AI tasting: An overview of Artificial Intelligence applications in hydraulic engineering

Flood Defence Resilience

Juan Pablo Aguilar-López

Hydraulic Engineering Department

HSFR section

Assistant Prof. on Flood Defence Resilience

TU Delft

Who am I

•Born in Bogotá-Colombia 9-12-1981.

• I'm a civil engineer.
COLOMBIAN SCHOOL OF ENGINEERING (2005)

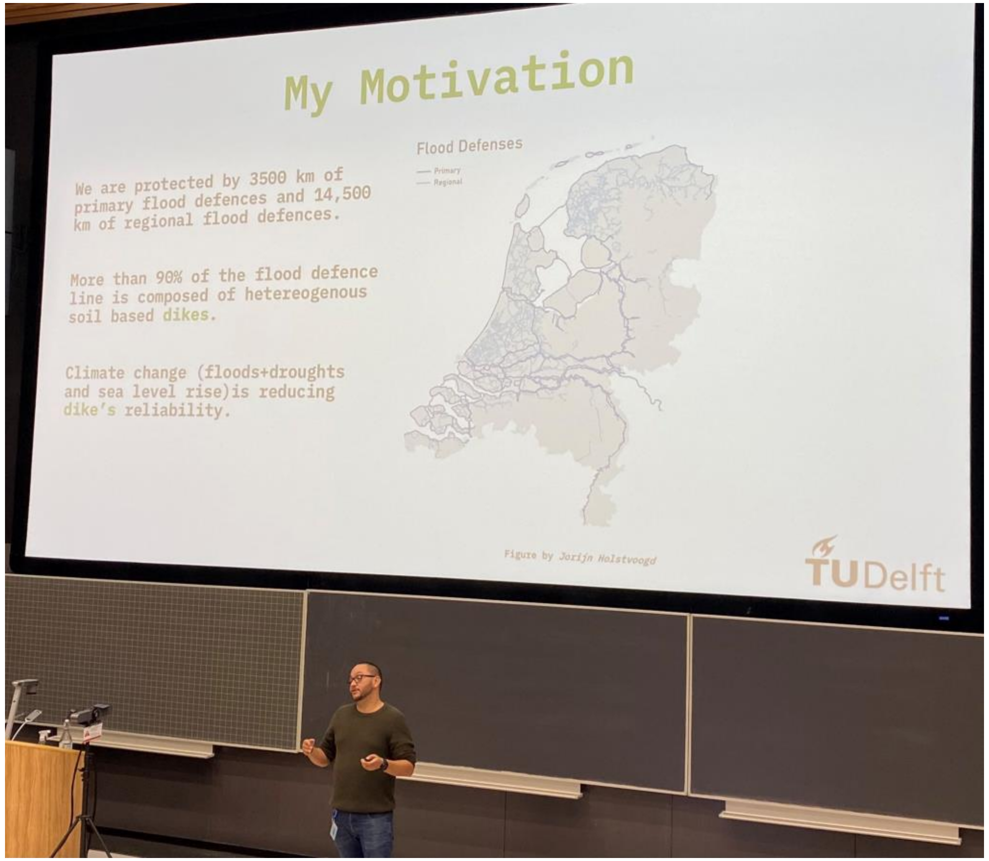
• Specialized in Hydraulics + Hydrology.
COLOMBIAN SCHOOL OF ENGINEERING (2007)

• MSc. Hydro-informatics.
UNESCO-IHE (2009)

• PhD. On Probabilistic design of Multi-functional dikes
Twente University (2016)

• Assistant Professor on Flood Defence Resilience
Delft University of Technology (2020)

• Aim to be head of a research group on
dikes + floods + AI + Sensors.



Hydraulic engineering systems are complex but with AI we can try to imitate (surrogate) them !

4 Questions / 4 Examples

a) Where to place pressure sensors to predict Backward Erosion Piping ?
AI Method: PCA

b) Which dikes are more prone to develop drought induced cracks?
AI Method: (Random Forest) Decision Trees

c) How to make a fully probabilistic flood model ?
AI Method: LSTM Deep learning Convolution Encoder-Decoders

d) How to detect cracks with distributed temperature fiber optic sensors ?
AI Method: Convolutional Deep Learning Encoders

Ongoing AI related research at Flood Defence Resilience Group

Case a: Where and how many pressure head (Hp) sensors to predict/monitor Backward Erosion Piping (BEP) ?

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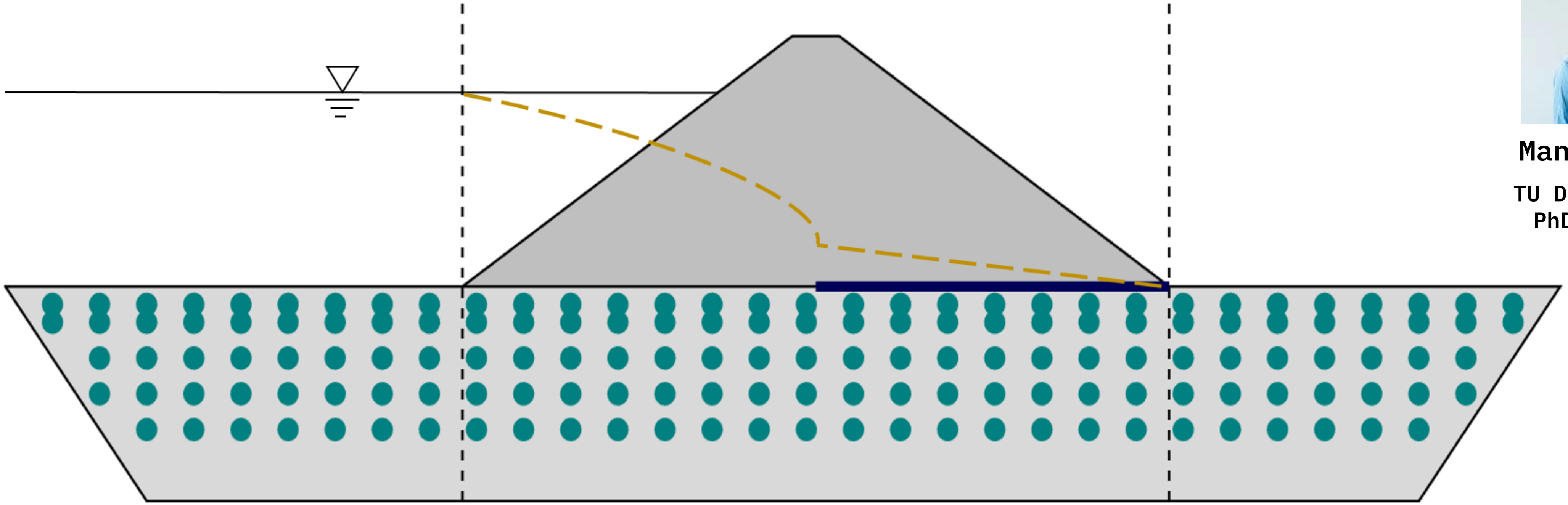

Manuel Wewer

TU Dresden / TUD
PhD Candidate

?

GOAL: To predict the erosion progression based on pressure sensors !

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We proposed a time dependent physically based piping model

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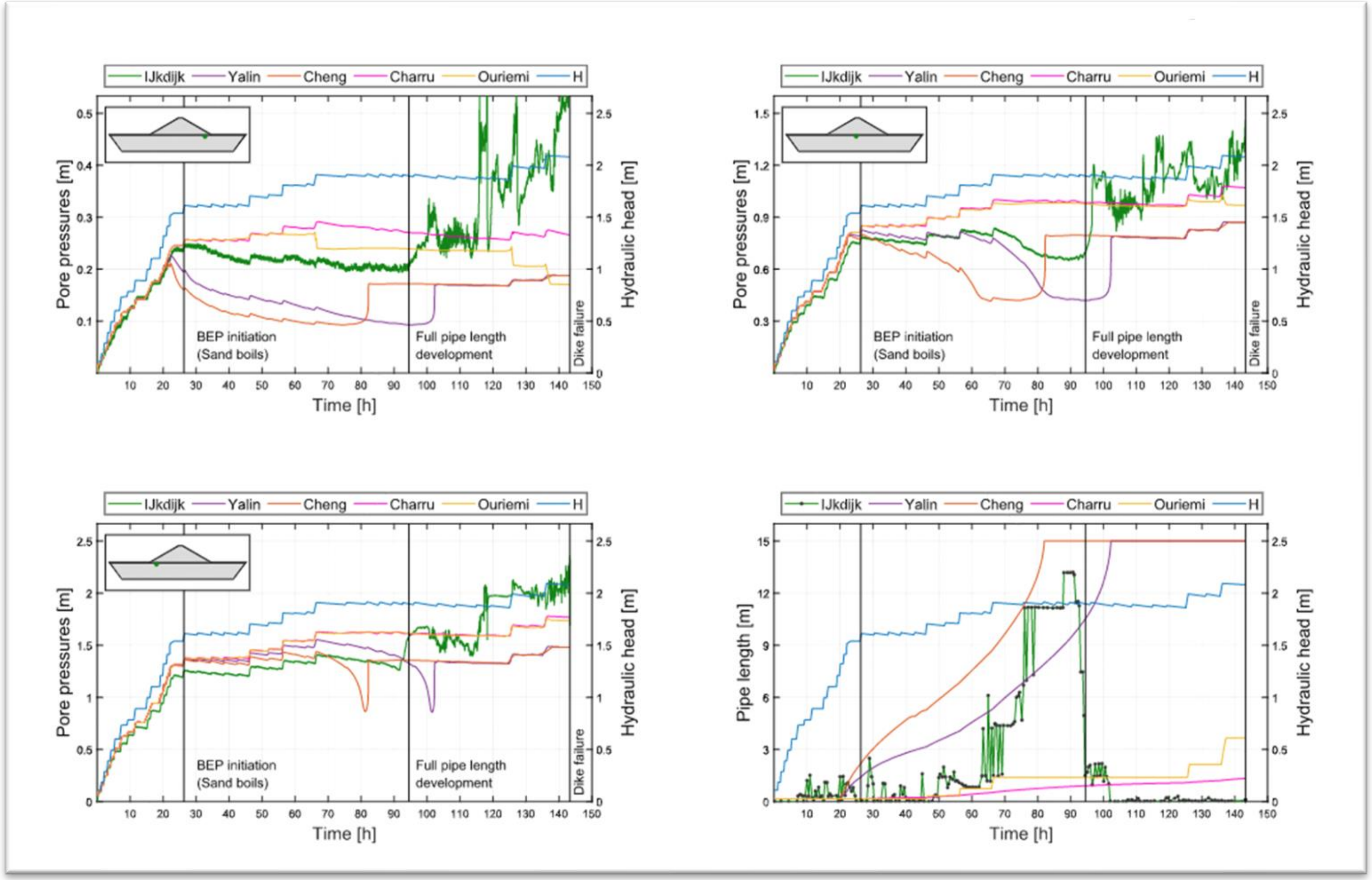
A transient backward erosion piping model based on laminar flow transport equations. Wewer, M., Aguilar-López, J. P., Kok, M., & Bogaard, T. (2021). Computers and Geotechnics, 132, 103992 - https://doi.org/10.1016/j.compgeo.2020.103992

But it takes too long to run !

