TKI AI-kennis voor grondwaterverkenningen

Projectgroepoverleg 4 + scopingsessie
13 september 2023

HydroLogic

stowa STICHTING TOEGEPAST ONDERZOEK WATERBEHEER

HKV LIJN IN WATER

HOOGHEEMRAADSCHAP DE STICHTSE RIJNLANDEN

Witteveen + Bos

Waterschap Noorderzijlvest

Vitens

WATERSCHAP vechtstromen

WATERSCHAP ZUIDERZEELAND

Rijkswaterstaat
Ministerie van Infrastructuur en Waterstaat

Deltares

Agenda

1. Opening, vaststellen agenda, mededelingen	09:30 - 09:35 (5 min)
2. Notulen, acties, update projectplan n.a.v. vorig overleg	09:35 - 09:45 (10 min)
3. Stand van zaken t.a.v. techniekontwikkeling	09:45 - 10:45 (1 uur)
koffie / thee / even benen strekken	10:45 - 10:55 (10 min)
4. Hoe beoordelen we of een AI-simulatie goed genoeg is of niet?	10:55 - 11:05 (10 min)
5. Hoeveel budget te reserveren voor inzet ‘cloud-hardware’?	11:05 - 11:15 (10 min)
6. Inplannen Machine Learning cursus	11:15 - 11:20 (5 min)
7. Afspraken en volgend projectgroepoverleg	11:20 - 11:25 (5 min)
8. Rondvraag en afsluiting	11:25 - 11:30 (5 min)

1. Opening, vaststellen agenda, mededelingen

- Afmeldingen:
  - Hans Hakvoort
  - Michiel Pezij
  - Sjon Monincx
  - Wilbert Berendrecht

- Mededelingen:
  - Symposium on emulating 2D flood modelling, woensdag 27 September 2023.

- Maria Luisa Taccari in herfst in Nederland.

27

Sep

Symposium on Emulating 2D flood modelling

27 Sep 2023

09:00 - 17:00 (GMT+02:00)

Symposium

€ Free

Room : Patio - Building : Toren

Remaining places : 30

+ Add to my Calendar

Symposium on "Emulating 2D flood modelling: exploring deep learning techniques and low-fidelity approaches"

In recent years, deep learning methods and low-fidelity approaches have been increasingly applied to simulate 2D flooding processes. Frequently, their performance is compared to numerical models like Delft3D FM 1D2D Suite, and in the case of the deep learning methods those modelling suites are often also used to provide a training and test dataset. For this symposium, and as part of the Delft Software Days - Edition 2023 (DSD-INT 2023), we've invited several academic researchers and consultants to present their recent work on emulating 2D flooding processes and discuss with us the direction this field is moving to and what it means for the future of flood modelling and management.

09:20 - 09:30	Welcome	Hans van Putten (Deltares, Netherlands)
09:30 - 11:00	**Block 1**	
09:30 - 10:00	Dike breach flood modelling using machine learning	Leon Besseling (University of Twente, Netherlands)
10:00 - 10:30	Modelling floods with geometric deep learning	Roberto Bentivoglio (Delft University of Technology, Netherlands)
10:30 - 11:00	Surrogate model for real-time urban pluvial flood inundation mapping	Daan Buekenhout (KU Leuven, Belgium)
11:00 - 11:15	**Coffee break**	
11:15 - 12:45	**Block 2**	
11:15 - 11:45	Probabilistic inundation forecast using deep learning	Koen Reef (HydroLogic, Netherlands)
11:45 - 12:15	Application of hybrid urban nowcasting model in real-time operational systems - lessons learned from a case of Antwerp	Mees Radema (Deltares, Netherlands)
12:15 - 12:45	Creating flood scenarios for spatial development: A pragmatic approach based on existing LIWO scenarios	Thomas Stolp (HKV, Netherlands)
12:45 - 13:45	**Lunch break**	
13:45 - 14:45	**Block 3**	
13:45 - 14:15	Speeding up hydrodynamic models for real-time flood inundation predictions	Niels Fraehr (University of Melbourne, Australia)
14:15 - 14:45	Fast compound flood modelling using reduced complexity model (SFINCS)	Roel de Goede (Deltares, Netherlands)
14:45 - 14:50	**Group Picture**	
14:50 - 15:00	**Coffee break**	
15:00 - 15:50	**Block 4**	
15:00 - 15:50	Panel discussion	Hans van Putten (Deltares, Netherlands)
15:50 - 16:00	**Plenary wrap up / Conclusion**	
16:00 - 17:00	**Drinks and snacks**	

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2. Notulen, acties, update projectplan n.a.v. vorig overleg

- Doornemen verslag vorig overleg (d.d. 05-07-2023)
  - **Actielijst**

Volgnr	Actie	Naam	Vervaldatum
1	~~Naamgeving STOWA/NHI aanpassen in projectplan en Jan Dirk toevoegen aan namen bij Witteveen en Bos~~	~~Bennie~~	~~12-5-2023~~
2	Naam administratief contactpersoon doorgeven aan Bennie	Sjon, Rudolf	31-5-2023
~~3~~	~~Bijgewerkt projectplan rondsturen~~	~~Bennie~~	~~31-5-2023~~
~~4~~	~~Casusmodel Vechtstromen aanleveren~~	~~Sjon, Niels~~	~~z.s.m.~~
~~5~~	~~Casusmodel Zuiderzeeland aanleveren~~	~~Rudolf~~	~~z.s.m.~~
~~6~~	~~Datumprikker PGO / scopingsessie rondsturen~~	~~Bennie~~	~~17-5-2023~~
~~7~~	~~Link naar vakantie-excel rondsturen~~	~~Bennie~~	~~17-5-2023~~
8	Beschrijving RWS-casus opnemen in projectplan	Bennie	13-9-2023
9	Inplannen stand-up meetings	Romee	5-7-2023
10	Navragen beschikbaarheid peilen Maas	Ysbrand	13-9-2023
11	Uitvraag naar administratieve contactpersonen van gerealiseerde in-kind uren	Bennie	31-7-2023
12	Invullen/bijwerken vakanties in excel	allen	31-7-2023
13	Documentatie met format input/output/metadata file rondsturen	Jonathan	31-7-2023

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3. Stand van zaken t.a.v. techniekontwikkeling

Meeting Agenda

- Initial results presentation and discussion
  - Discharge-field to head/drawdown (Vitens case)
  - Transmissivity to steady-state head (hypo 1)
  - Transient case (hypo 4)

Topics to discuss

- Define standards of accuracy
- Computing power - project cost trade-off

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Case Studies

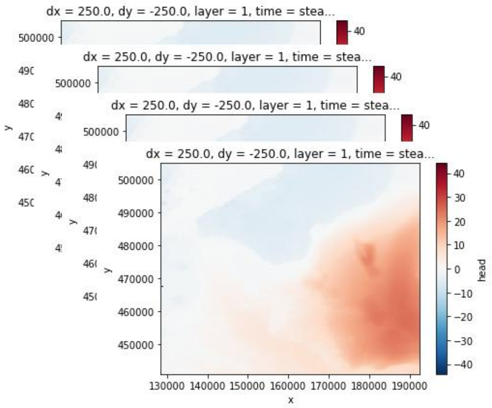
Updates on moving well problem – Vitens case 1

Vitens case 1 (steady-state)

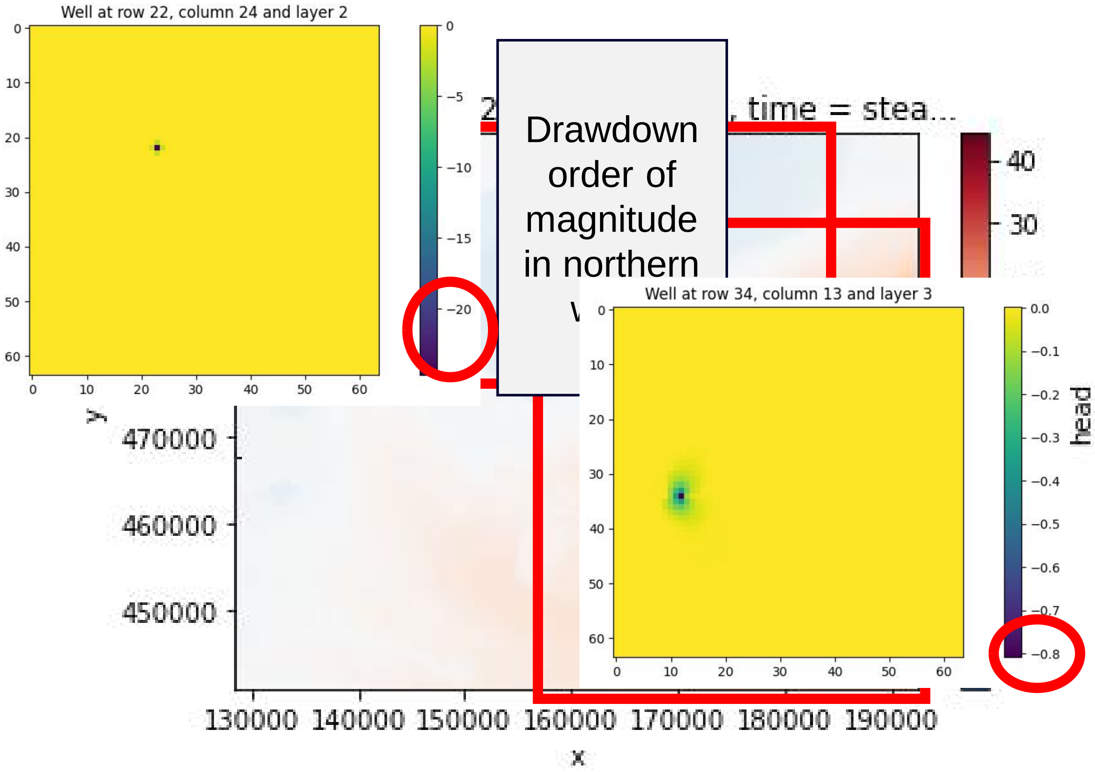
Input:
- Moving well
- Fixed interval for [x, y, z]
- Fixed q

Model:
- Steady-state
- LHM
- (256 x 256 x 8) or (64 x 64 x 8)
- Layer 2-8: 12.600 examples

Output:
- Head (L1)
- 2D raster

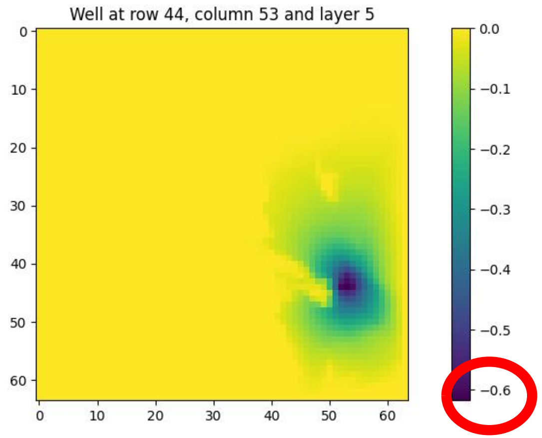


Few words about the data



Drawdown order of magnitude in northern

In wells outside of the "low head" area the drawd is mir



In the “high head” eastern area wells usually have larger spatial influence

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Techniques

1. Encoder-Decoder (Unet)
2. Generative Adverserial Networks (pix2pix GAN)
3. Stable Diffusion (Img2Img)
4. Fourier Neural Operators (FNO)
5. DeepOnets (DON)

