ANALYSIS OF WAVEFORMS IN THE SATELLITE ALTIMETRY BY USING NEURAL NETWORKS

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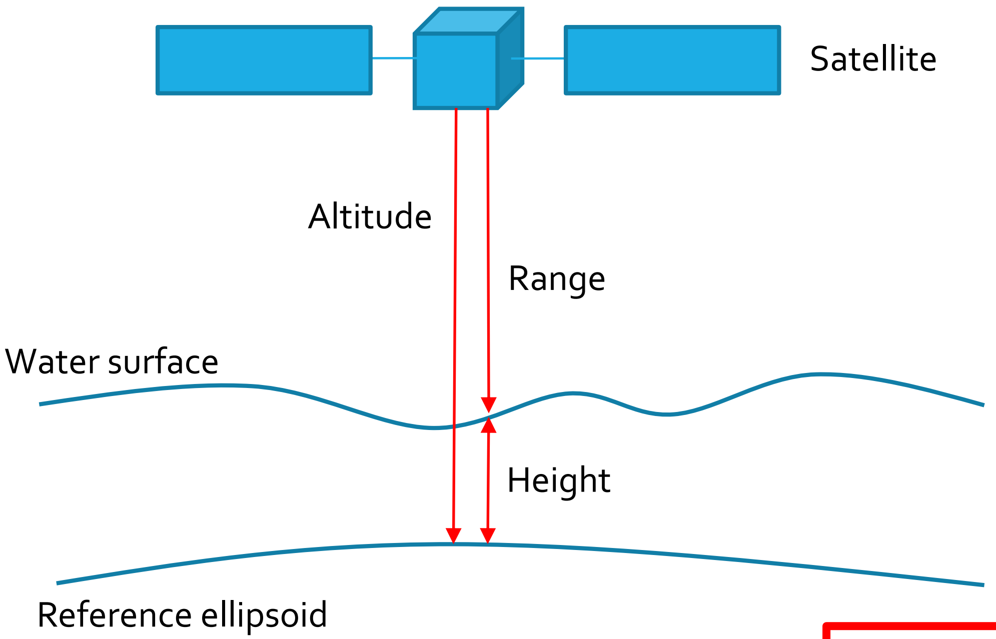
What is retracking and why is it important?

Receiving height information by using radar signals

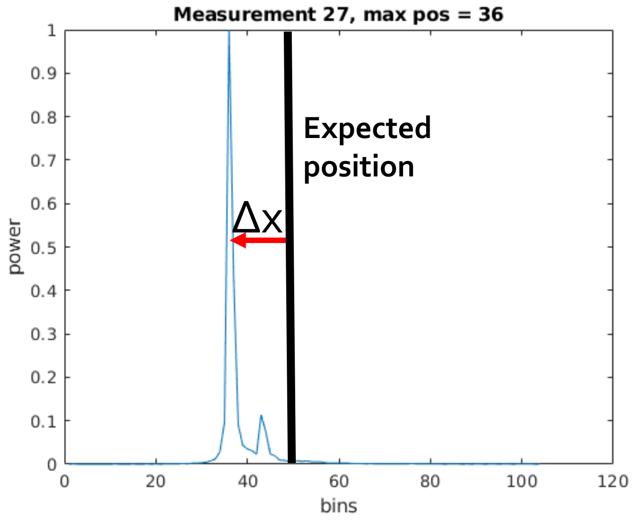


Height = Altitude - Range

$$H = A - (R + \Delta R)$$

➔ Therefore we need special techniques to define the correct position of the water peak

Range correction:



$$\Delta R = \frac{1}{2} \cdot \Delta x \cdot c \cdot \tau$$

ΔR = Retracked range
Δx = offset
c = speed of light in vacuum
τ = Puls duration

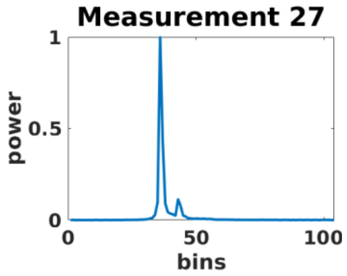
Motivation

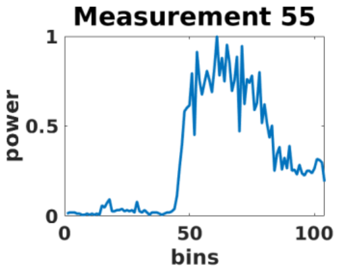
The satellite track covers water and land areas

Neural networks can:
- ➔ Learn characterisic pattern
- ➔ Detect the correct waveform
- ➔ Do the retracking

The first question which occurs is: is the measurement over water or land?