(Ijkdijk experiment simulation was 3 hours)



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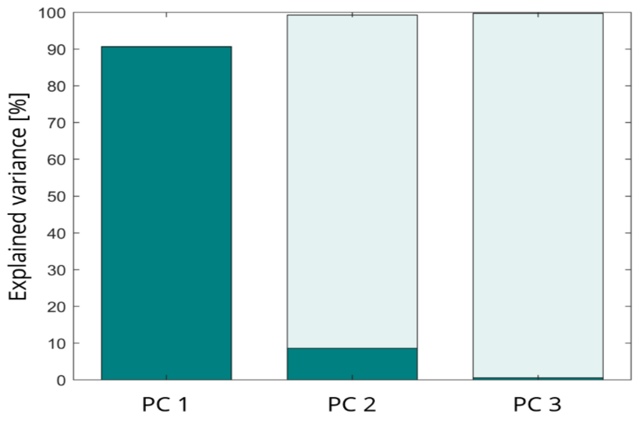
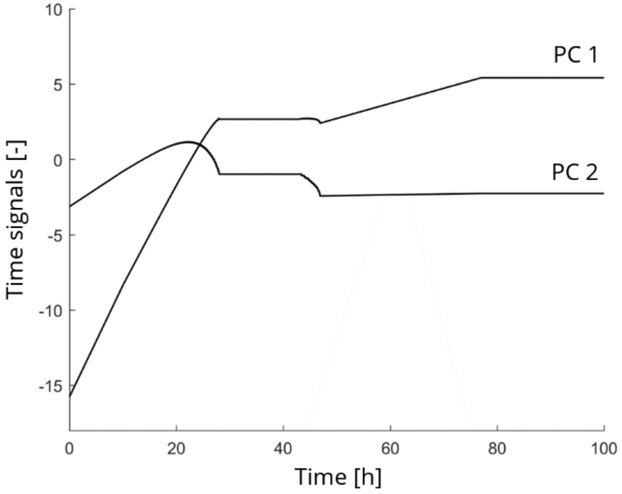
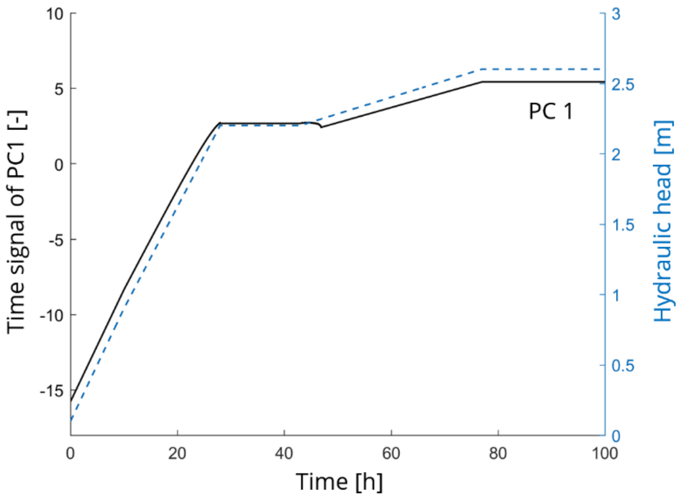
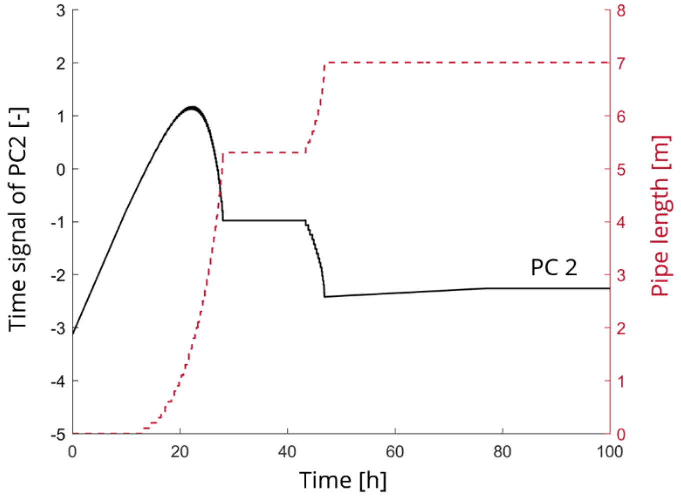
We use PCA to find the main signals of the problem