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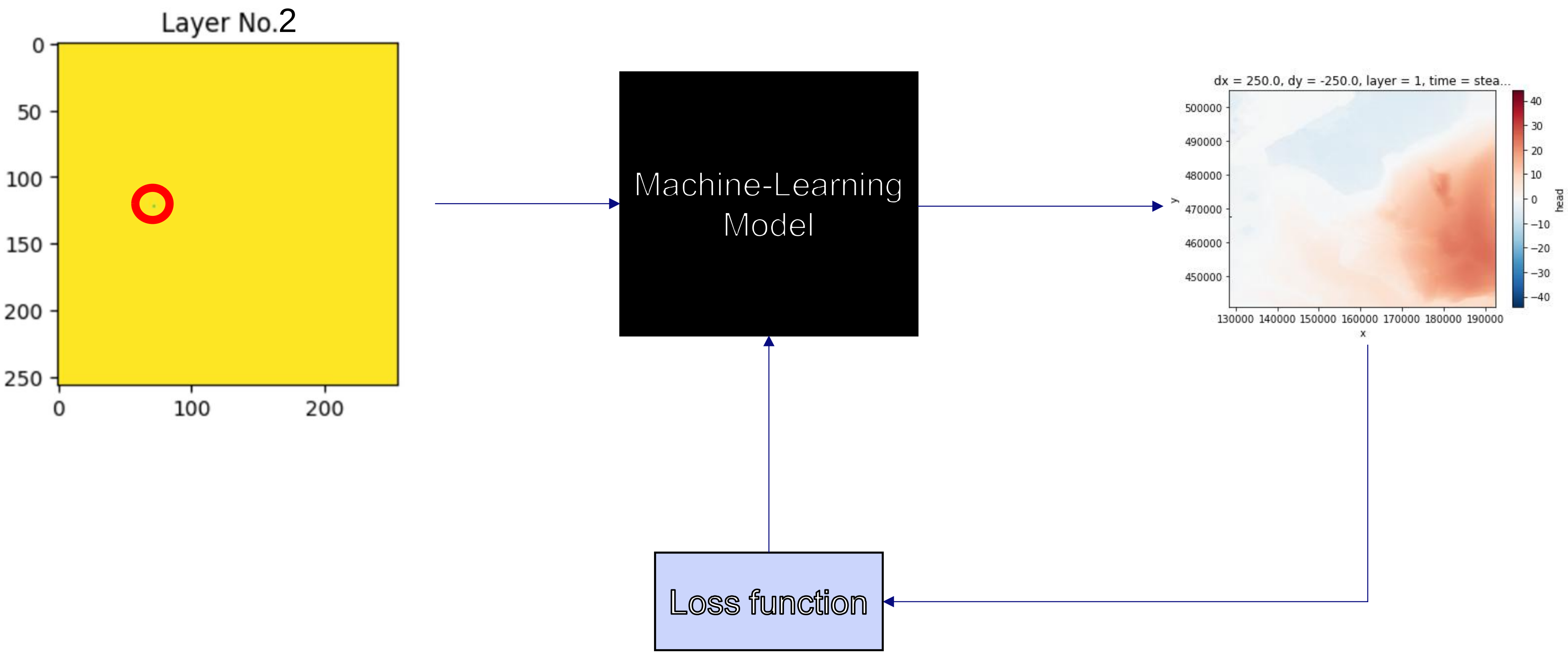
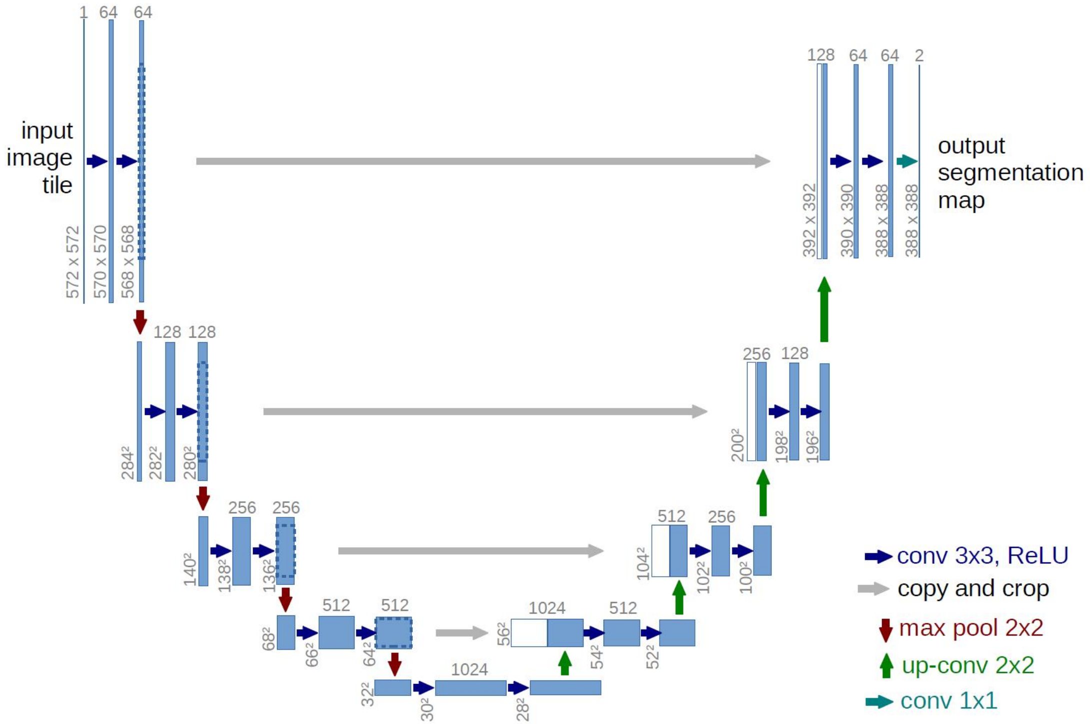
How is model used?



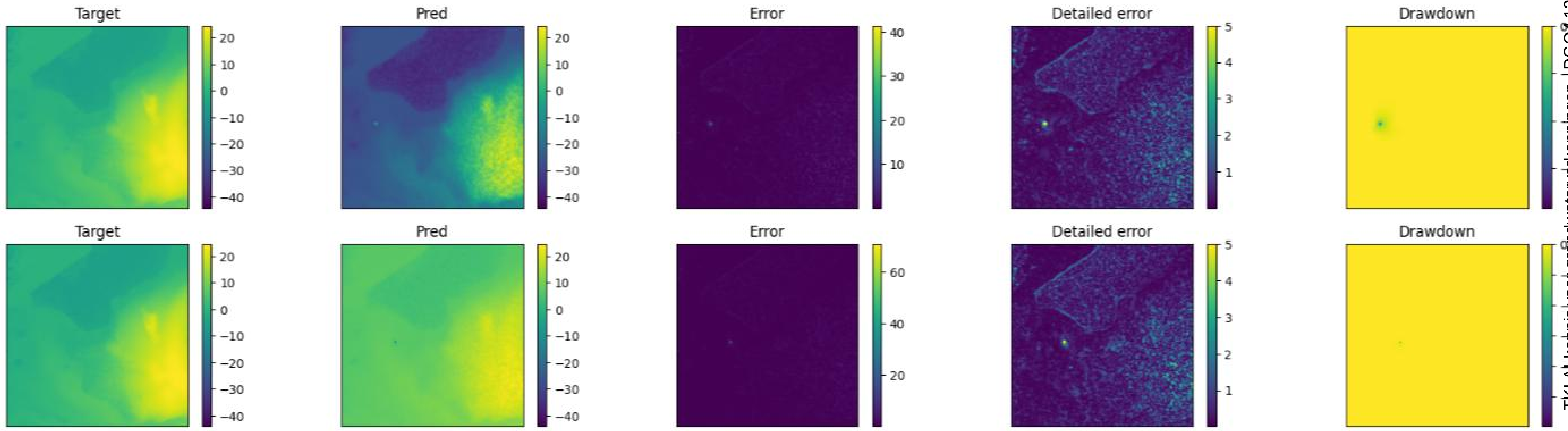
Unet Model Architecture

- 256 x 256 pixels input (Q field) and output
- Tested both on steady-state head and drawdown output
- Tested different depths and kernel sizes - with and without attention units
- Tested different loss functions – emphasis around the well



Unet results on Vitens case 1 (steady-state)

- Unet identifies the overall pattern of head
- Still returns significant errors



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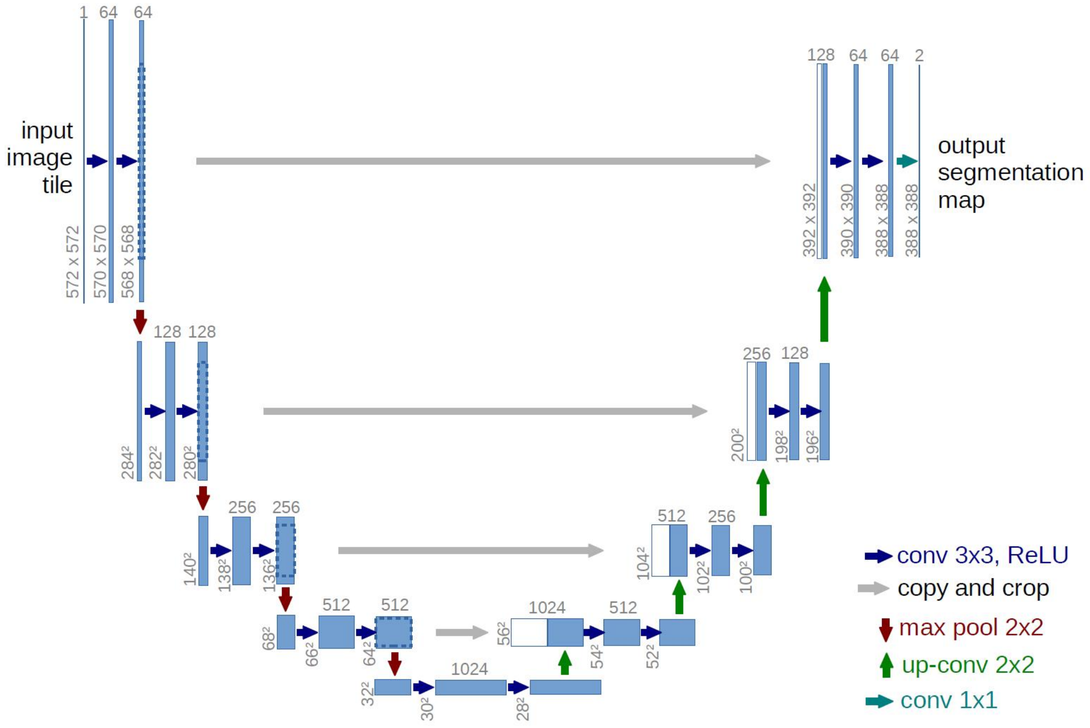
Unet Loss Functions

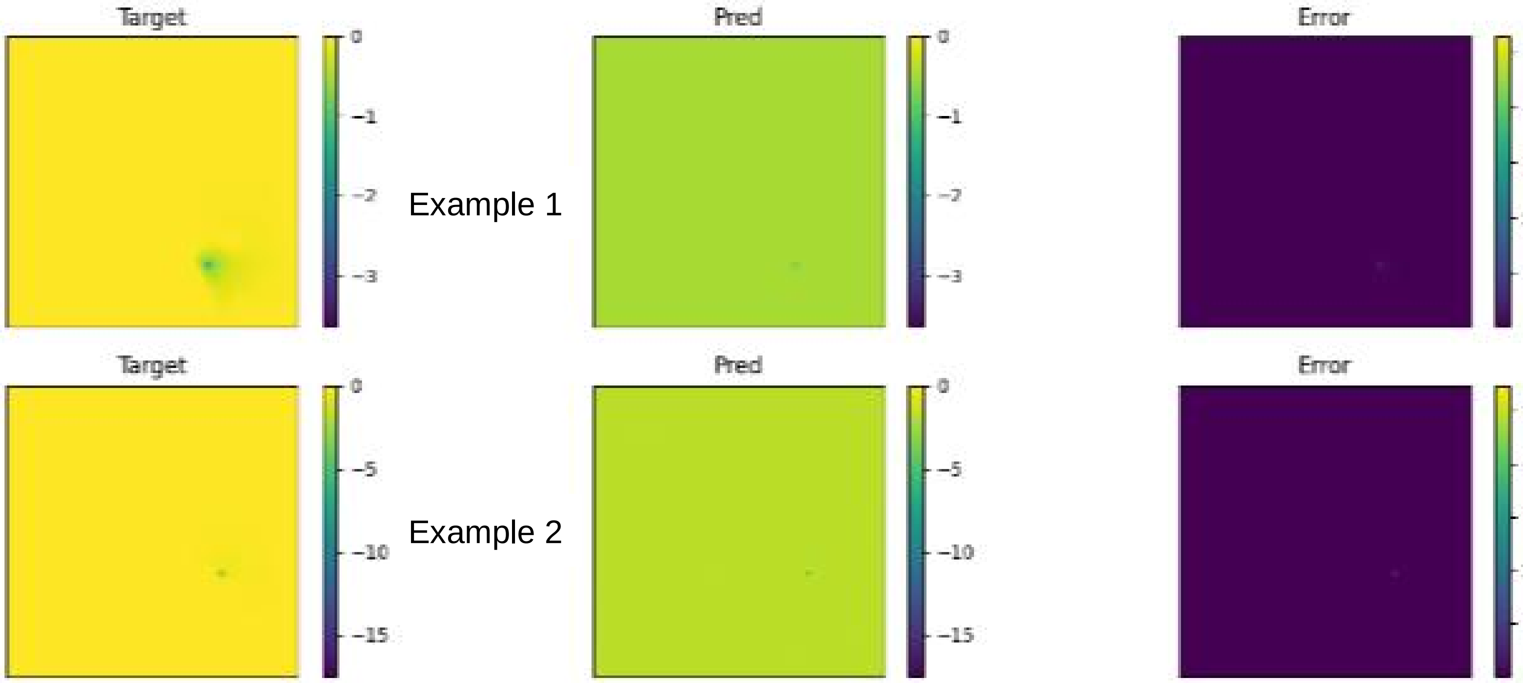
Different loss functions yield the same results:

- Absolute error
- Weighted error based on distance from the well
- Weighted error based on the pixels with drawdown (drawdown part of loss function, even for steady-state heads)



Unet results on Vitens case 1 (drawdown)

- Unet fails to identify spatial patterns of drawdown
- In several cases the order of magnitude of drawdown or the cone of influence



Pix2Pix GAN model architecture

- Neural network split into two parts:
  1. **Generator** learns to generate realistic output
  2. **Discriminator** learns to distinguish (and ultimately accept/reject) real from fake output

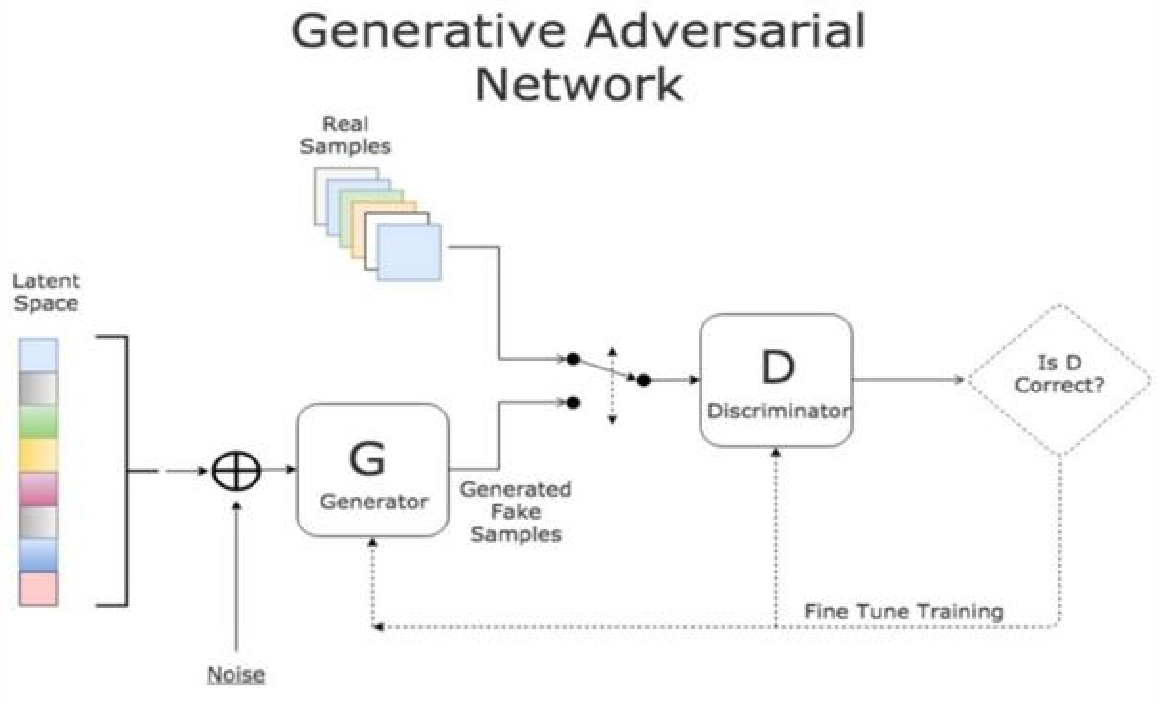
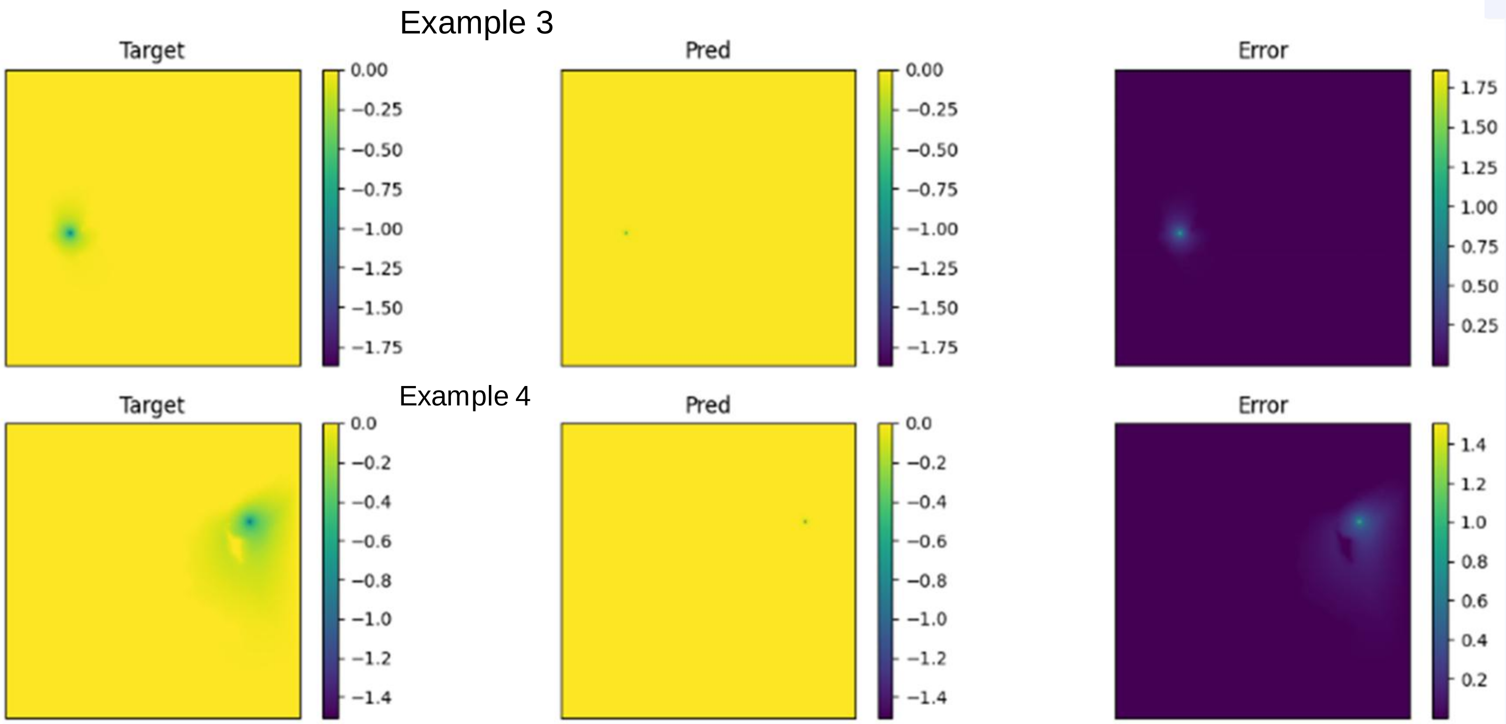


Image from: https://ai.plainenglish.io/understanding-pix2pix-gan-e21c2bedd213

GAN results on Vitens case 1

- GAN results slightly better Unet’s in terms of mean absolute error
- Still patterns and magnitude far off in several cases
- In a later step, discriminator could be replaced by a physics-based discriminating model



Img2Img Stable Diffusion model architecture

- Technique mostly used for text-to-image translation
- Image-to-Image alternative researched but probably not suitable for the Vitens case 1 problem
  1. Computing requirements
  2. Input-to-output flow not suitable
- Highly likely to not be researched further

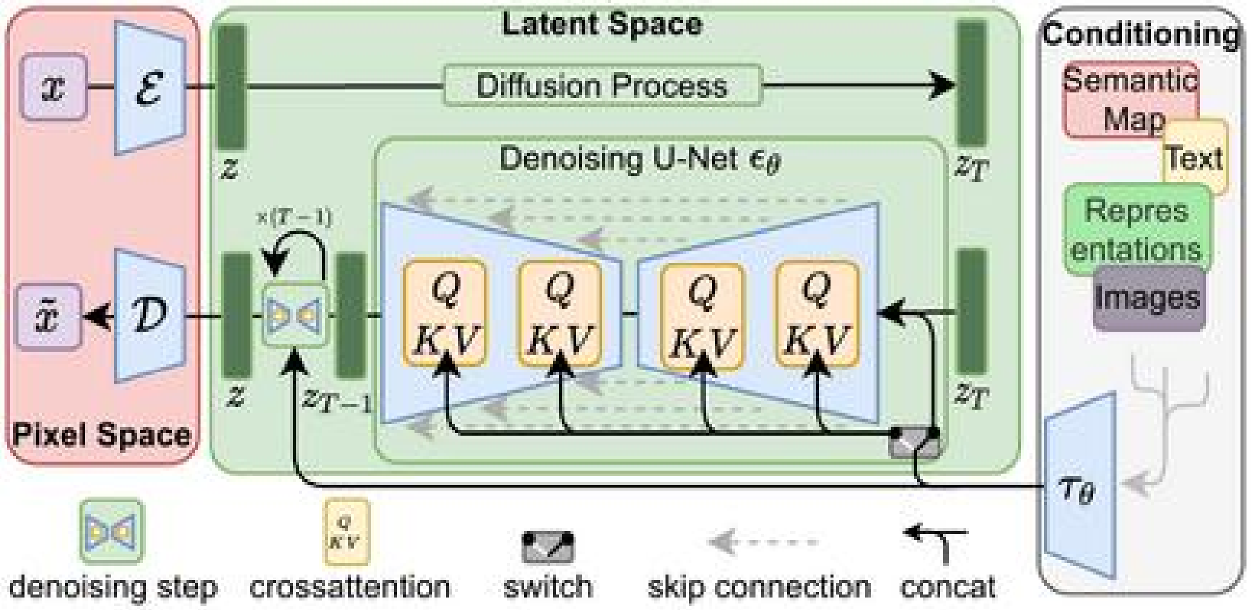


Image from: https://en.wikipedia.org/wiki/Stable_Diffusion

FNO model architecture

- Currently using (64, 64, 8) image input, researching ways to reduce it to (row, column, layer)
- Main advantages:
  1. Fast Fourier Transform is fast!
  2. Trained models can be immediately deployed on finer/coarser resolutions