Water



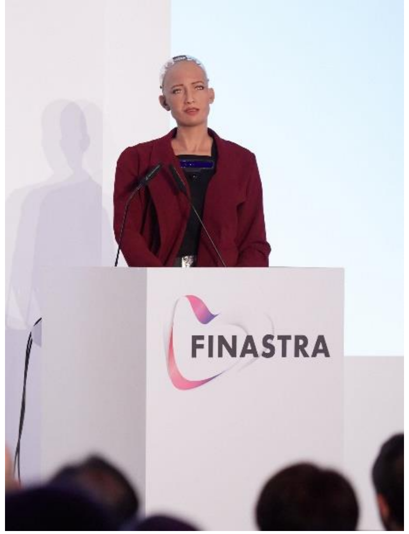


Land

How neural networks work
Introduction

- First works about neural networks are published in the 1950s
- With the resources of big companies (e.g. Google, Baidu, Huawei, ...) they are now on a level that they can be used in our daily life
- Even human like interactions are now possible (e.g. Sophia from Hanson Robotics)

As a basic for this work and also for the presentation the book **Make your own neural network** from **Tariq Rashid** was used

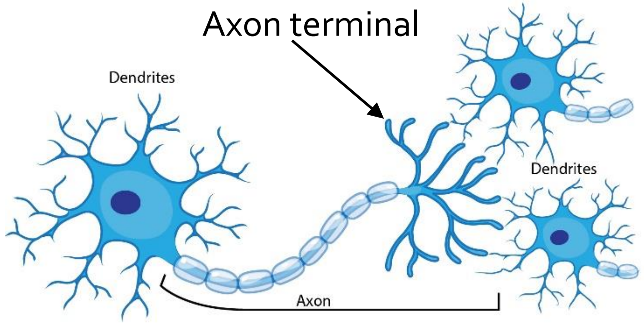


Sophia at the Finastra University (Singapore)

Source: https://twitter.com/realsophiarobot

How neural networks work
The basic idea

A biological neuron as an idea:



Input → Processing → Output

Source: https://askabiologist.asu.edu/sites/default/files/resources/plosable/Brain_Speed/connected-neurons.jpg

Basic idea of a simple artificial neuron:

Input a

Input b

Input c

$$x = a + b + c$$

?

Output y

Does every input should create an output?

How neural networks work
How to activate a neuron – Part 1

Actual situation:

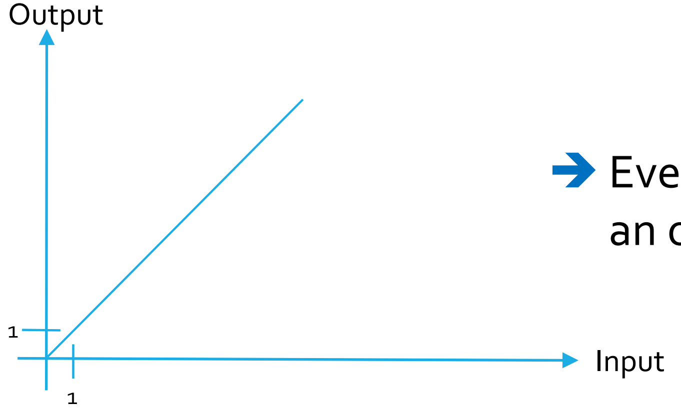
Input a

Input b

Input c

$$x = a + b + c$$

Output y



➔ Every input creates an output

Improvement:

Input a

Input b

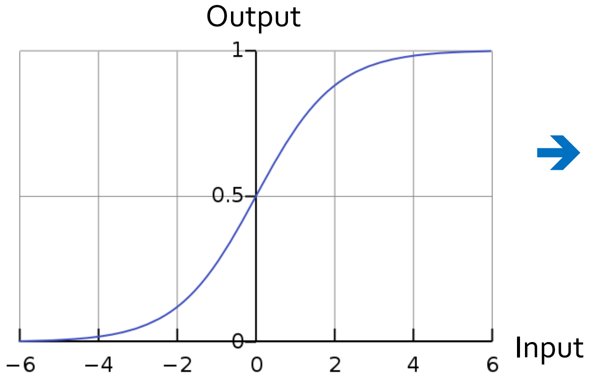
Input c

$$x = a + b + c$$

$$\Downarrow$$

$$y(x)$$

Output y

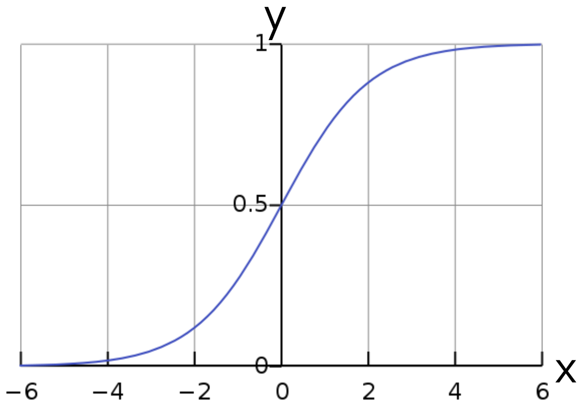


➔ Smooth increase between 0 and 1

Source: https://commons.wikimedia.org/w/index.php?curid=4310325

How neural networks work
How to activate a neuron – Part 2

To avoid an abrupt jump we will use the **sigmoid function**: $y = \frac{1}{1 + e^{-x}}$



Source: https://commons.wikimedia.org/w/index.php?curid=4310325

With this:

- ➔ Small signals are suppressed
- ➔ Strong signals are increased
- ➔ Range is between 0 and 1

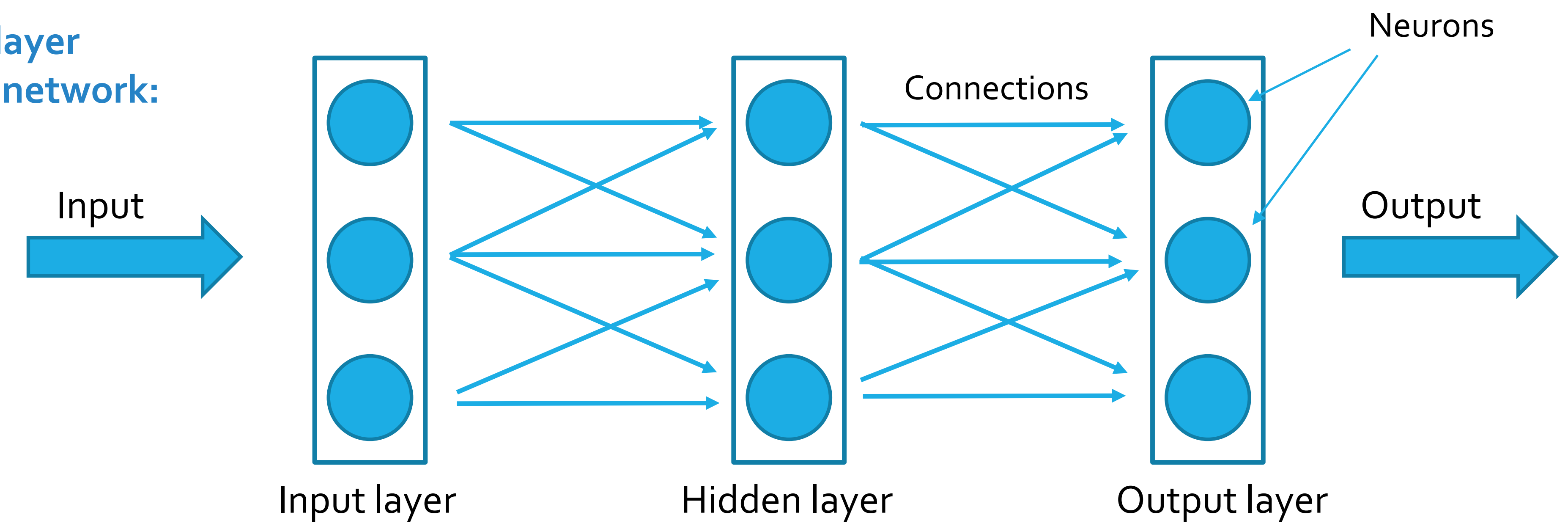
Inputs i ➔ $x = \sum i$ ➔ $y(x) = \frac{1}{1 + e^{-x}}$ ➔ Output y