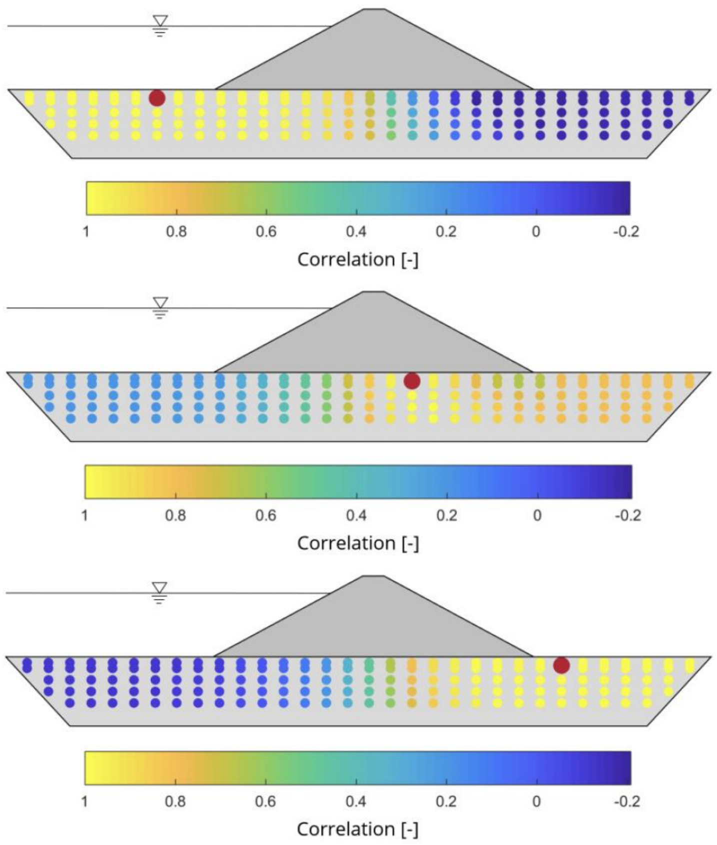
1. We Determine PCA's in time





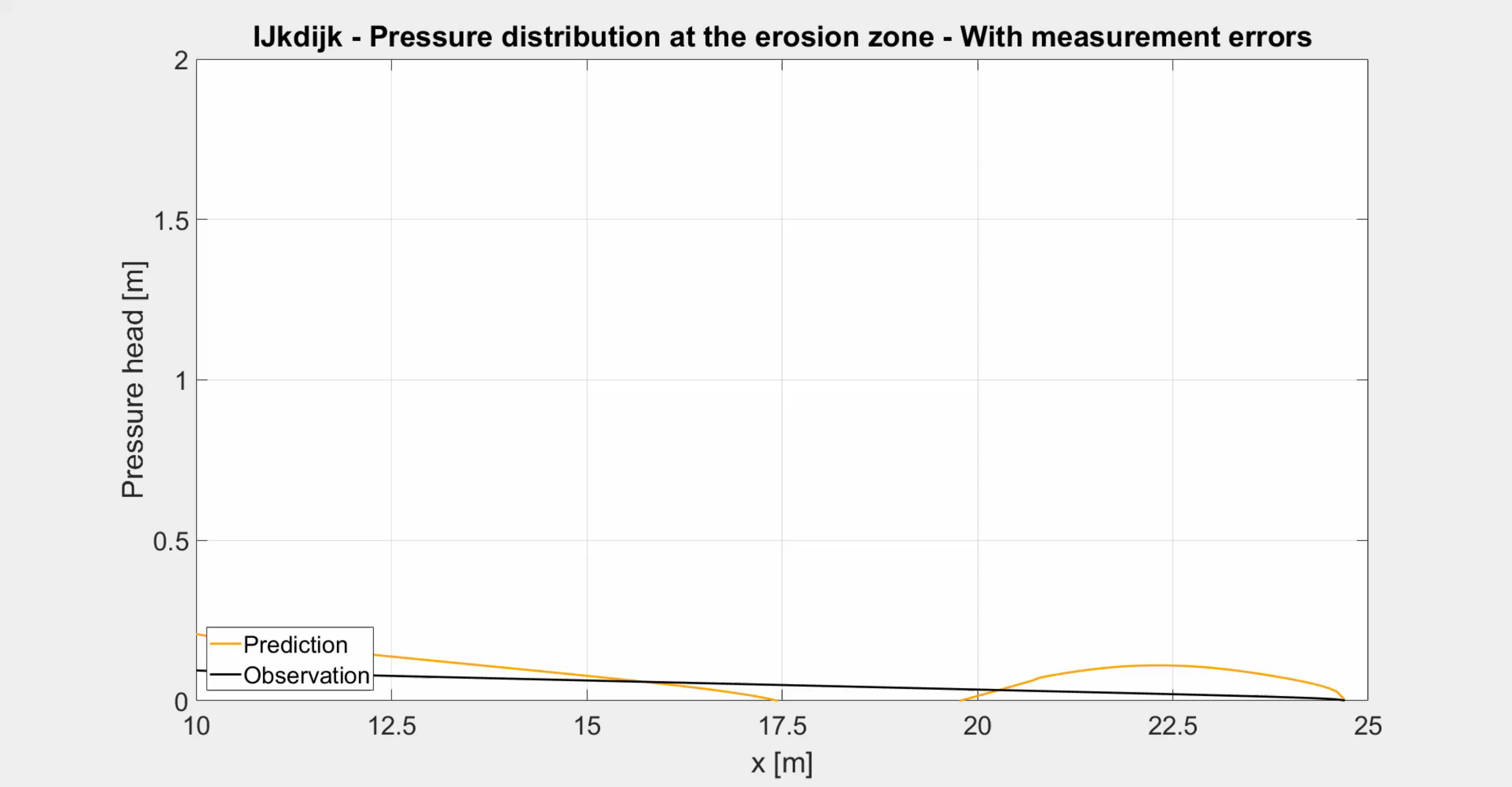
2. We found PCA's vs BEP

Rijkswaterstaat and Waterboard friendly results ☺



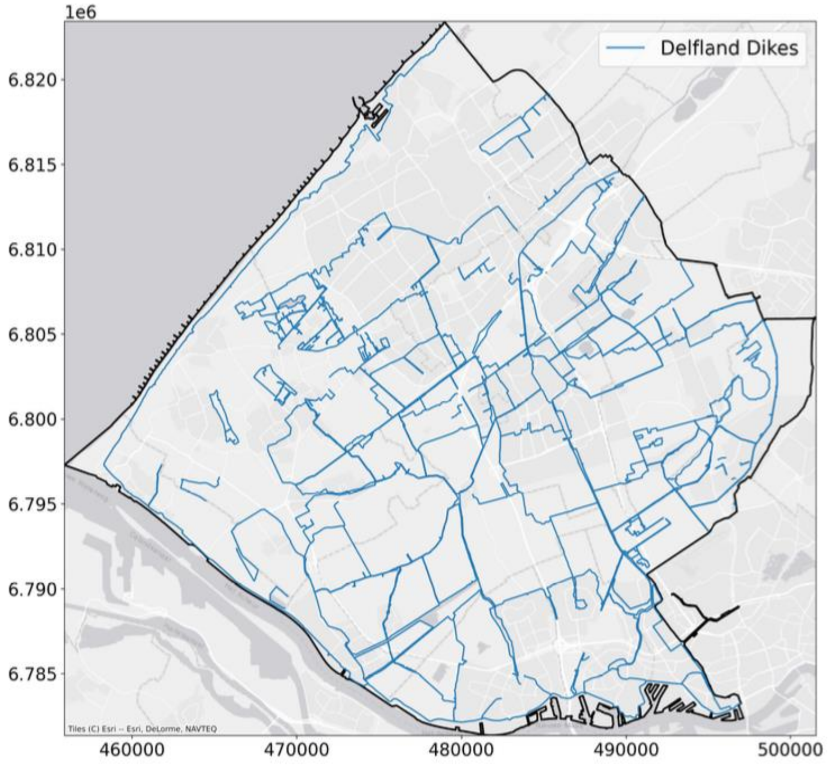
3. We searched the best sensor combination for PCA

Sensor + PCA vs Actual BEP-FEM



We can predict backward erosion piping in 2D in real time with just two sensors !!!

Case b: Which dikes are more prone to develop drought induced cracks?



Shaniel Chotkan

Royal Haskoning DHV

Let’s use PROXY variables to try to predic observations !

Chotkan, Shaniel, et al. "**A data-driven method for identifying drought-induced crack-prone levees based on decision trees.**" Sustainability 14.11 (2022): 6820.

We collected other data come from different sensors at different resolutions.

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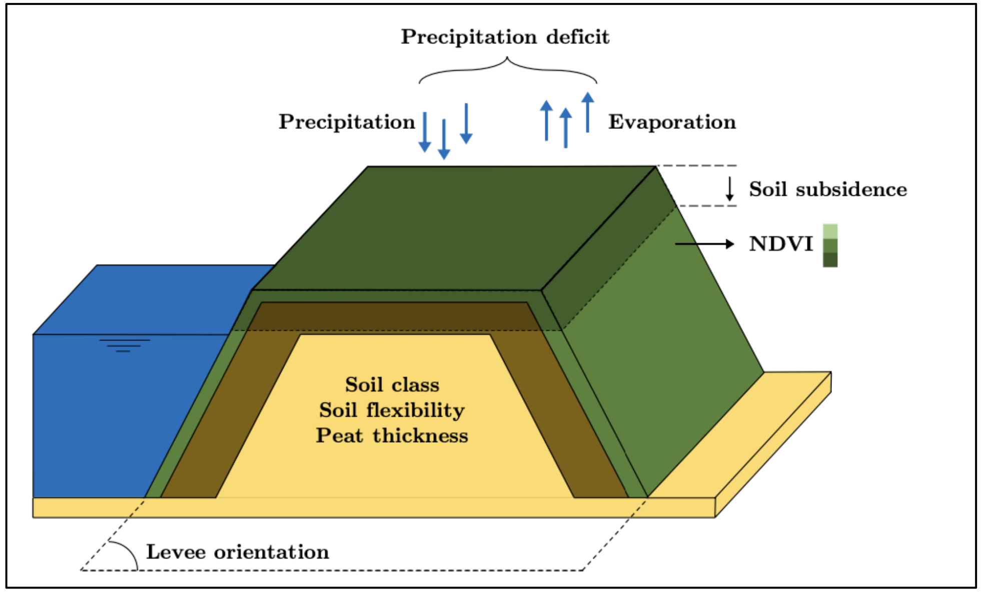
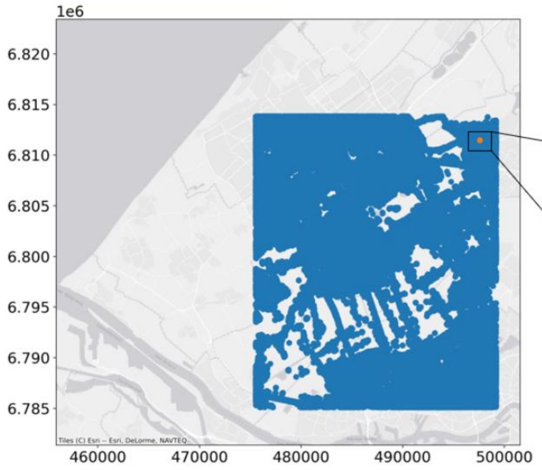
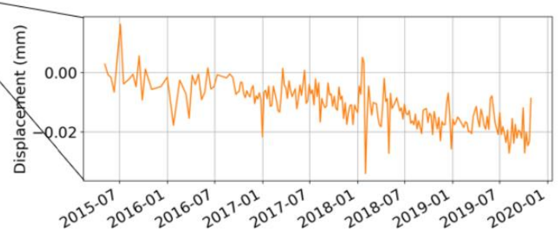
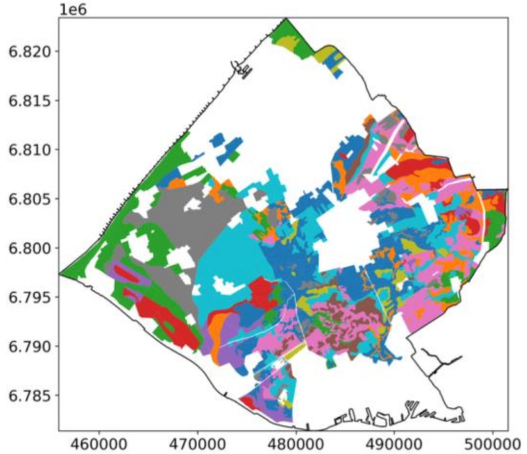


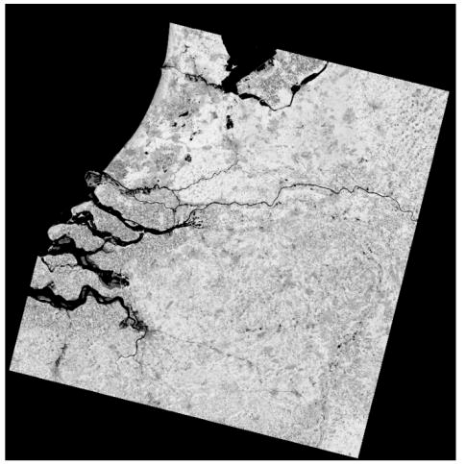




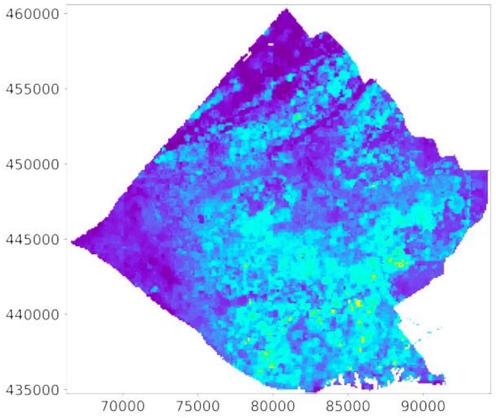
Subsidence – InSar 300x300 m2
6 days –BODEMDALINGSKAART
(1.4 days average)