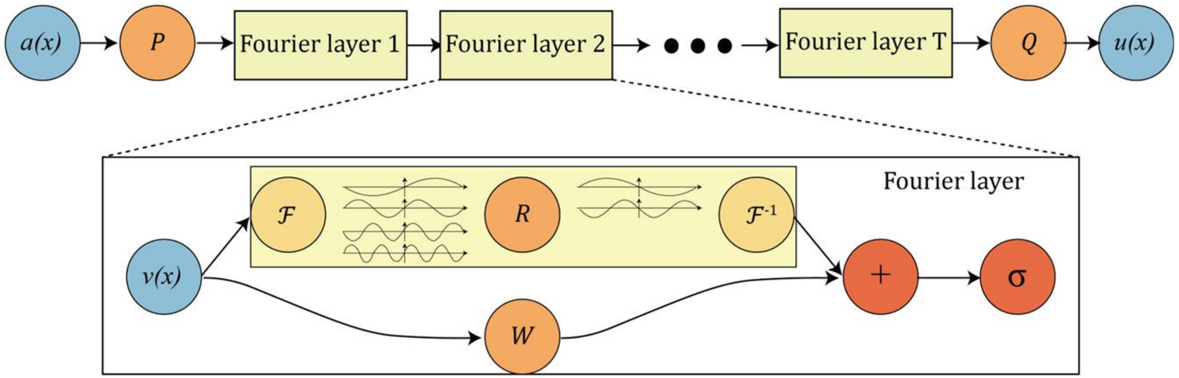
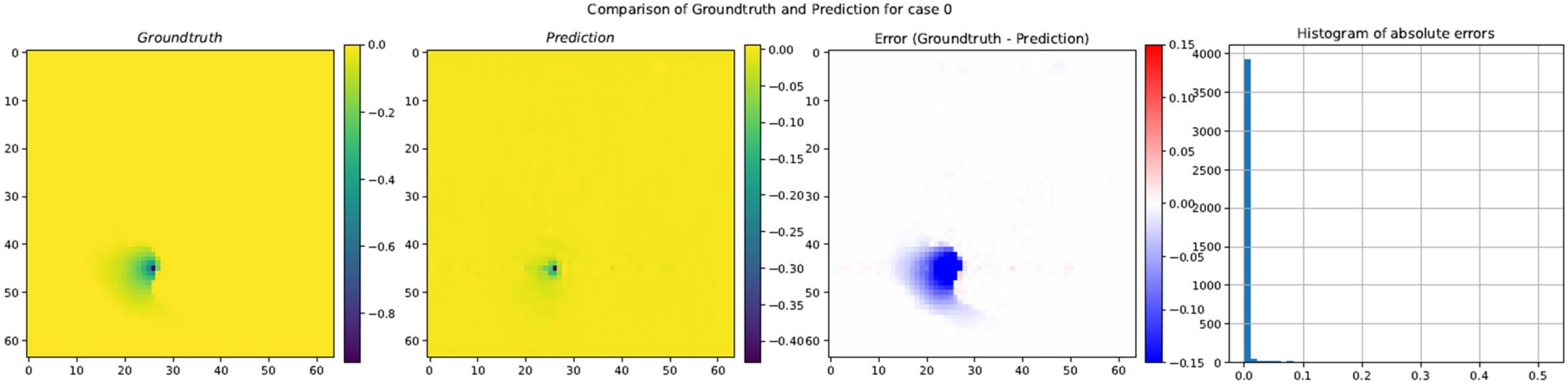


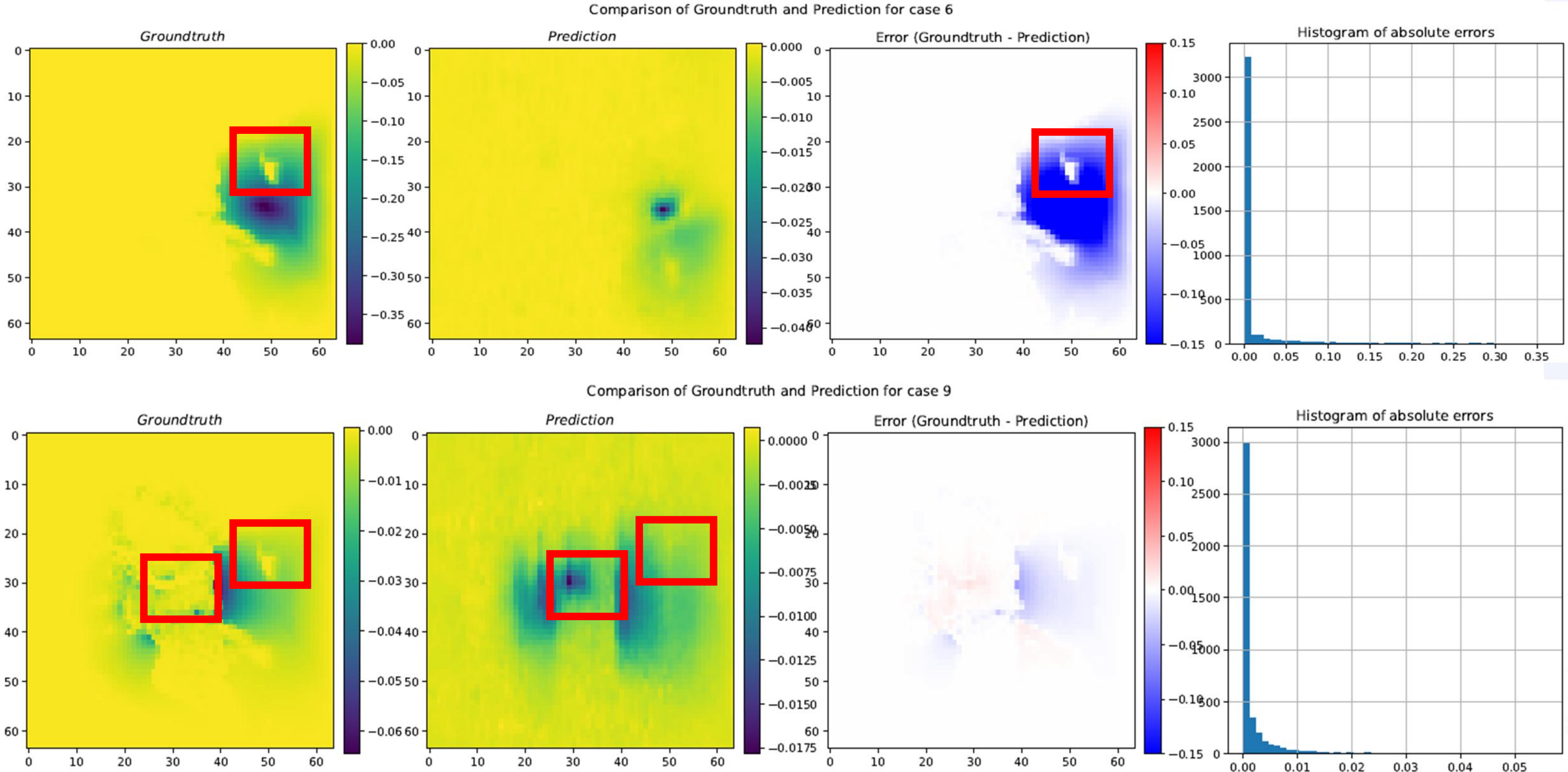
Image from: https://zongyi-li.github.io/neural-operator/

FNO results on Vitens case 1 (1/2)

- Significant improvement on drawdowns and steady-state heads compared to previous techniques
- Predicted magnitude of drawdowns significantly closer to observed
- Spatial patterns yet to be improved **(next slide)**

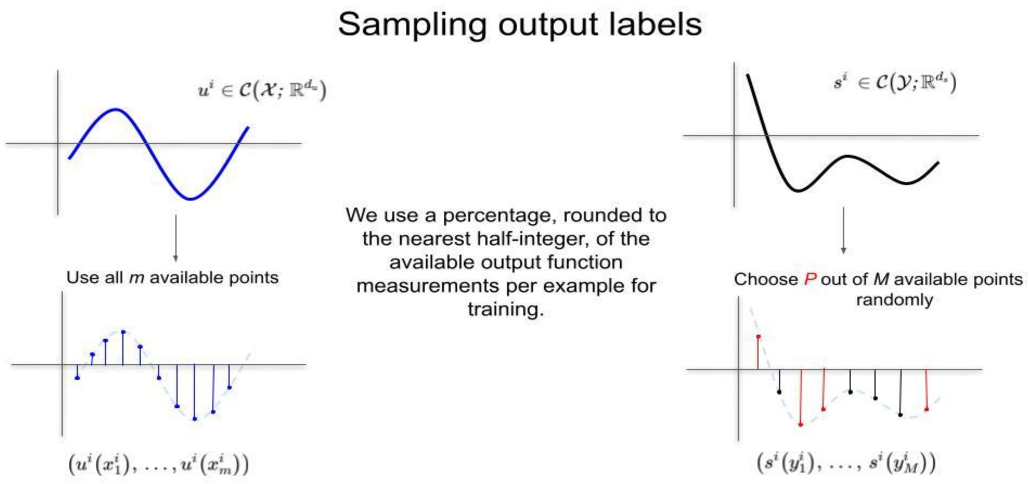


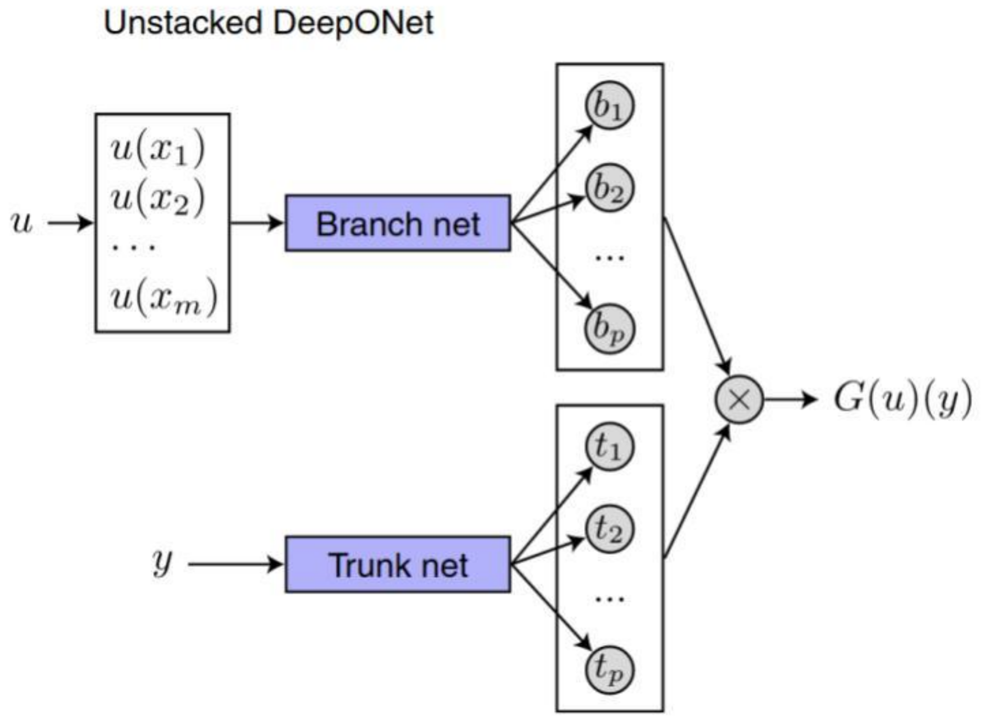
FNO results on Vitens case 1 (2/2)



DeepONet (DON) model architecture

- Continuous (not discretized) method
  - Universality
- Input (row, column, layer) in branch network
- Sampling points in trunk network





