil fields
  - 21 and 40 wells measured from two relatively homogeneous field
  - 3 wells measured from a third oil field
  - TOW data used as ground truth
  - TOW data down to 1400ft

Machine learning

EM data → temperature using ML

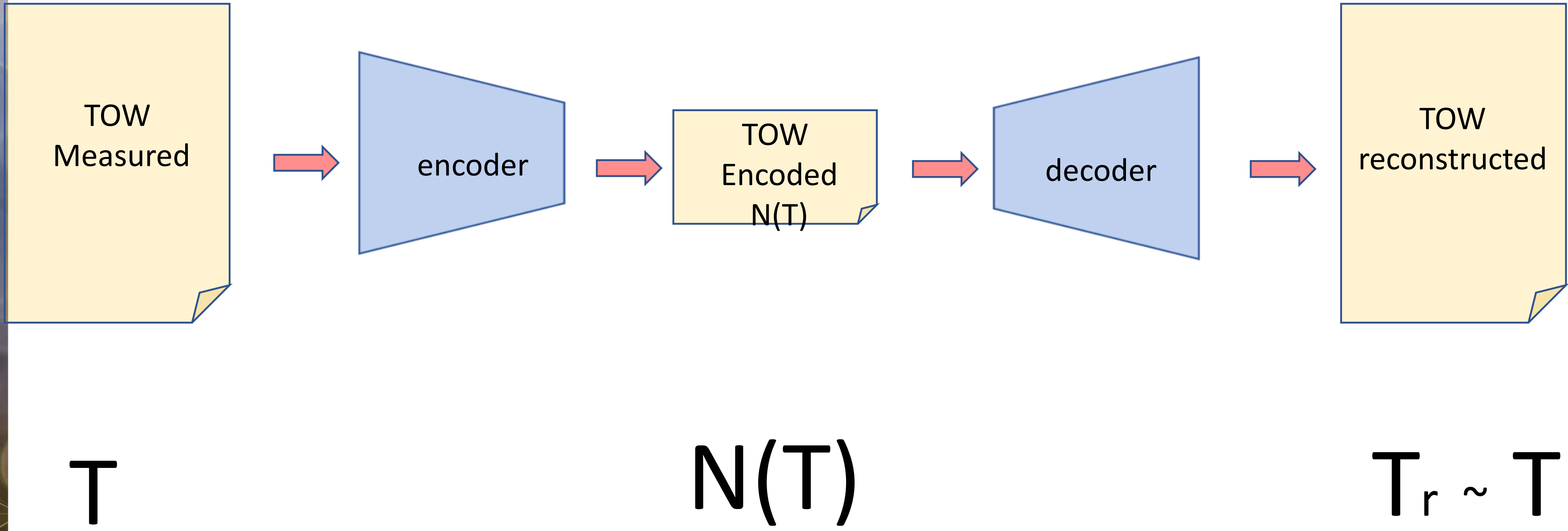
- Both data are "time series"
- Using ML to predict temperature (T) from EM data (M)
- Exclude 1 well from data set and train on rest (blind tests)
- Autoencoder and 5 layer feedforward neural network used
  - Encode T data (not M!) into neural representation N(T)
  - Train feedforward network on M,N(T) pairs
  - Then predict well not trained on: M→N(T)→(decode)→ T
- 3 sites from third field not used in training
  - Used to evaluate effect of ground conditions