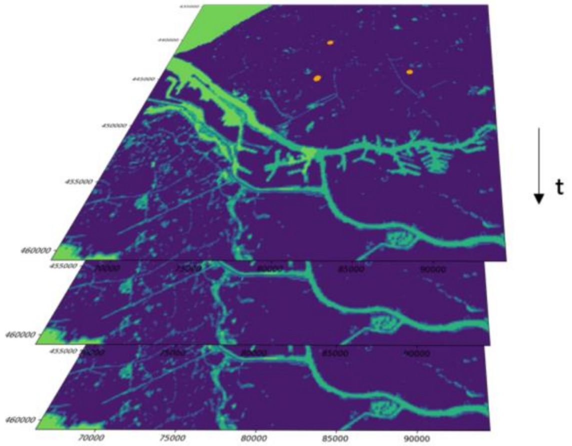
Soil Map (Peat)
(Constant 1x1 Km)



NDVI – Landsat bands 4 and 5
- 30X30 mts – 16 days



Soil Flexibility
(Estimated Deformation)
100x100 mts



Evaporation and Precipitation
(Interpolated Raster from
Points at 10 minutes)

We trained 2 Random forest models for hazard mapping with all data

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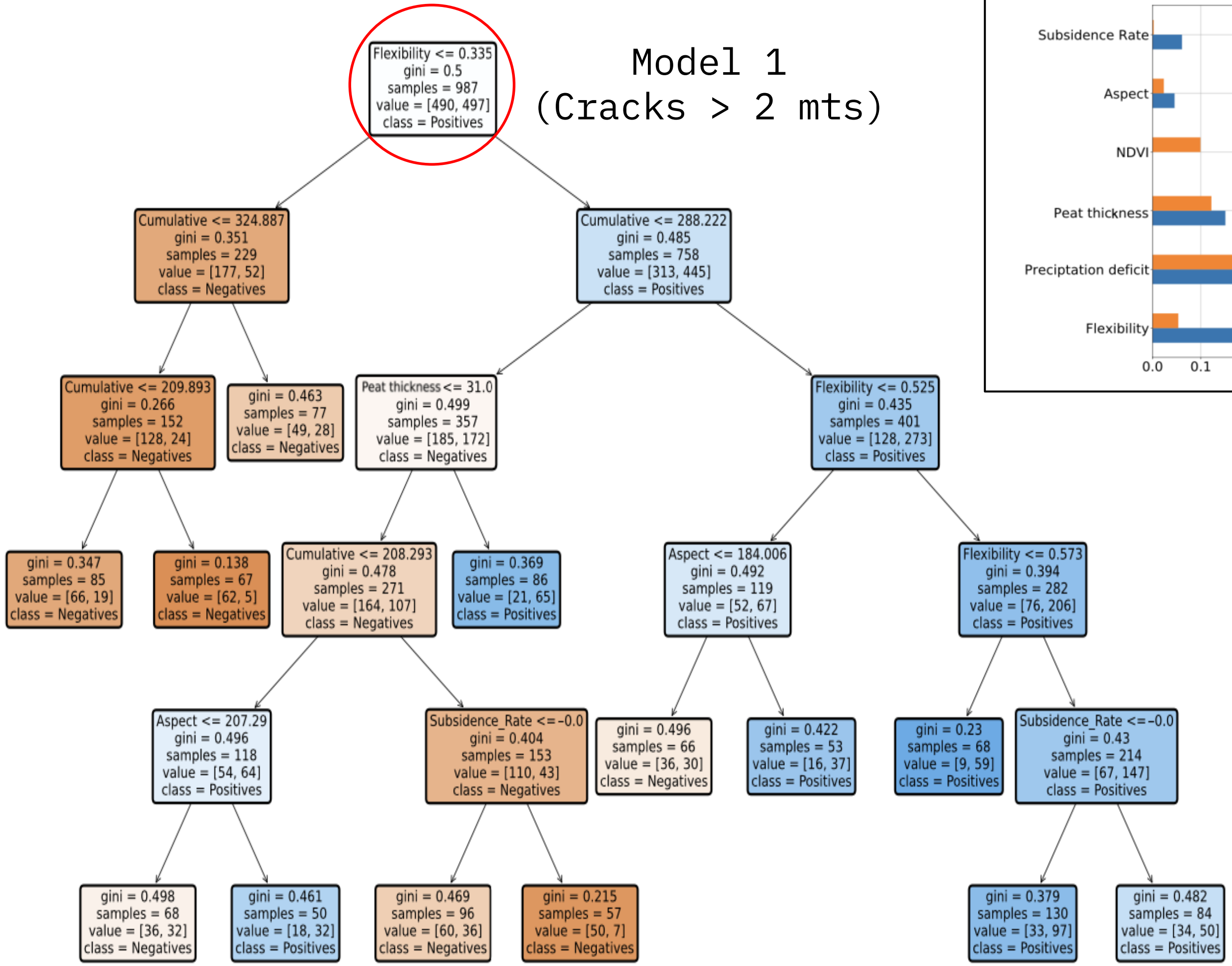
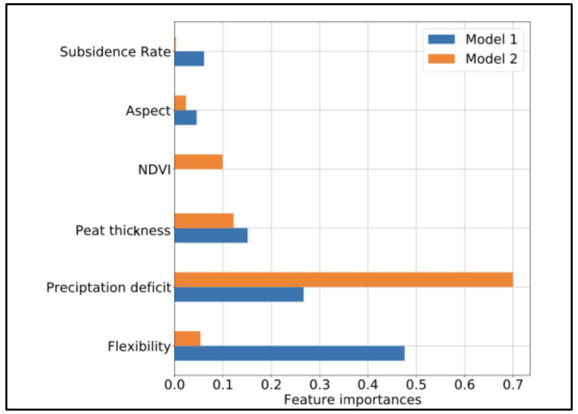
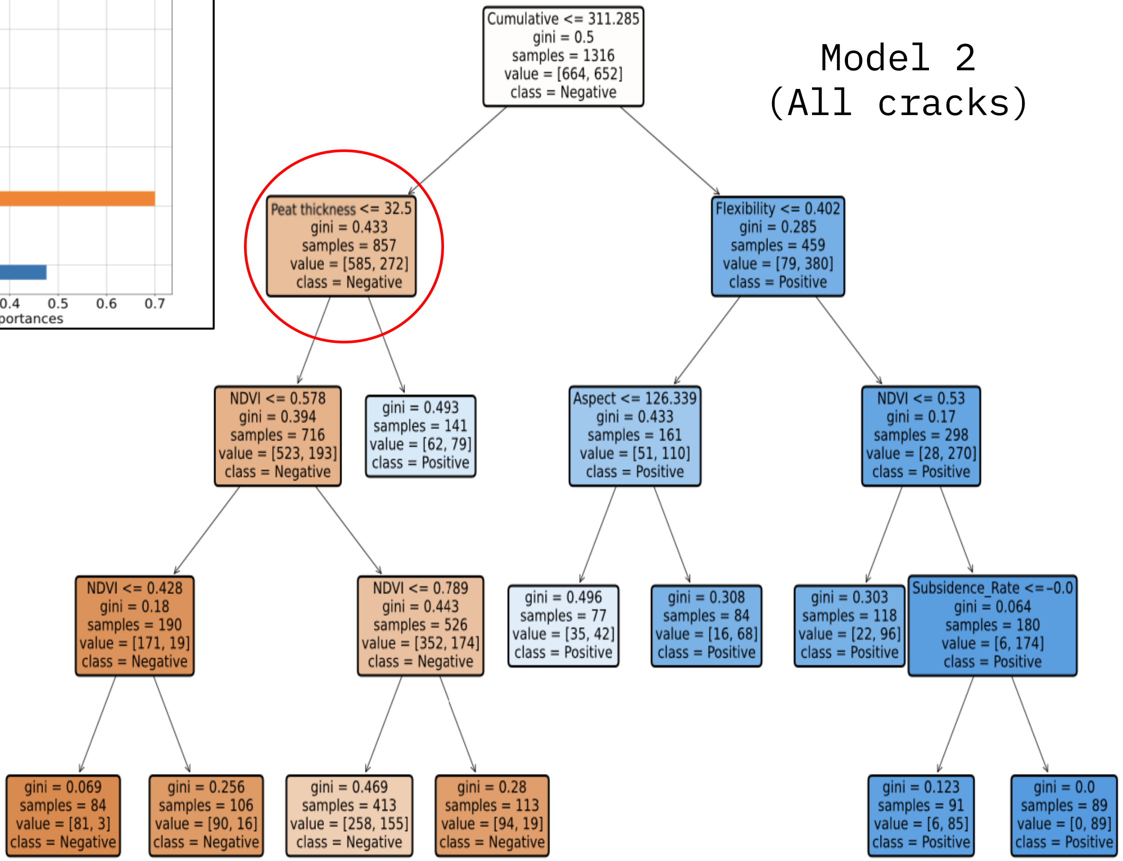
Model 1
(Cracks > 2 mts)





Model 2
(All cracks)



Model 1: Cracks larger than 2 meters are not observed on soil bodies characterized by a **low flexibility** (0.335m/kPa).

Model 2: Cracks mostly occur on dikes founded in thick peat layers (>32.5 cm).