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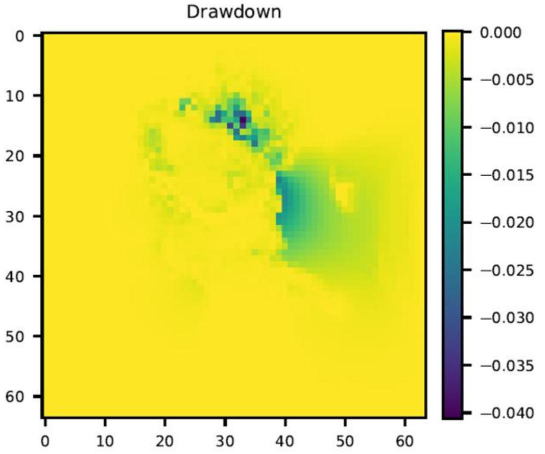
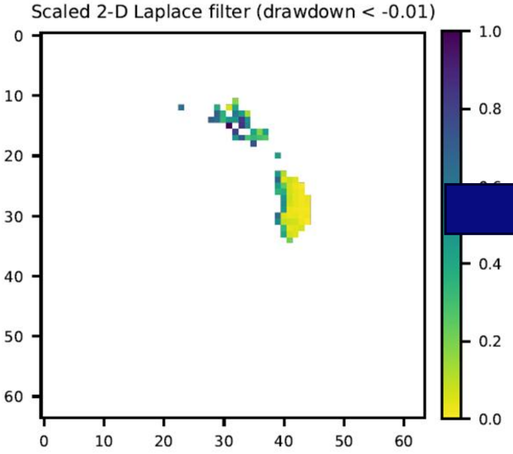
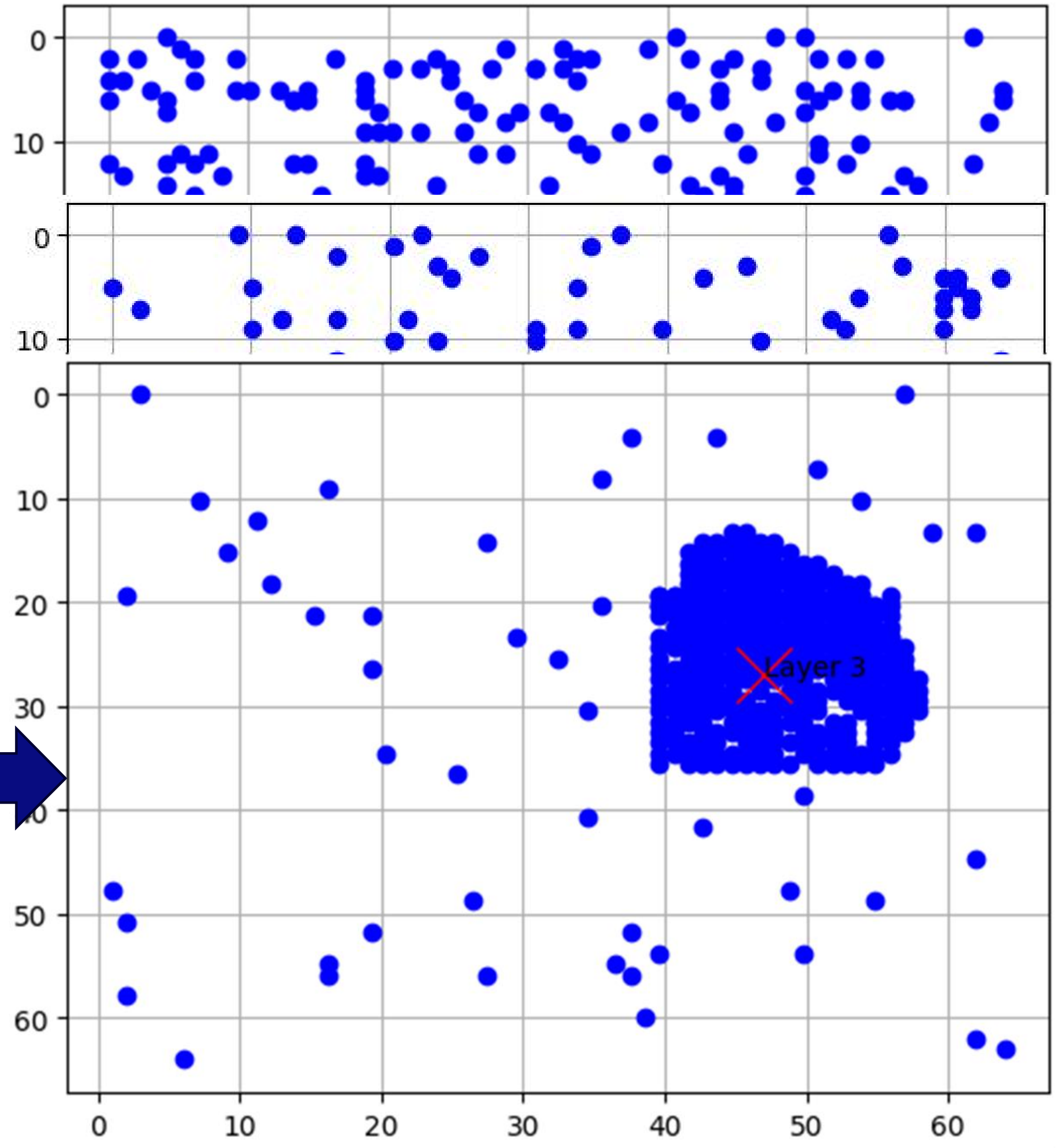
DON sampling techniques (500 total sampling points)

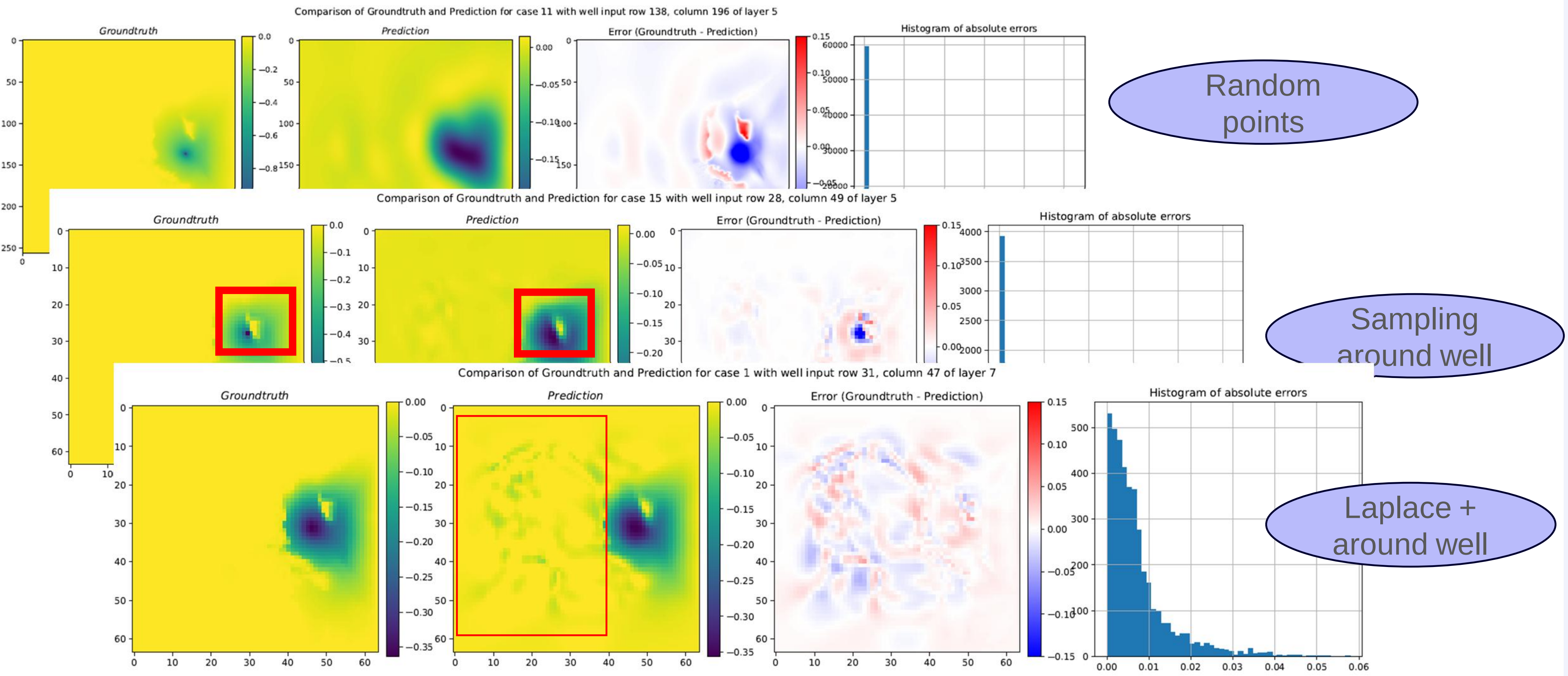
1. Random points
2. 17 x 17 around well + random points
3. Masked Laplace second derivative points + points around well + random