EM data from backscatter

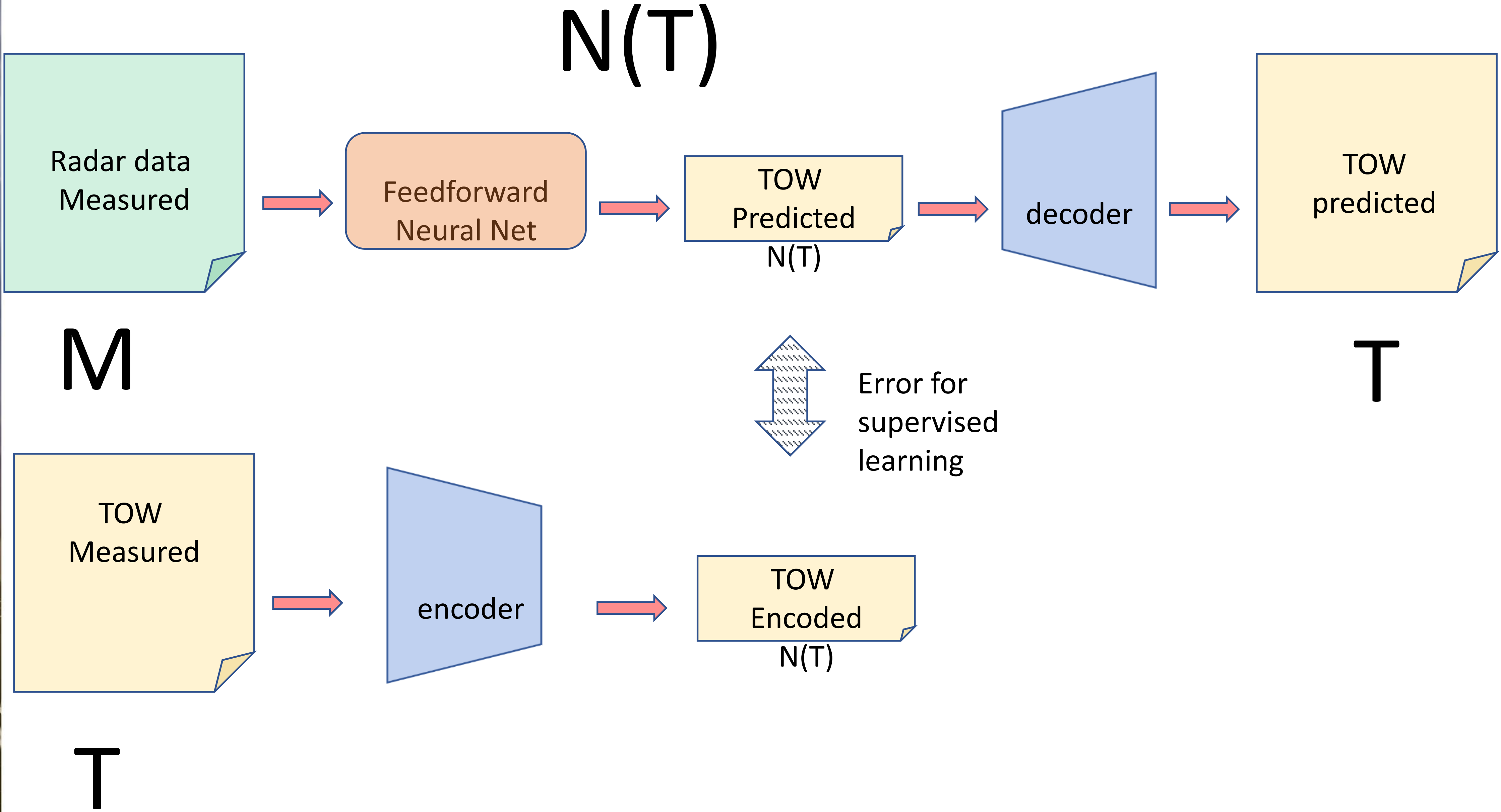


- Transmits broadband pulses of radio waves between **1 to 100 MHz** into the ground.
- Detects the modulated reflections returned from the subsurface.
- Backscatter due to variations in dielectric permittivity and conductivity of material. Time ~ depth.
- Analyses spectral content of the returns to help classify materials (energy, frequency, phase).