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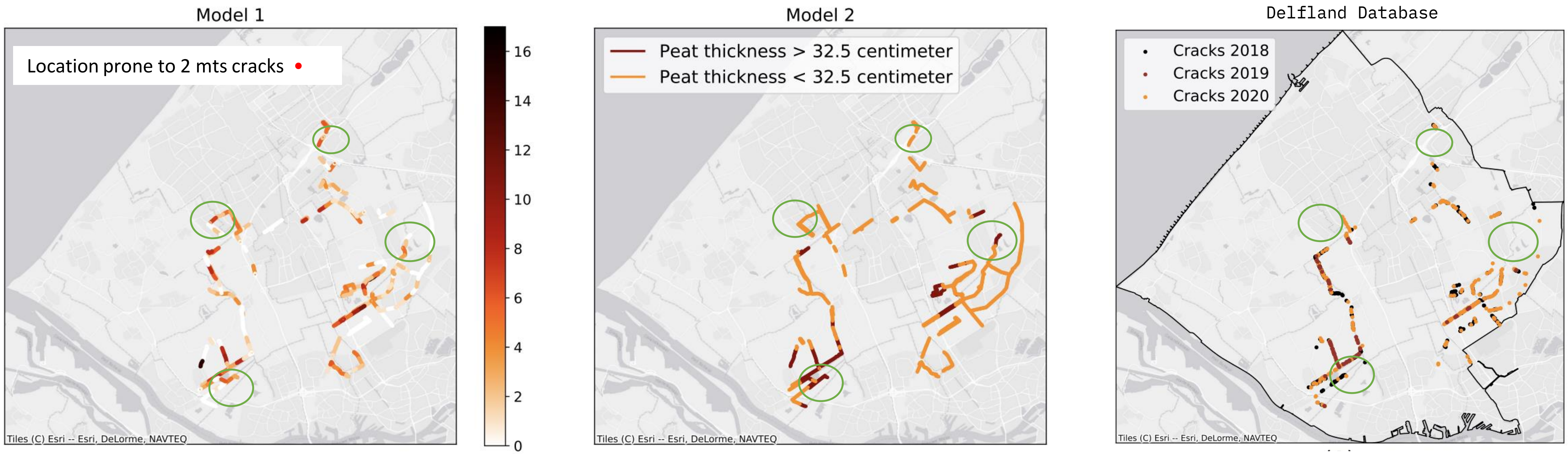
This is how the maps look like and what we found !



(Cracks > 2 mts)

(All size cracks)

Decision tress showed us that:

- Long cracks are not observed on levees for flexibility was smaller than 0.355 m/kPa.
- Long cracks (longer than 2mts) are more often found on levees of which the slope is oriented towards the southern side.
- Both model trees state that a peat thickness of the upper layer of at least 31 cm indicates that levees are susceptible to the formation of cracks.
- Levees composed of soils which have peat layers thinner than 31 cm do not seem to crack for precipitation deficit values lower than 311 mm.

Case C: How to make fully probabilistic flood modeling?

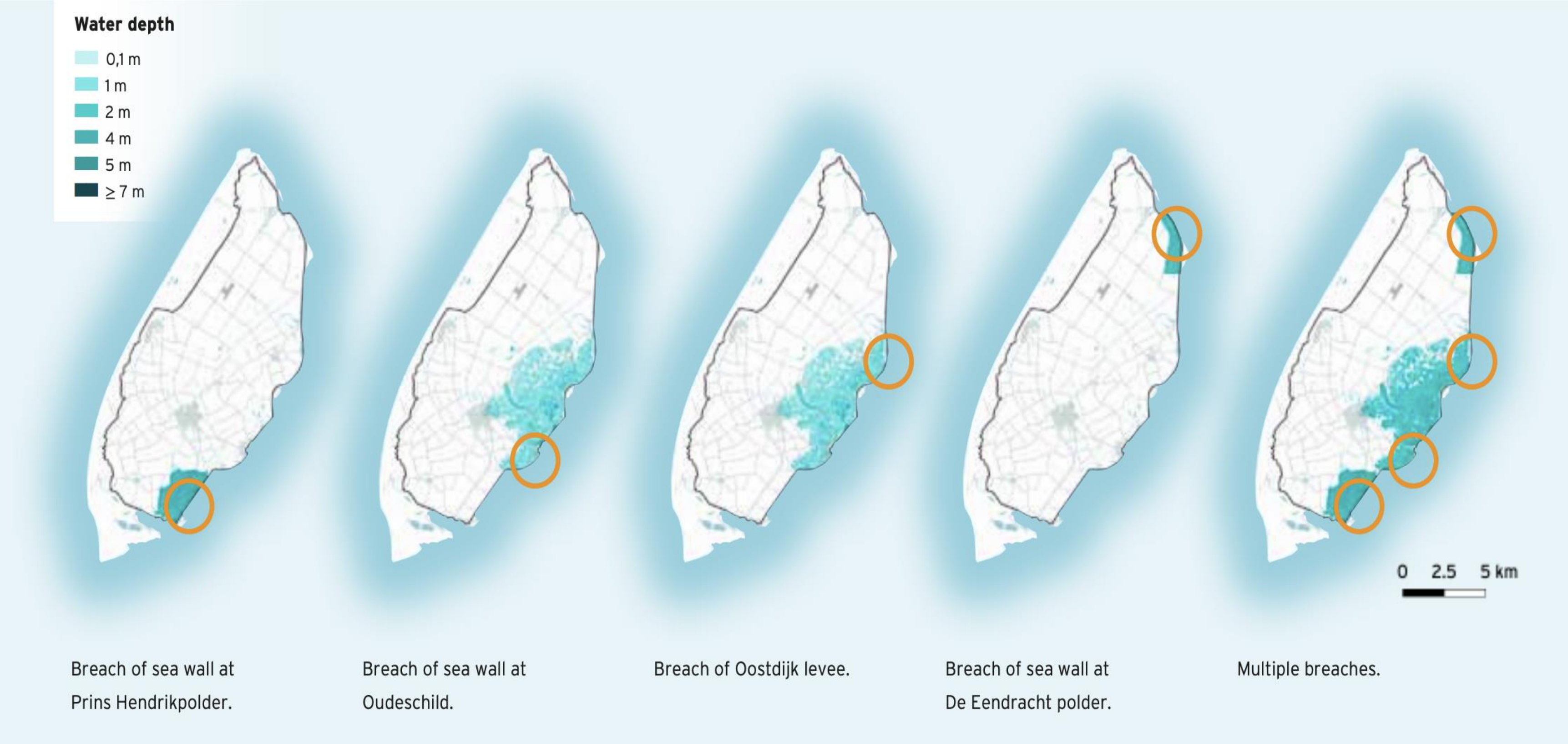


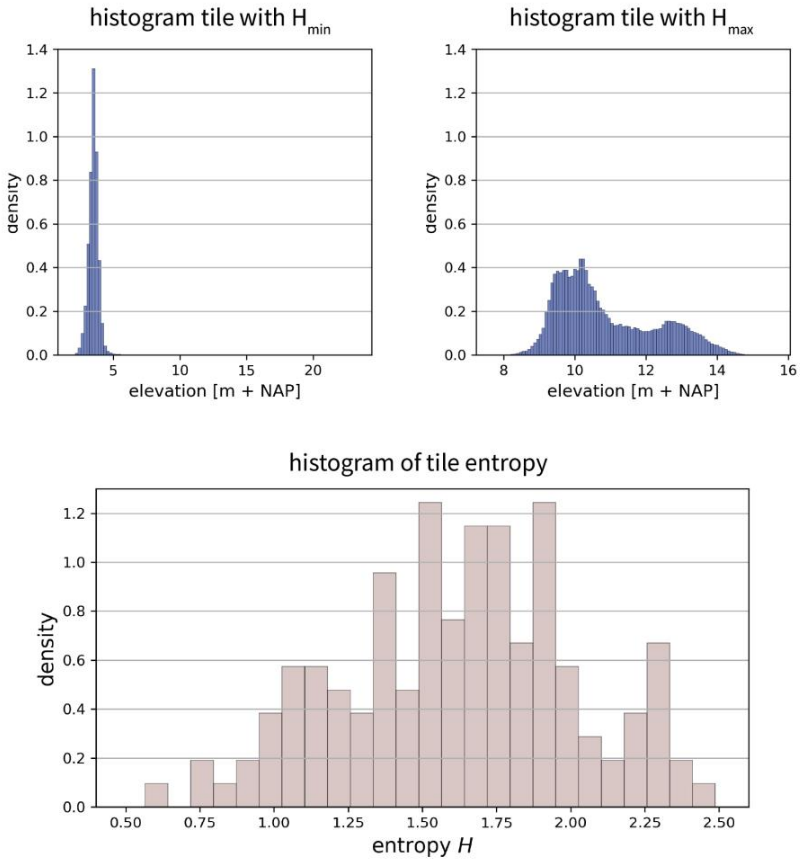
Image from : VNK2 – Veiligheid Nederland in Kaart (Oversromingrisico Dijkring 5 (Texel))

Thomas Stolp

HKV

" **Deep learning-based surrogate modelling for 2D flood simulation**" MSc Thesis Thomas Stolp (2021) – TU Delft – Available on the TU Delft repository.

We sampled terrain tiles all around NL and flood them with different hydrographs.

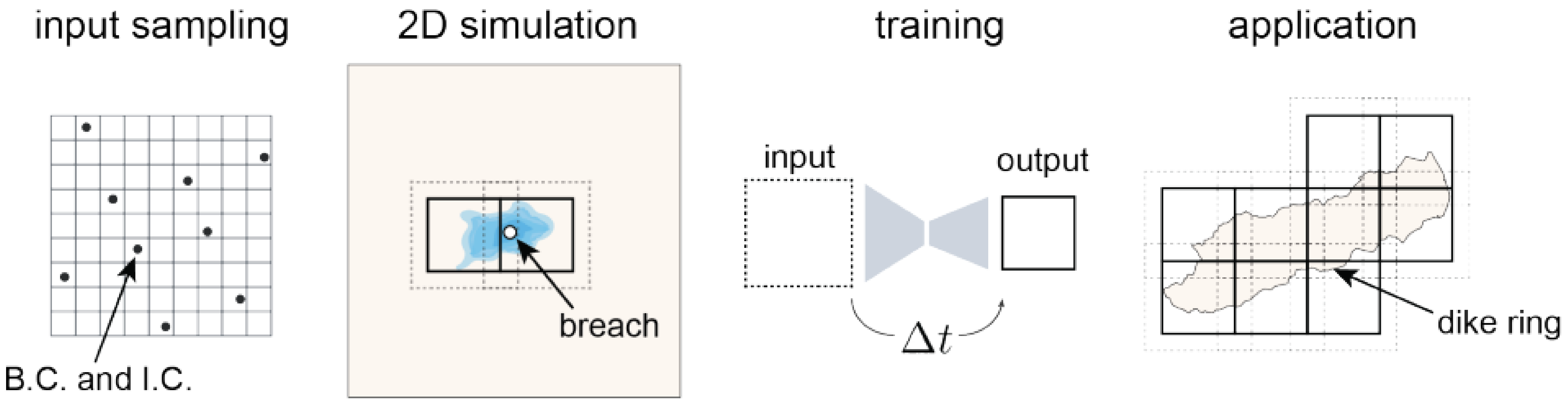


Tons of random simulations of breaches are available already.