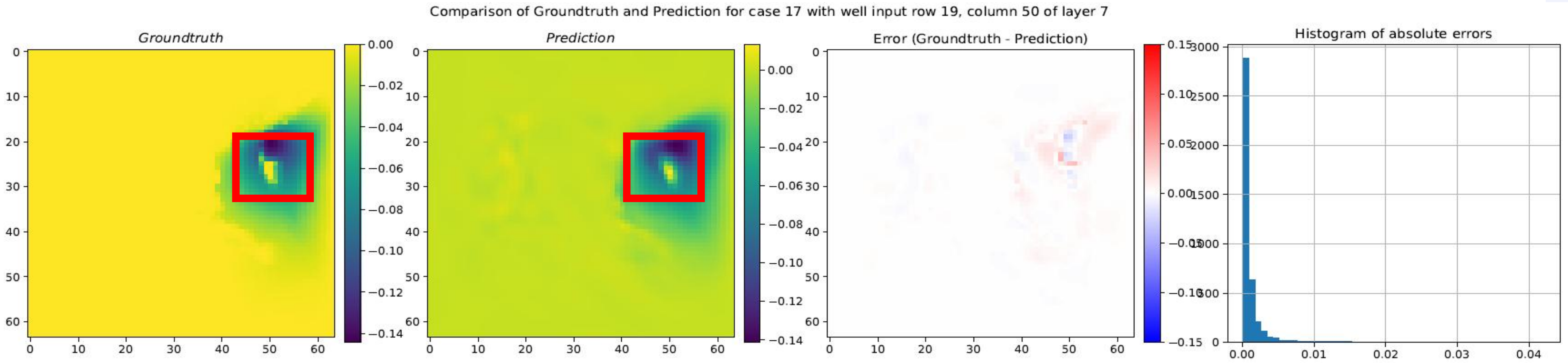


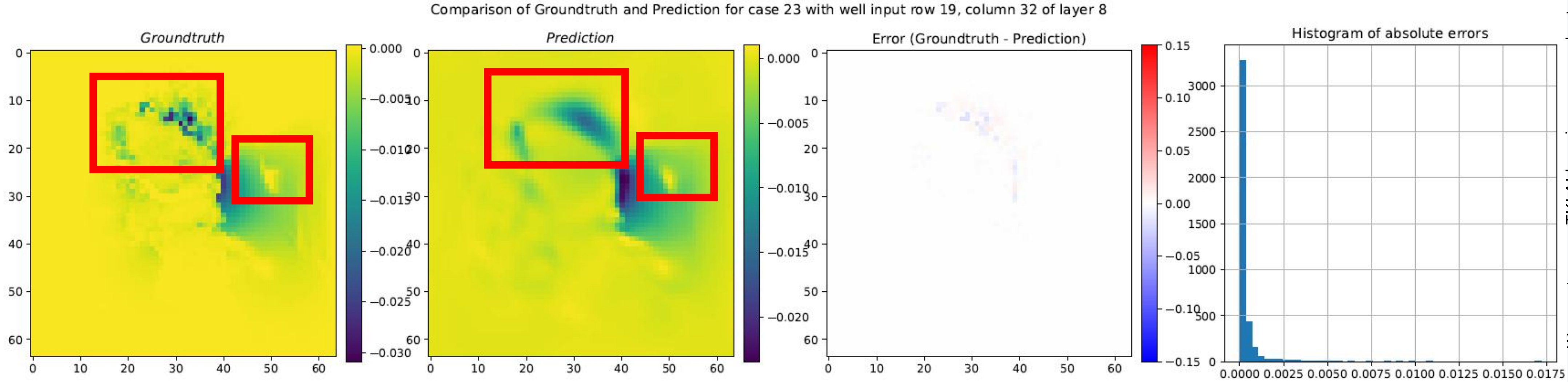


Comparing sampling techniques

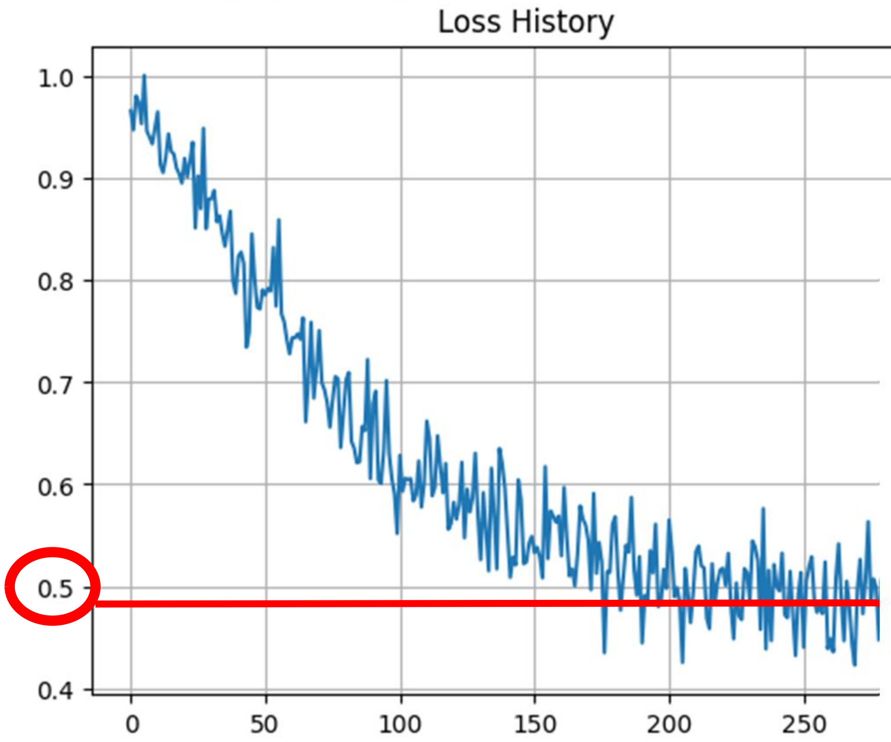


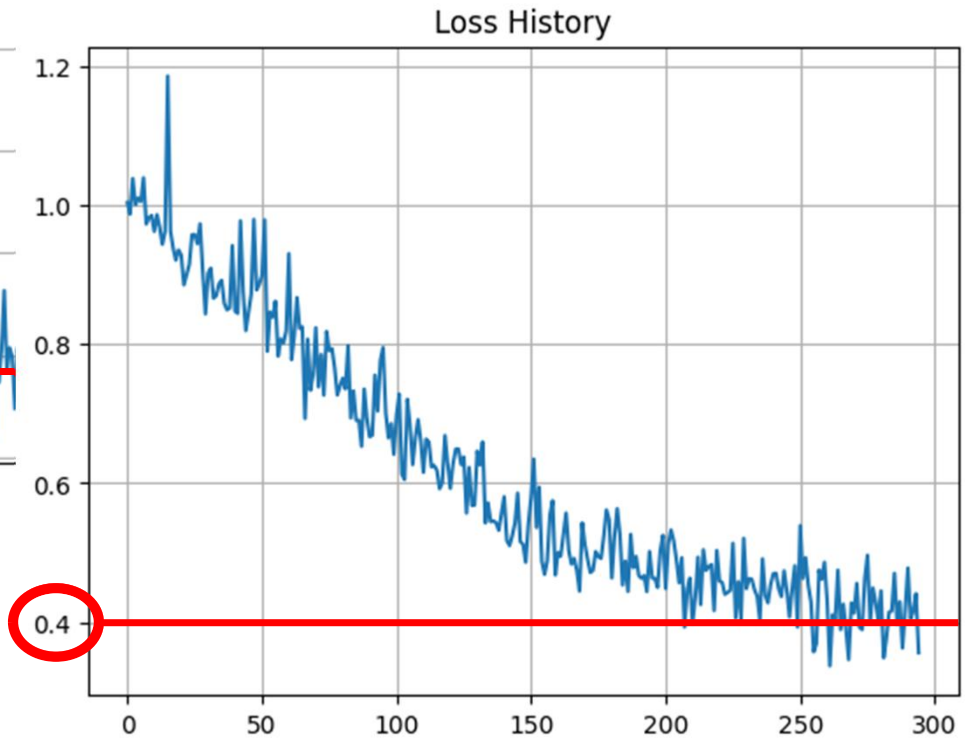
More sampling around the well results





DON Hyperparameter results





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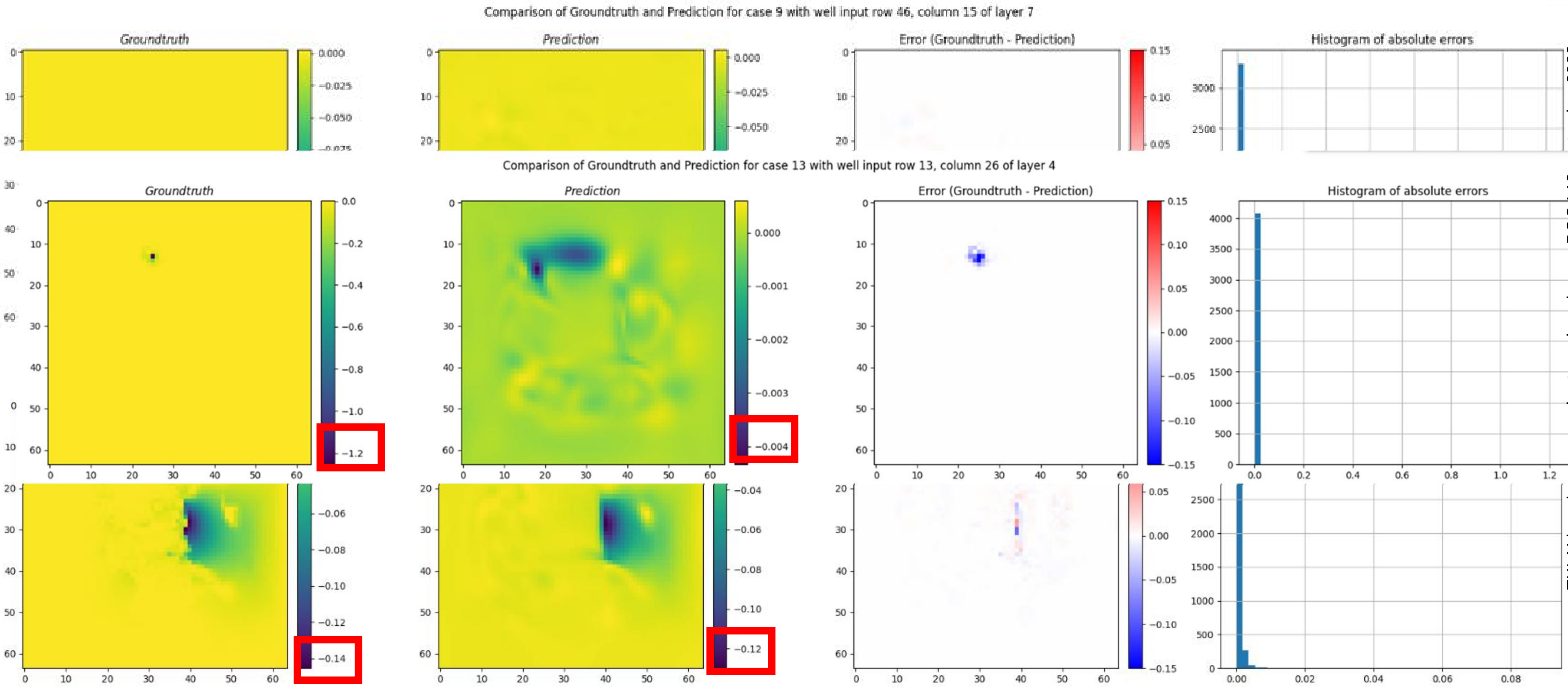
Optimized network results



Case Studies

Updates on moving well with random Q problem – Vitens case 2

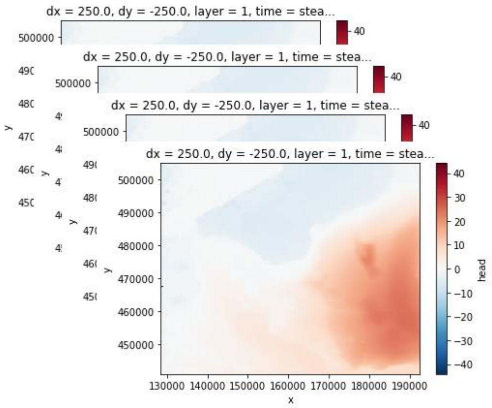
Vitens case 2 (steady-state)

Input:
- Moving well
- Random allocation [x, y, z]
- Random q

Model:
- Steady-state
- LHM
- (256 x 256 x 8) or (64 x 64 x 8)

Output:
- Head (L1)
- 2D raster

As in Vitens case 1, DONs only are able to detect underlying patterns



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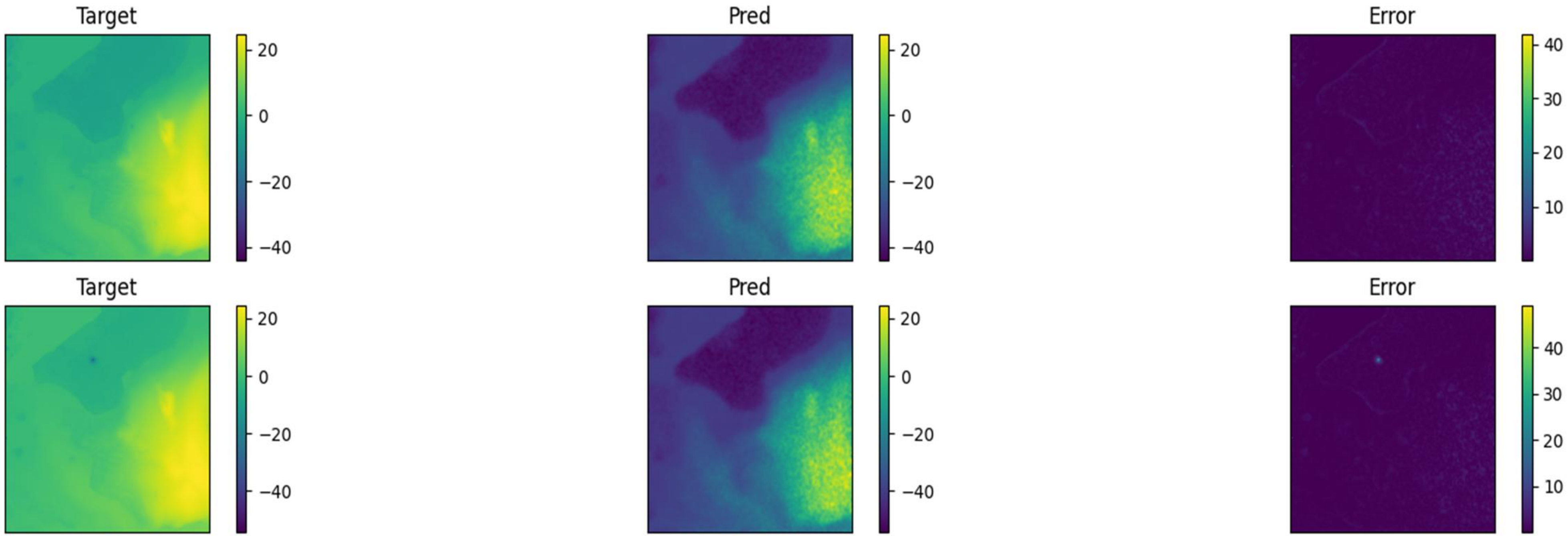
Unet results on Vitens case 2