Autoencoder

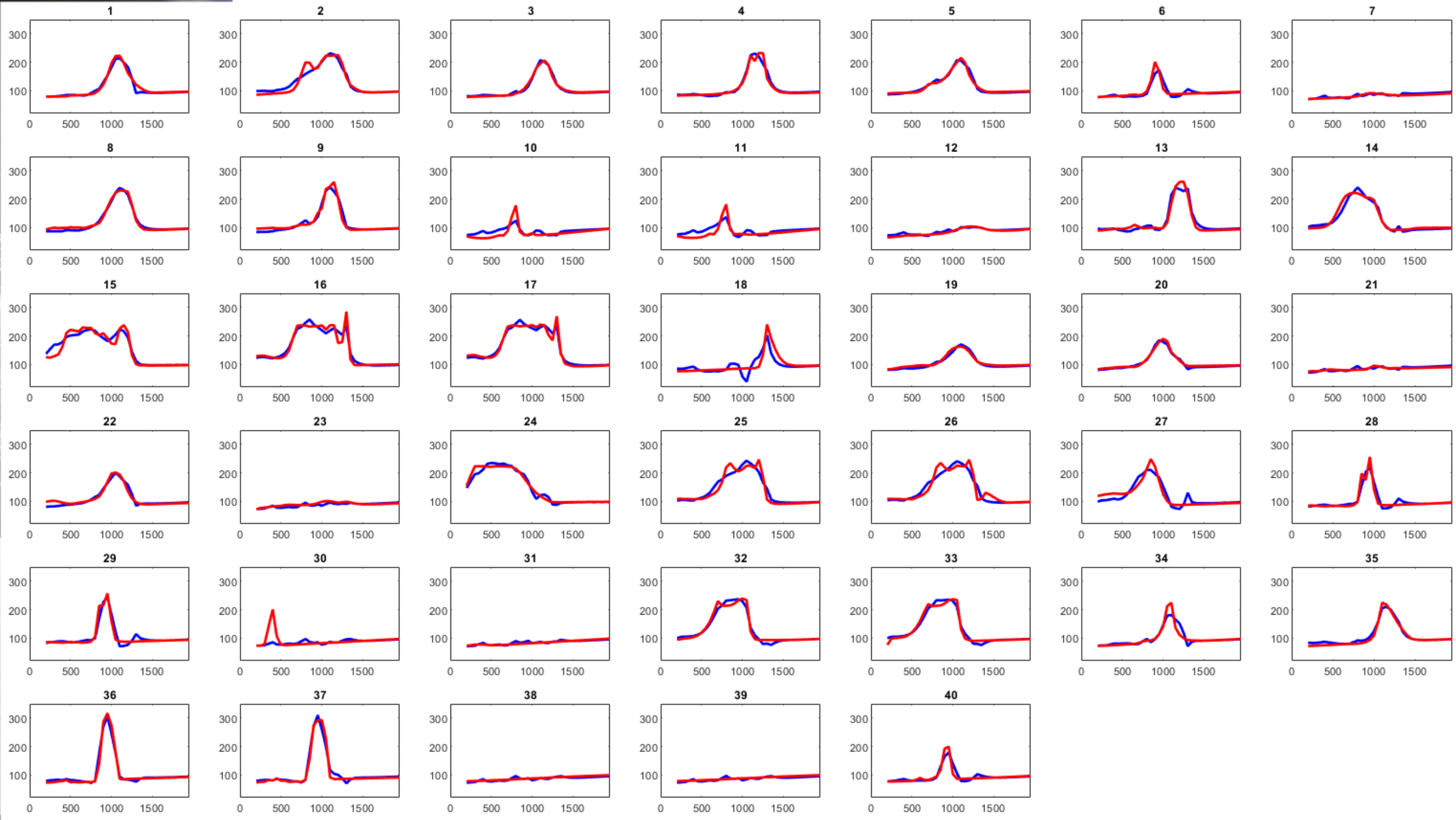


Feedforward neural et



Results

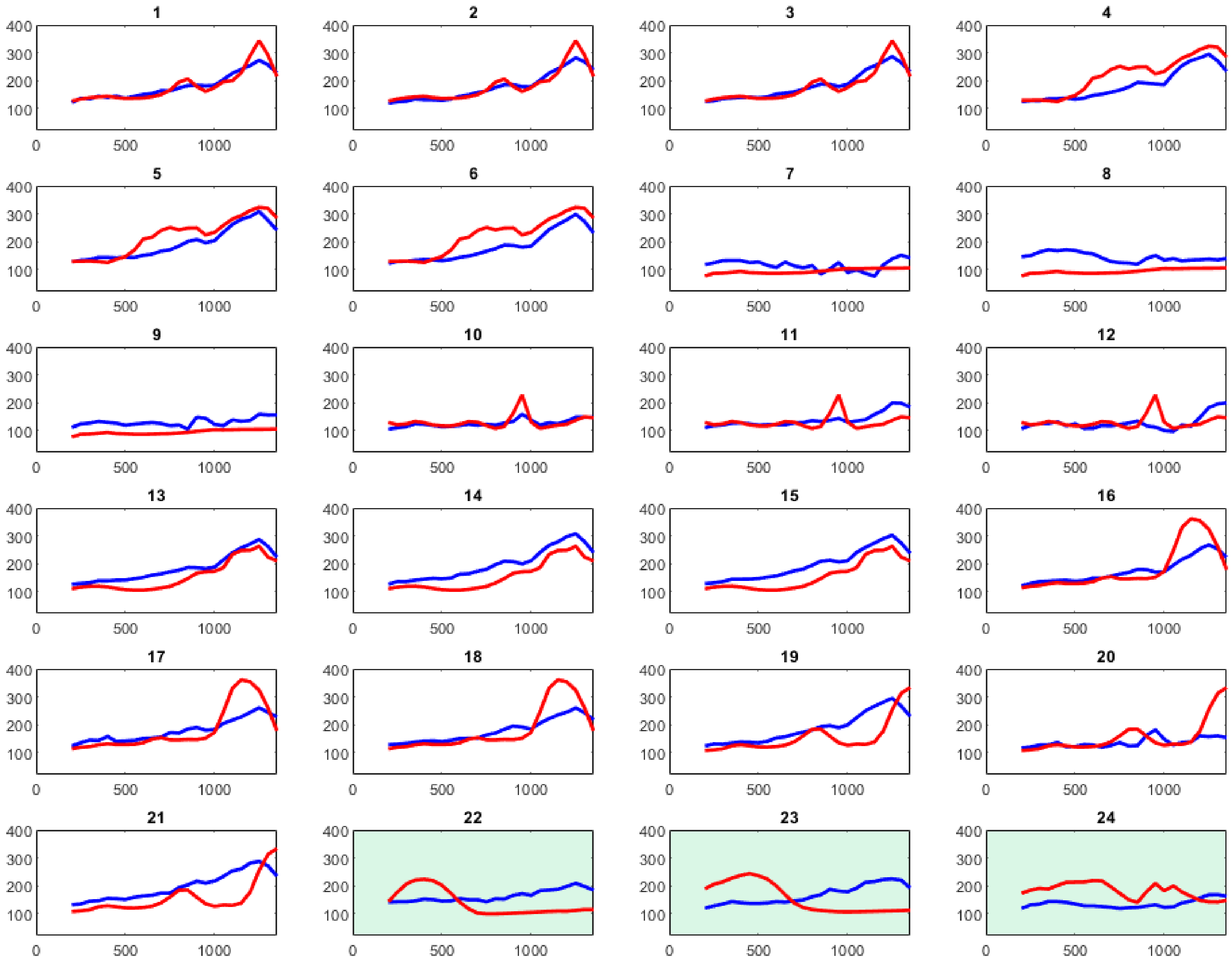
Autoencode T data to 5 activations



40 TOW profiles (red) encoded to 5 activations using an autoencoder network (Blue).

Units:
Fahrenheit + feet.