And we generated even more based on topographical variation.

Lots of work …

What is the flood modeling surrogate method ?



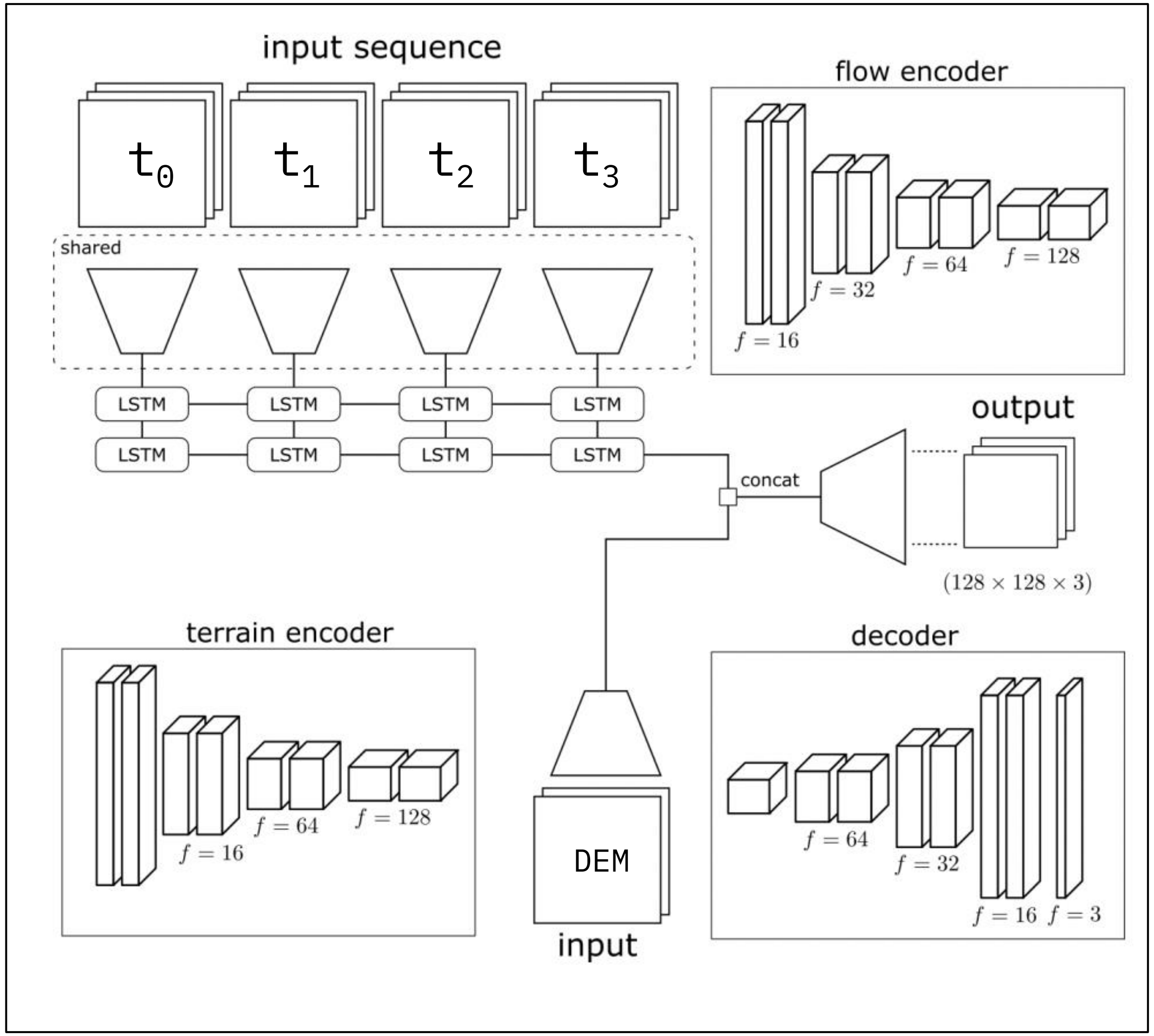
1. Sampling tiles from Digital elevation Models.

2. Flood models in different breach points and different hydrographs.

3. Test different Deep Learning models (CAE and Unet) based on time stepping lagging.

4. Solve the model full domain with a "Patching" algorithm.

The results look promising, but we are far …



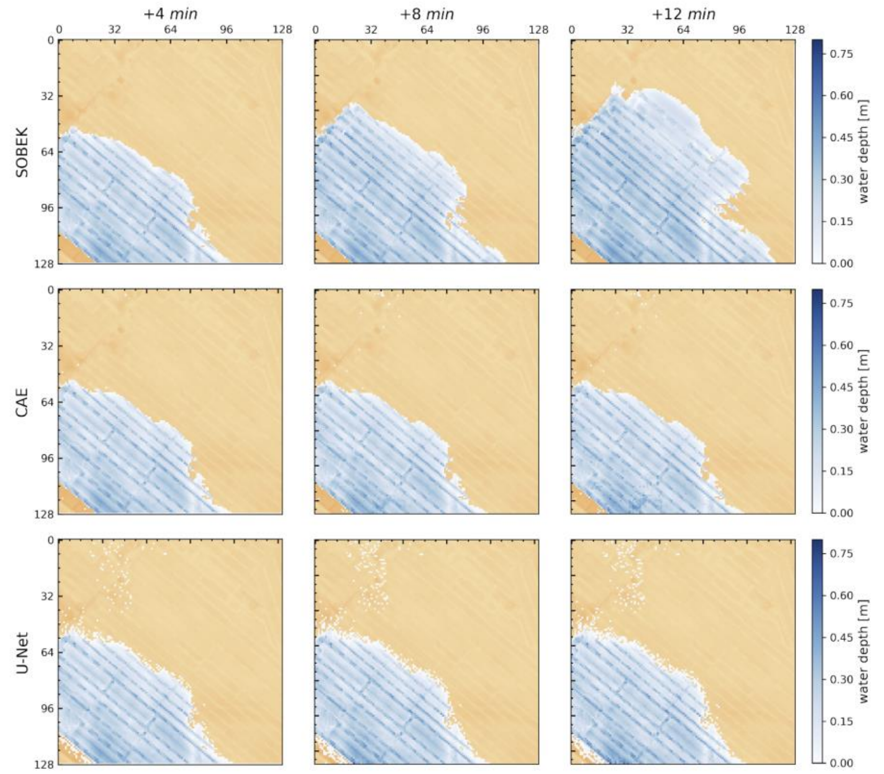
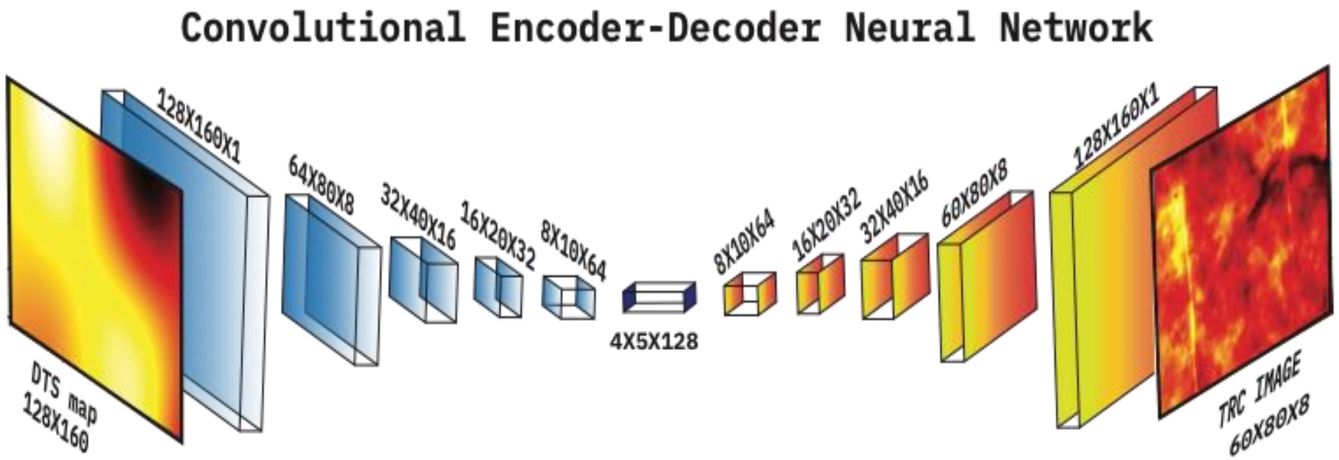


Figure 6.14: **Water depth predictions for a flow patch in the test simulation**. Here a begin time $t_0 = 50\ min$ is used and the 4, 8 and 12 minute forecast is presented.

A hydrodynamic model that doesn't follow its fundamental laws (Mass conservation and Momentum) is useless … But we know so much new stuff to improve !

Case d: How to detect desiccation cracks in dikes with FOS and deep learning algorithms?