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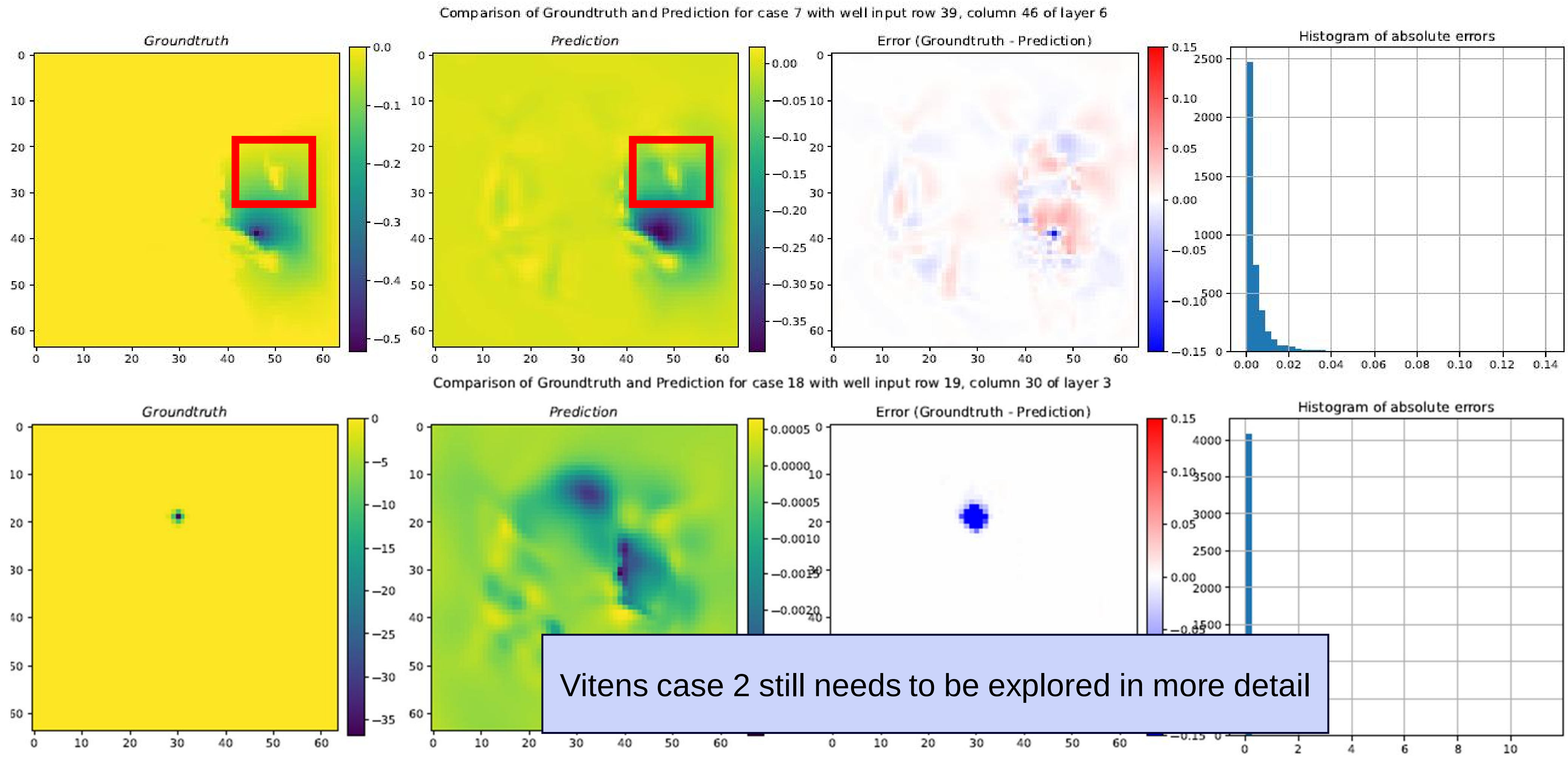
DON results on Vitens case 2



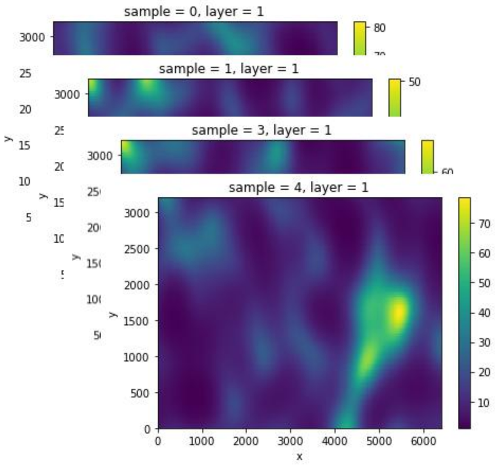
Vitens case 2 still needs to be explored in more detail

Case Studies

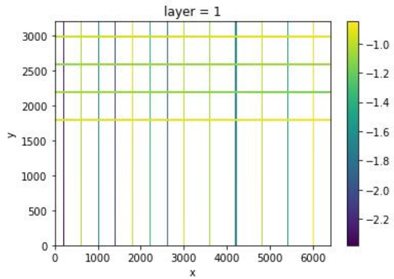
Permeability to steady-state – Hypothetical cases 1 & 4

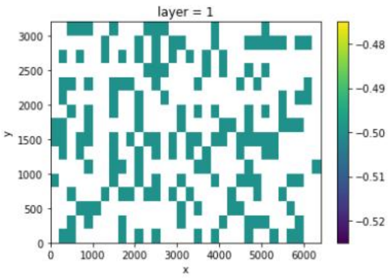
Hypothetical case 1 (steady-state)

Input:
- k-value
- 2D raster

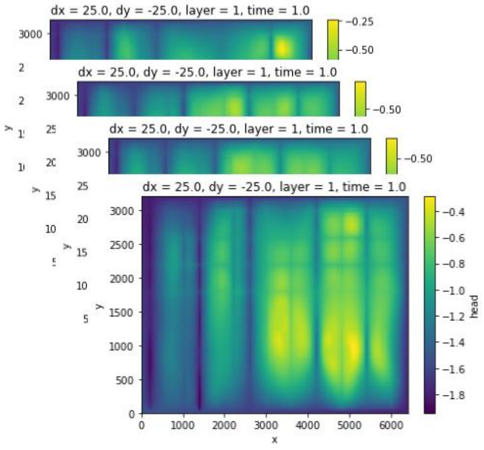


Model:
- Steady-state
- 128 x 256 x 1
- Structured network of rivers
- Random pattern of drains
- Surface run-off
- Transmissivity: see input

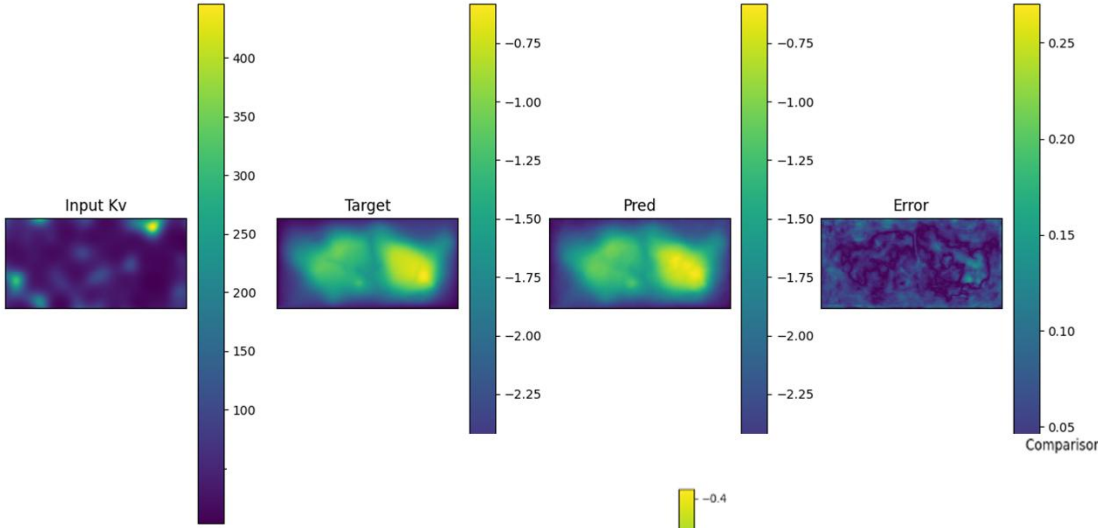




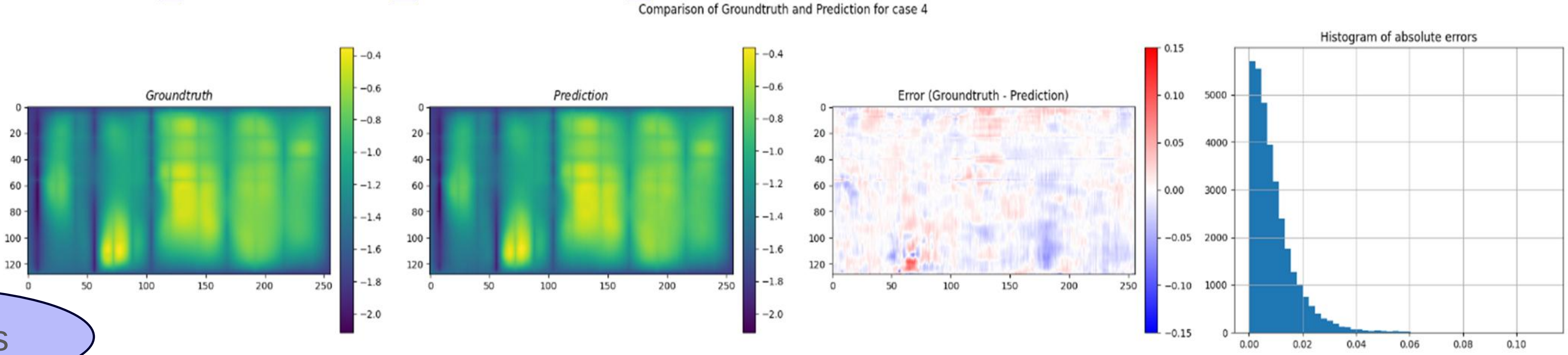
Output:
- head
- 2D raster



Hypothetical case 1 results



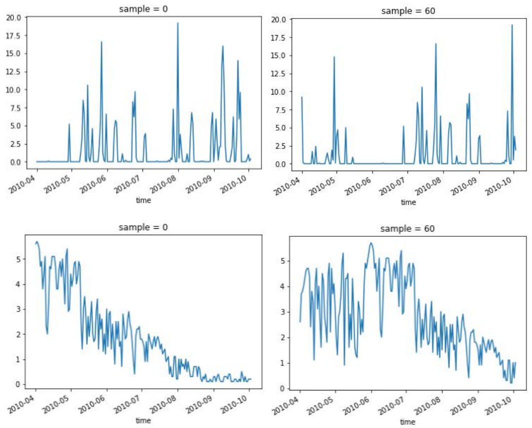
Unet results



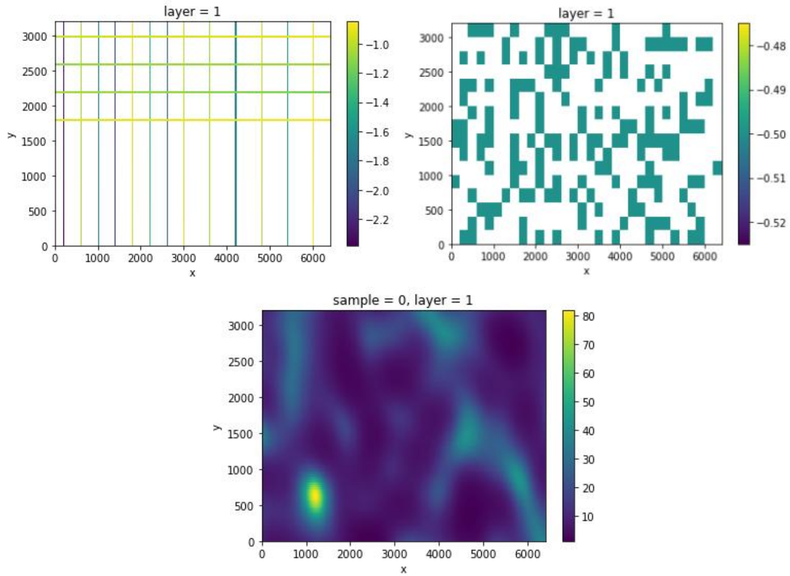
DON results

Hypothetical case 4 (transient) - head

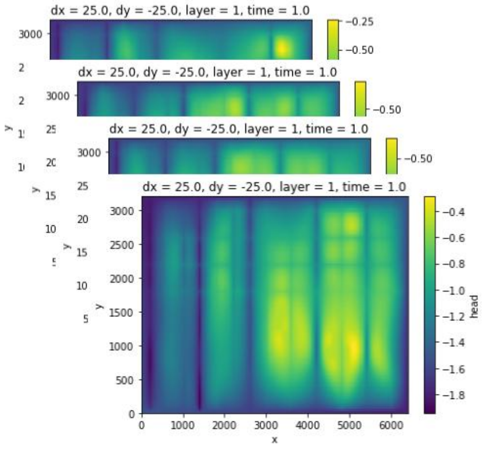
Input:
- Precipitation
- Evapotranspiration
- Time series
- Varying over time