Blind test results: Site 1



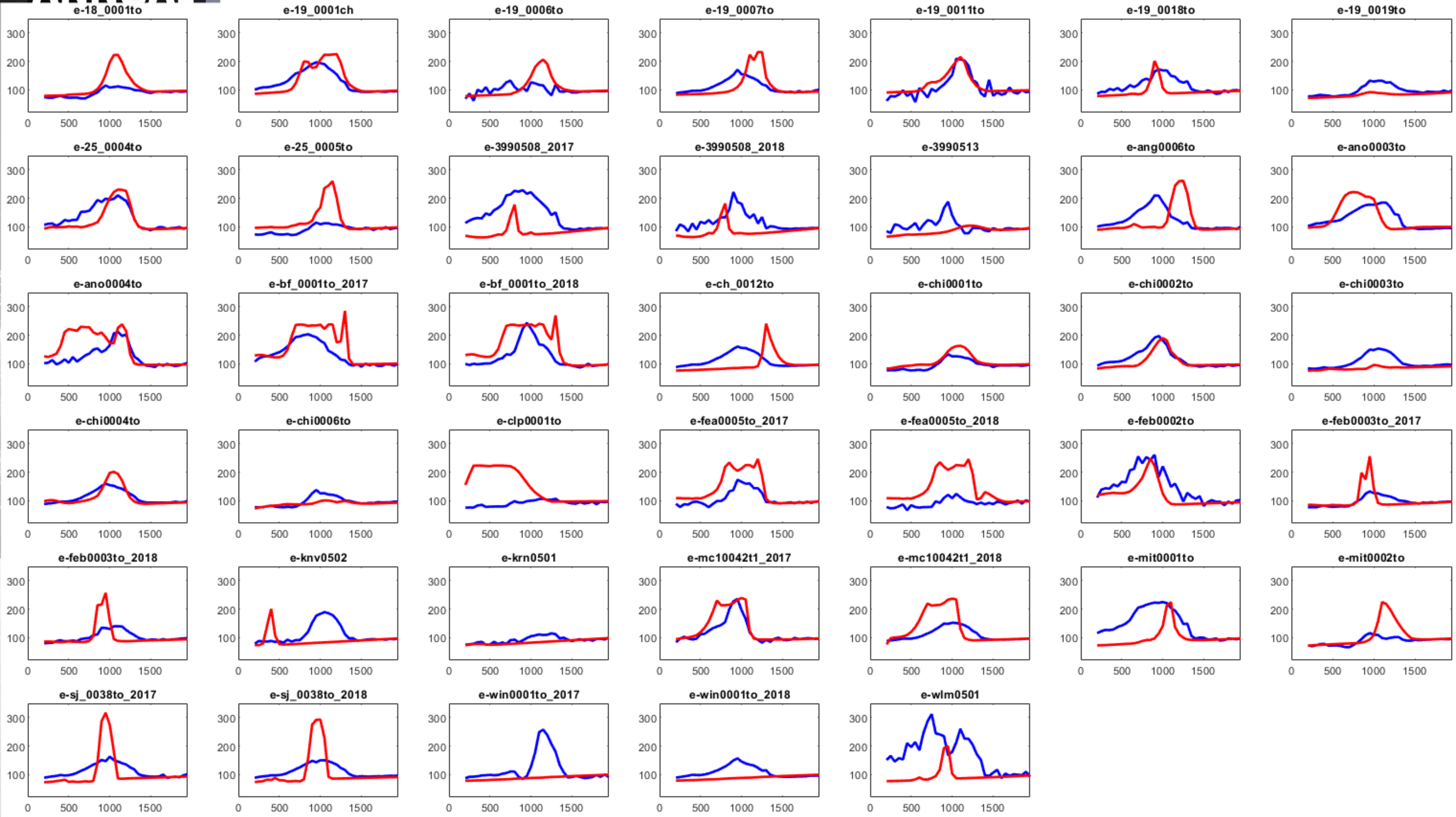
Red = TOW data (Fahrenheit)

Blue = EM prediction

Depth in feet

Last 3 are from a different field (not used in training)

Blind test results: Site 2



Discussion

Discussion

- Results are encouraging
- 3 “foreign” wells failed
  - Training site specific
  - Local variations in ground conditions “spoil” results
- How can we improve accuracy/reliability?
  - Assumed ground conditions homogeneous
  - Use also geological data for training to address this
- Why does it work?
  - EM waves penetrate sufficiently deep
  - Similar to apparent seabed imaging using conventional radar

Thank you for your attention!

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