Leonardo Duarte

TUDELFT -GeoSciences

Simone de Roos

Witteveen+Bos

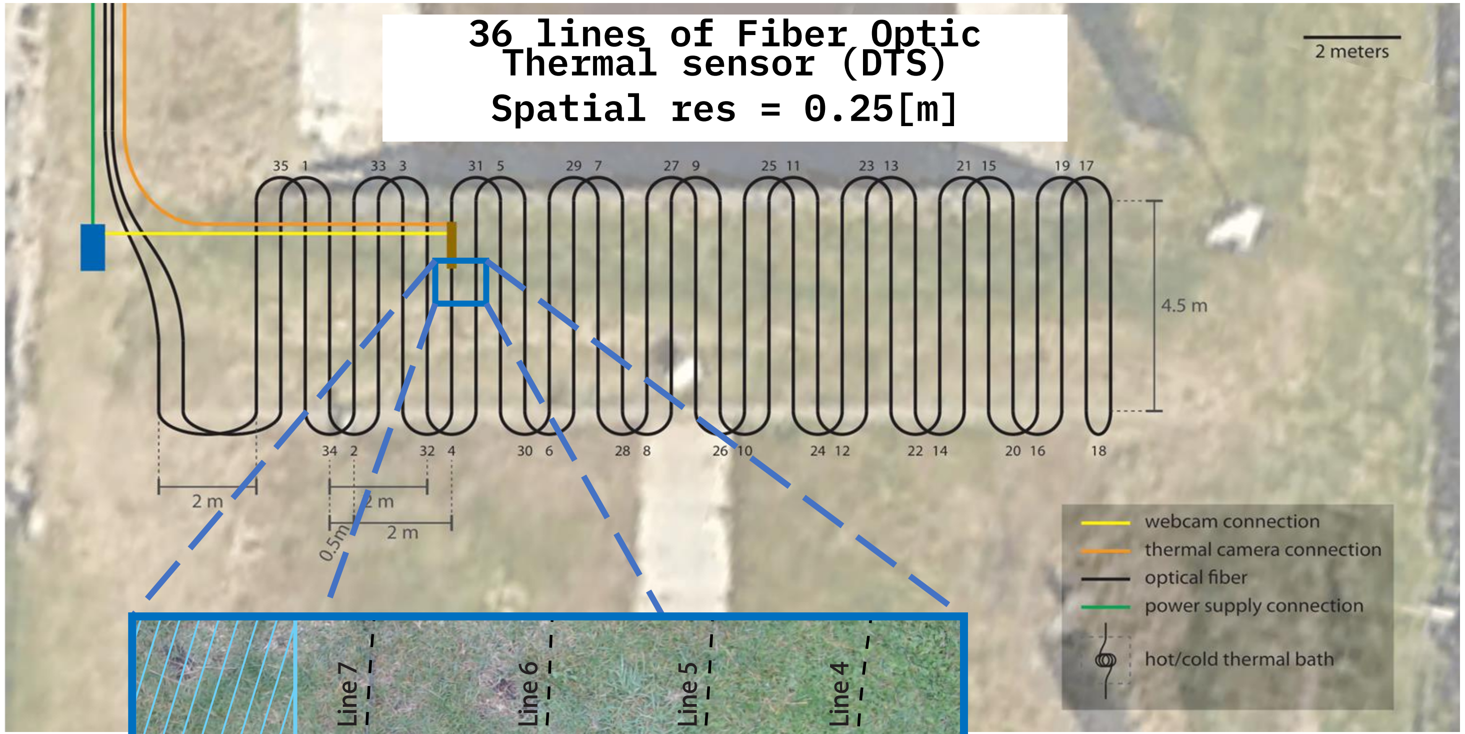
"**Crack detection for dikes using distributed temperature sesnsing**" MSc Thesis Simone de Roos (2022) – TU Delft

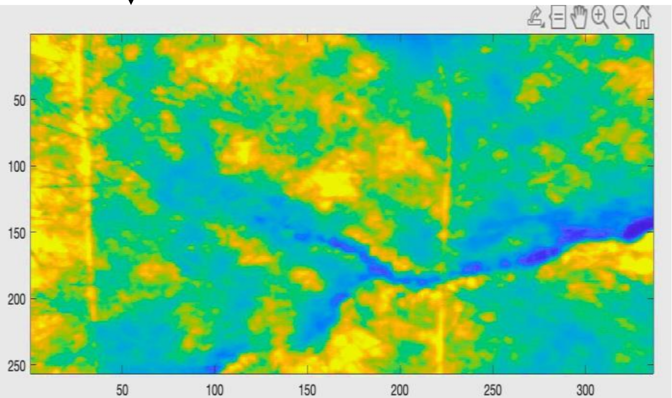
De Roos, Simone, et al. "**Understanding the thermal response of an unburied fiber-optic sensor for dike cracks detection.**" submitted to – Sensors Journal 2022.

Grant No. NWA.1228.192.258 Idea Generator (50k€) "Crack detection with FOS and DL"

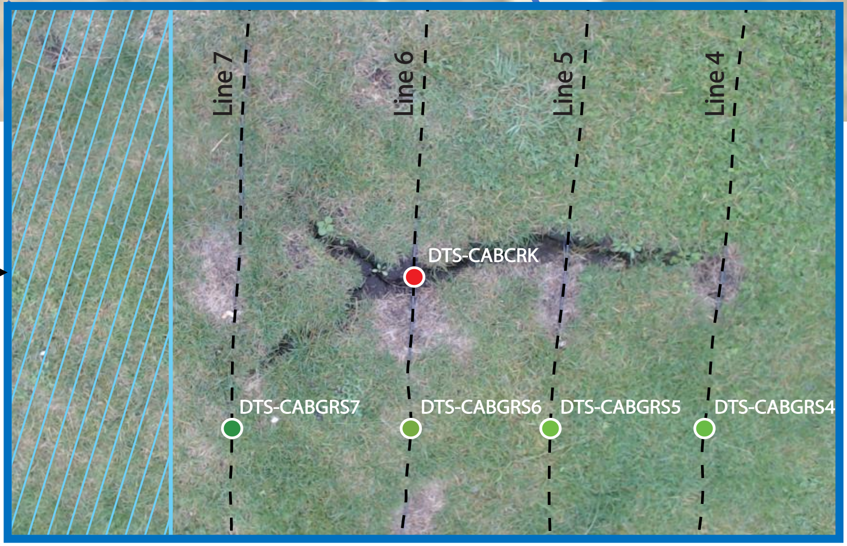
We monitored a dike with a crack for 3 months

Thermal camara (320x256)