Model:
- Transient
- 128 x 256 x 1
- Structured network of rivers
- Random pattern of drains
- Surface run-off
- Transmissivity: random field

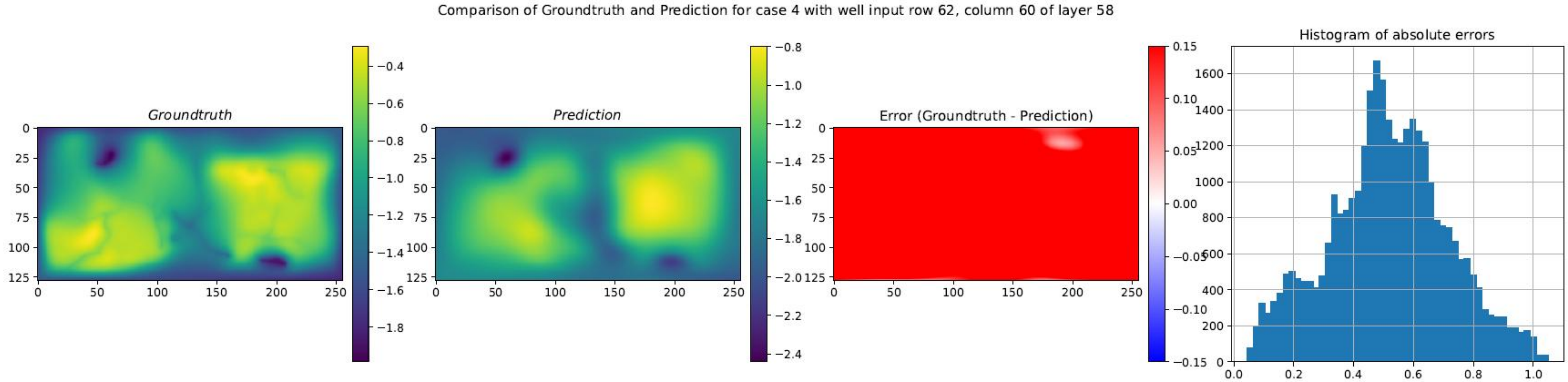


Output:
- Head
- T=[14, 31, 62, …, 184]
- 2D raster



Hypothetical case 4 results

- Flattened input: (128 x 256 permeability grid + 2 * 185 for the time series)
- Predictions for T = 14, using a DeepOnet



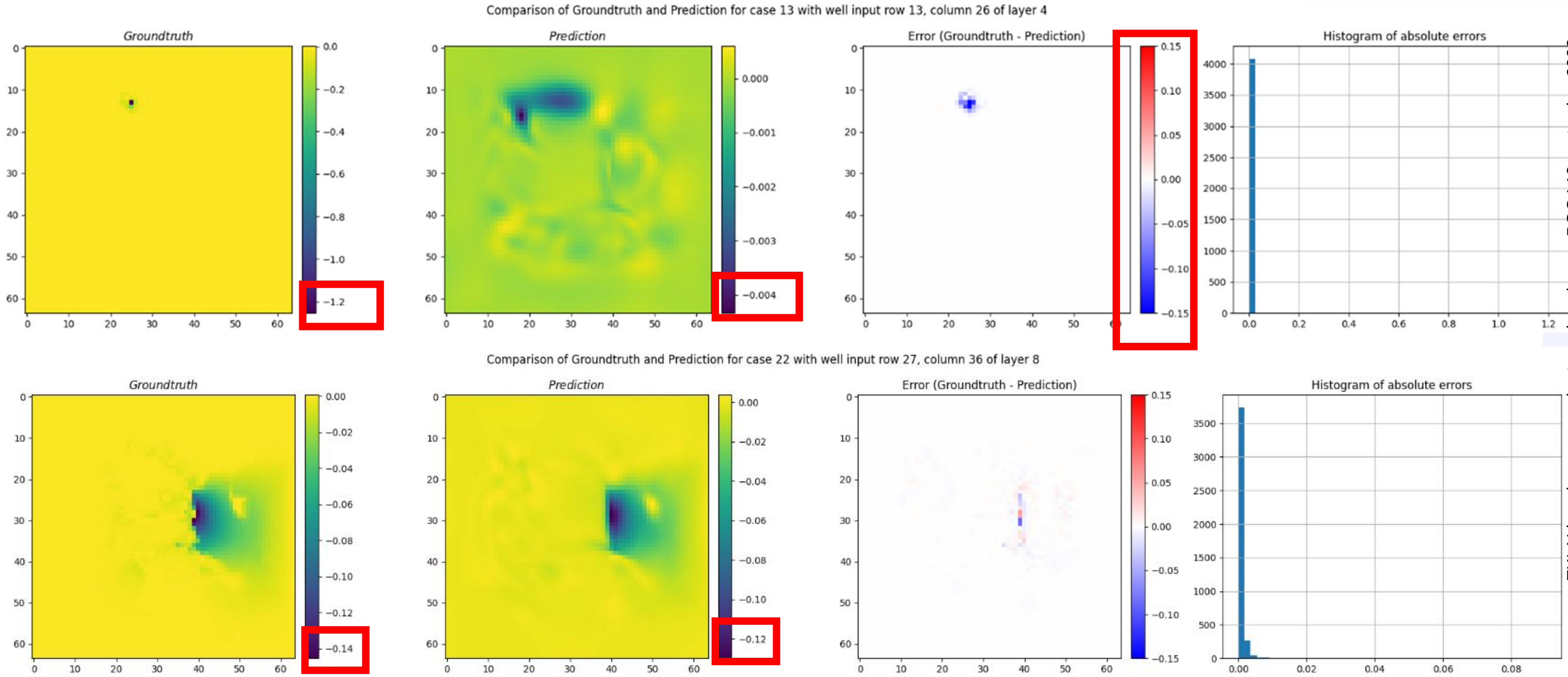
Flattening the gridded input probably leads to loss of spatial information → next step will be to alter DON for spatial + temporal input

Key takeaways - Discussion

Key takeaways

- Regarding Vitens case: drawdown predictions are more localised and, hence, give a better feel of the effect of Q
- DONs are performing better than the other alternatives in both predicting drawdowns or steady-state heads – however, detailed hyperparameter tuning might yield different results in the future
- Hyperparameter optimization for DON currently underway
  - More layers seem to be improving results
- Trade off between No. of sampling points, ANN layer depth VS RAM power
  - Google Collab
  - Larger machine

How accurate is accurate enough?



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Let’s Discuss

Agenda

1. Opening + vaststellen agenda	09:30 - 09:35	(5 min)
2. Notulen, acties, update projectplan n.a.v. vorig overleg	09:35 - 09:45	(10 min)
3. Stand van zaken t.a.v. techniekontwikkeling	09:45 - 10:45	(1 uur)
koffie / thee / even benen strekken	*10:45 - 10:55*	*(10 min)*
4. Hoe beoordelen we of een AI-simulatie goed genoeg is of niet?	10:55 - 11:05	(10 min)
5. Hoeveel budget te reserveren voor inzet 'cloud-hardware'?	11:05 - 11:15	(10 min)
6. Inplannen Machine Learning cursus	11:15 - 11:20	(5 min)
7. Afspraken en volgend projectgroepoverleg	11:20 - 11:25	(5 min)
8. Rondvraag en afsluiting	11:25 - 11:30	(5 min)

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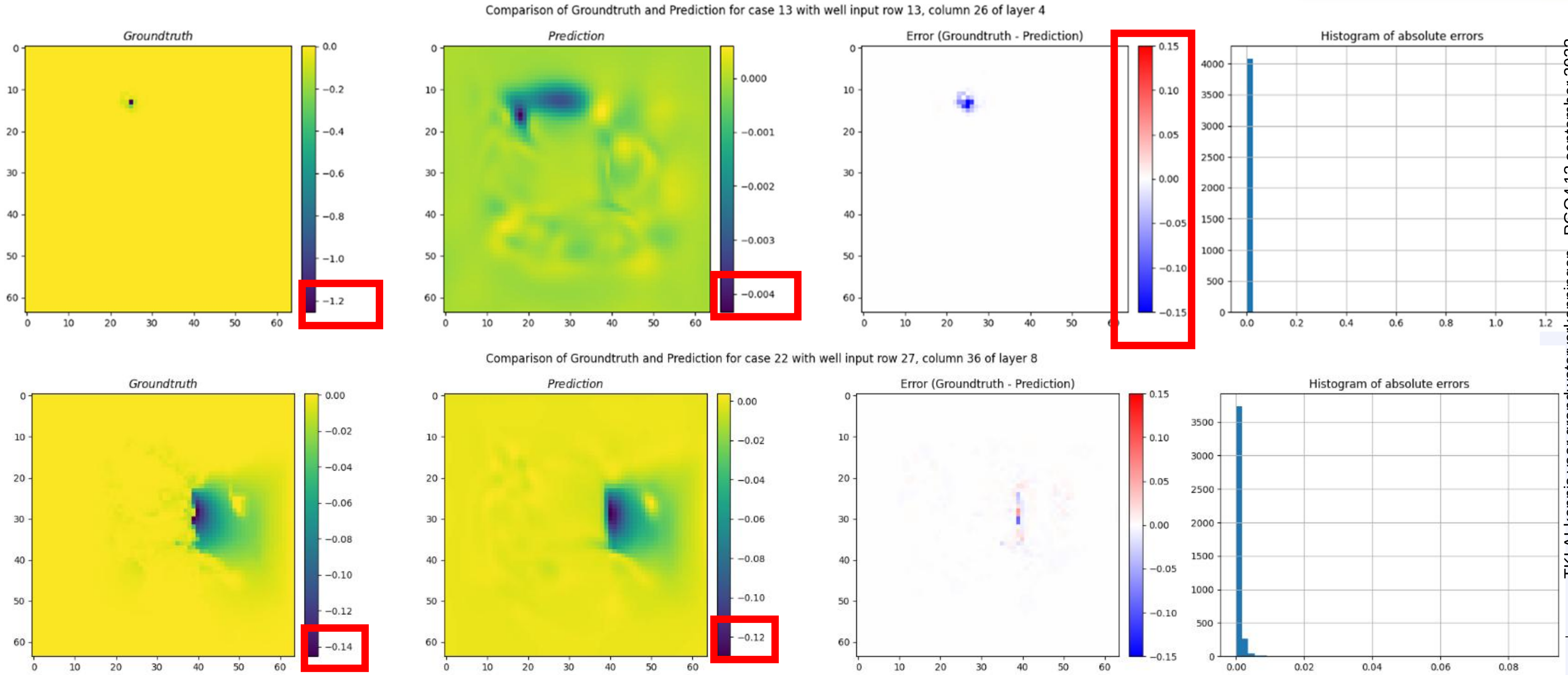
4. Hoe beoordelen of een AI-simulatie goed genoeg is of niet?

How accurate is accurate enough?



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5. Hoeveel budget te reserveren voor inzet ‘cloud-hardware’?

Aanpak nu:

- Focus op NN-technieken onder de knie krijgen voor relatief kleine sommen in combinatie met Google Colab
- Zodra we voldoende ervaring met o.a. de hyperparameter settings hebben gaan we opschalen naar grotere modellen.

Maarr, opschalen naar de cloud betekent ook meer rekenkosten:

- Amazon: prijs varieert van ~ 1 – 28 USD per uur, afhankelijk van hardware-eisen, dus we moeten zuinig zijn.

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6. Inplannen Machine Learning cursus voor projectgroepleden

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7. Afspraken en volgend projectgroepoverleg

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8. **Rondvraag en afsluiting**	11:25 - 11:30 (5 min)

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8. Rondvraag en afsluiting

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