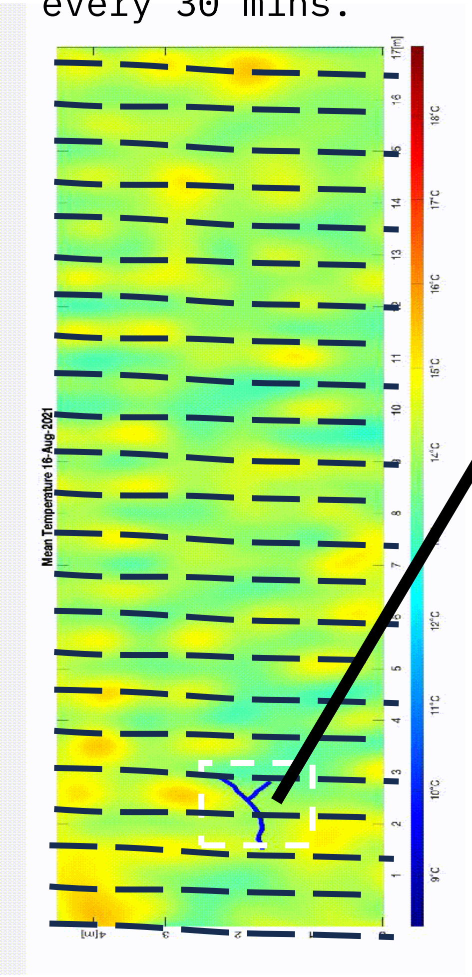


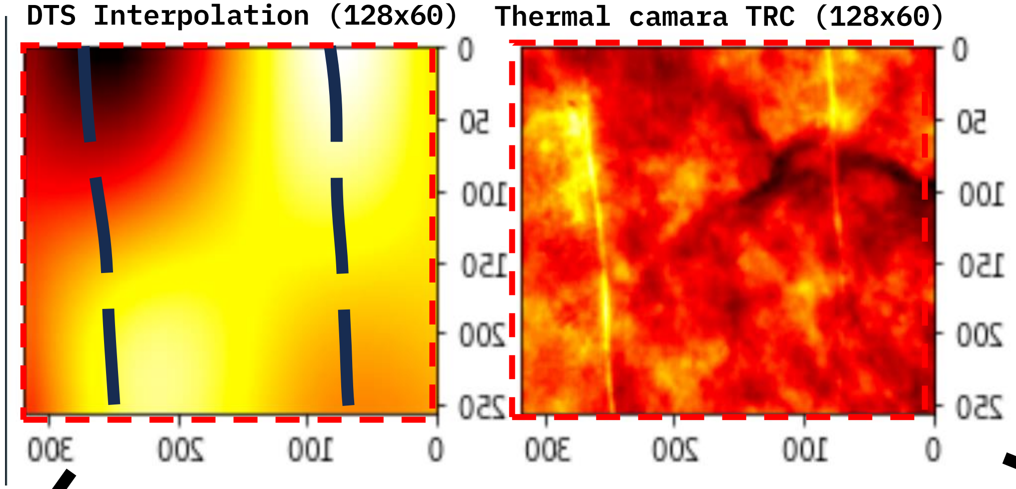
4 Webcams



Sensor-2-Image method

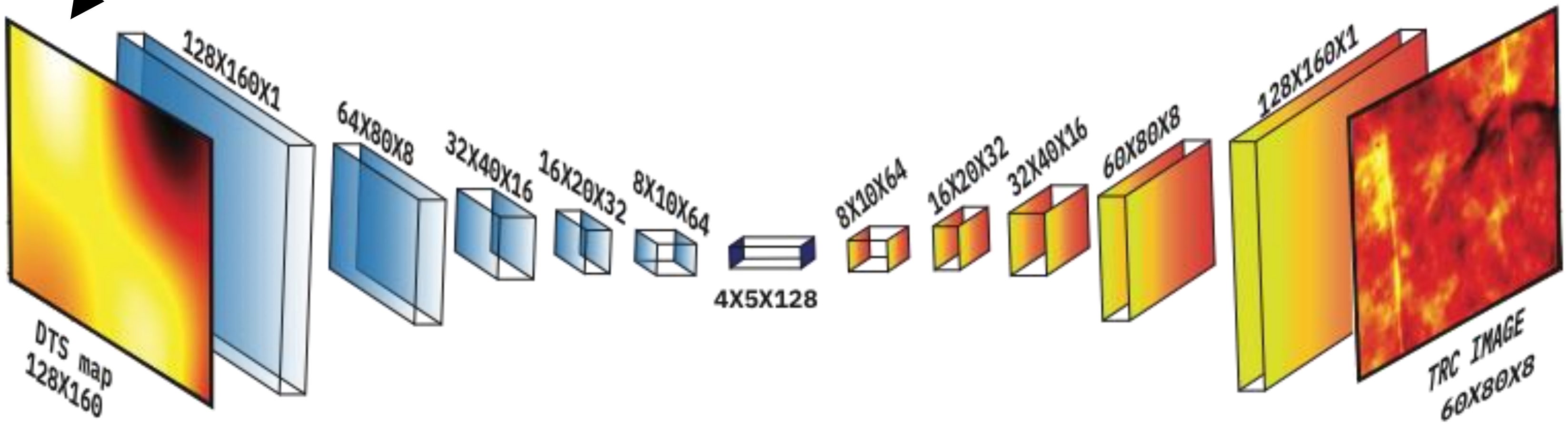
1. We generate A interpolated map of DTS cable temperature every 30 mins.





2. We cut all thermal images (TRC) (128X60) and DTS map in the same location (Data augmentation). Original image is 256X320.

Convolutional Encoder-Decoder Neural Network



3. We trained a Convolutional Encode-Decoder Deep learning algorithm to predict TRC images from DTS sensor interpolations.

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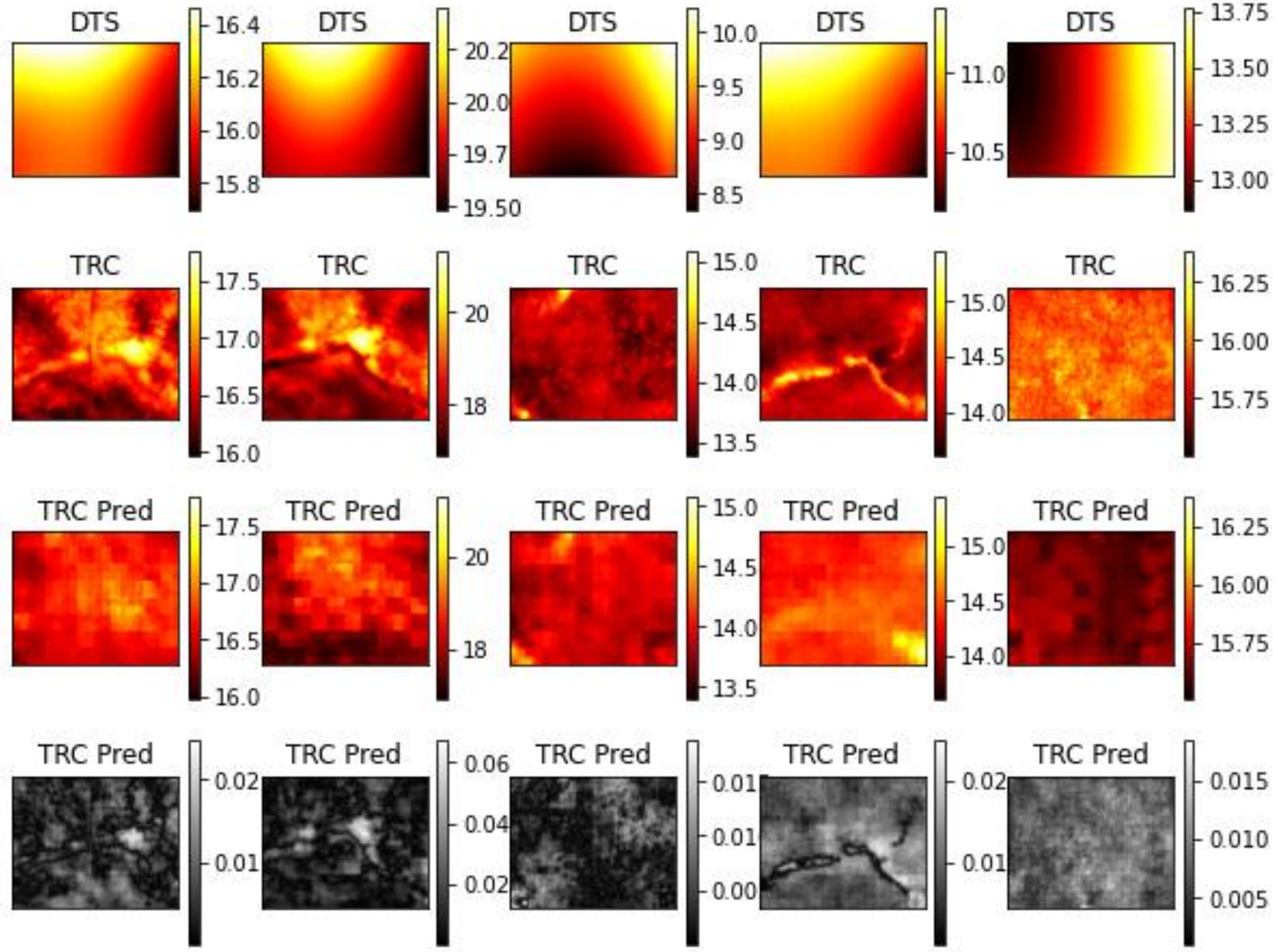
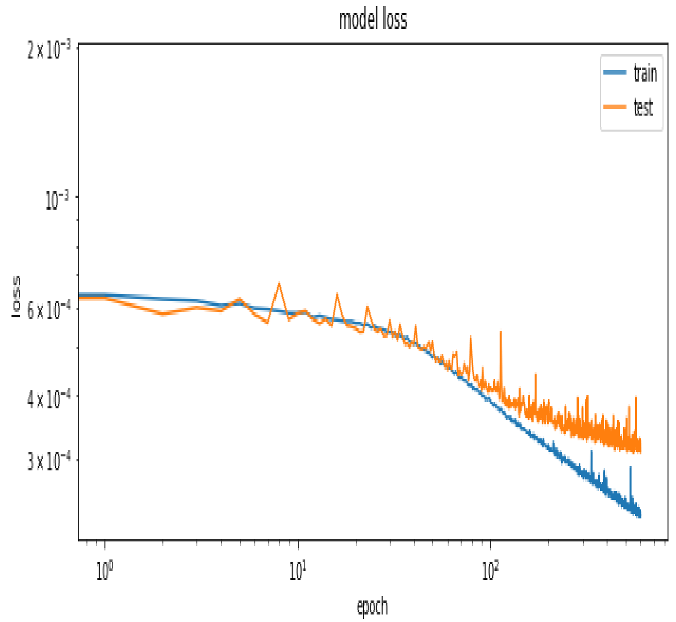
The results are promising but more training and datasets are needed.





We set training for 1000 epocs and finished early in 602 epocs with a mean error in predictions of around 1.4 degrees Celcius.

People to make it happen

Wouter Schrama

Wave Overtopping

Deep learning (Finishing MSc Thesis)

Surrogate ML model for Hydropower Ecological Resilience (PhD)

Ir. Jairo Villada

Piping erosion

Numerical modeling (PhD)

Ir. Lisa van der Linde (TU Delft)

Ir. Manuel Wewer (TU Dresden)

Piping erosion Physical Modeling (PhD)

Ir. Anton van der Meer (TU Delft)

Dike Deformation Monitoring (PhD)

Ir. Saul Buitrago (TU Delft)

Deep Learning Flood Modelling (PhD)

Ir. Chimango Mweso (TU Delft)

Fiber Optics

Dike Moisture Monitoring

Final Messages

- AI can be used to **imitate HE systems and augment knowledge** (patterns and relations)but does not understand physics. HE Engineers do !
- AI can help to cope with problems we still don’t fully understand but has to be approved by the HE Engineers.
- Having lots of data does not mean having information (Entropy).
- Hydraulic engineers **will never be replaced** as we are trained to work **with little to no data**.

Deltares

TUDelft

Thanks

"Development of an optimal sensing strategy for dike monitoring of backward erosion piping with fibre optic cable based sensors" MSc Thesis Manuel Wewer (2019) – TU Delft/TU Dresden

A transient backward erosion piping model based on laminar flow transport equations. Wewer, M., Aguilar-López, J. P., Kok, M., & Bogaard, T. (2021). Computers and Geotechnics, 132, 103992 - https://doi.org/10.1016/j.compgeo.2020.103992

" Predicting drought-induced cracks in dikes with artificial intelligence " MSc Thesis Shaniel Chotkan (2021) – TU Delft https://resolver.tudelft.nl/uuid:5cd0f50d-1133-4868-9e96-ccaa0f73905d

"**A data-driven method for identifying drought-induced crack-prone levees based on decision trees.**" Chotkan, Shaniel, et al. - Sustainability 14.11 (2022): 6820. - https://doi.org/10.3390/su14116820

"Deep learning-based surrogate modelling for 2D flood simulation" MSc Thesis Thomas Stolp (2021) – TU Delft - https://resolver.tudelft.nl/uuid:ed5d4d57-017f-491f-8dd5-de910861aac9

"Crack detection for dikes using distributed temperature sesnsing" MSc Thesis Simone de Roos (2022) – TU Delft https://resolver.tudelft.nl/uuid:61999eab-1630-43b2-9b49-b2691d630e4e

"Understanding the thermal response of an unburied fiber-optic sensor for dike cracks detection." De Roos, Simone, et al. - submitted to – Sensors Journal 2024.