How neural networks work
Combine the neurons

- Now we know how one artificial neuron works
- The next step is to combine them

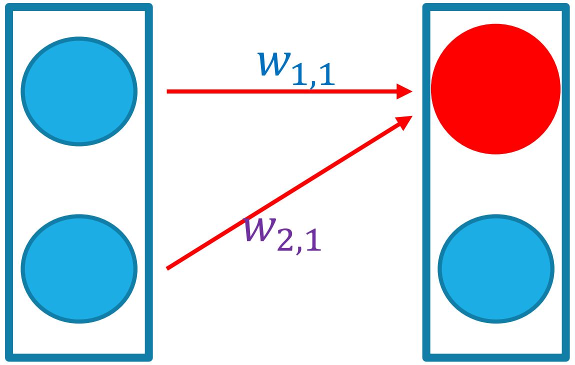
➔ The human brain is also organized in different layers of neurons to propagate the signals to their destination

Three layer neural network:



How neural networks work
The learning process

- The question now is, how can a neural network learn?
- The answer is in the **connections** between the layer!



Each connection has a special weight which will be multiplied with the transmitted value

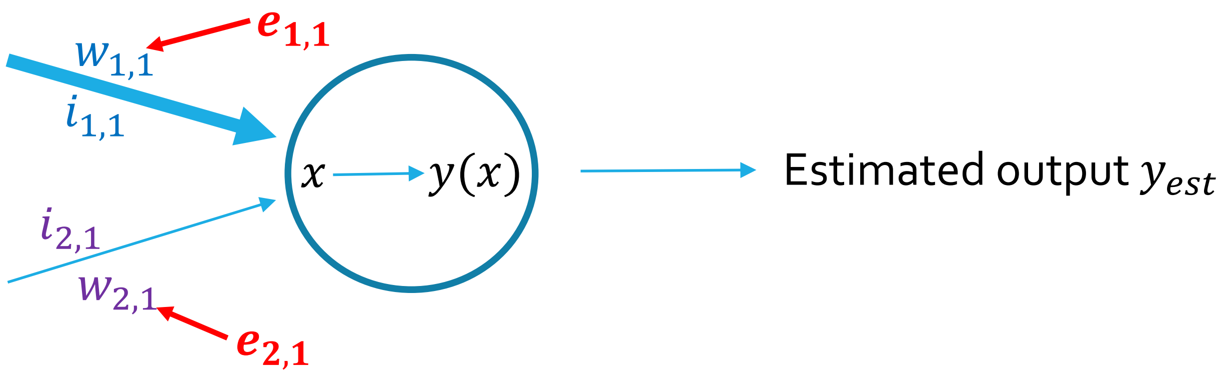
Example for node $N_{2,1}$: $x = i_{1,1} \cdot w_{1,1} + i_{2,1} \cdot w_{2,1}$

With these weights it is possible:
➔To strength a connection which provides useful informations
➔To suppress a connection which provides less useful informations

How neural networks work
Backpropagation

- The neural network adjust the **weights** of the connections during the training phase
- The weight adjustment depends on the **error** during the learning process:

Step 1:



Step 2: The learning error e is then calculated by:

$$e = y_{true} - y_{est}$$

Step 3: Now the error is distributed to the connections depending on their actual weight:

$$e_{1,1} = \frac{w_{1,1}}{w_{1,1} + w_{2,1}} \cdot e$$

How neural networks work
What is the output?

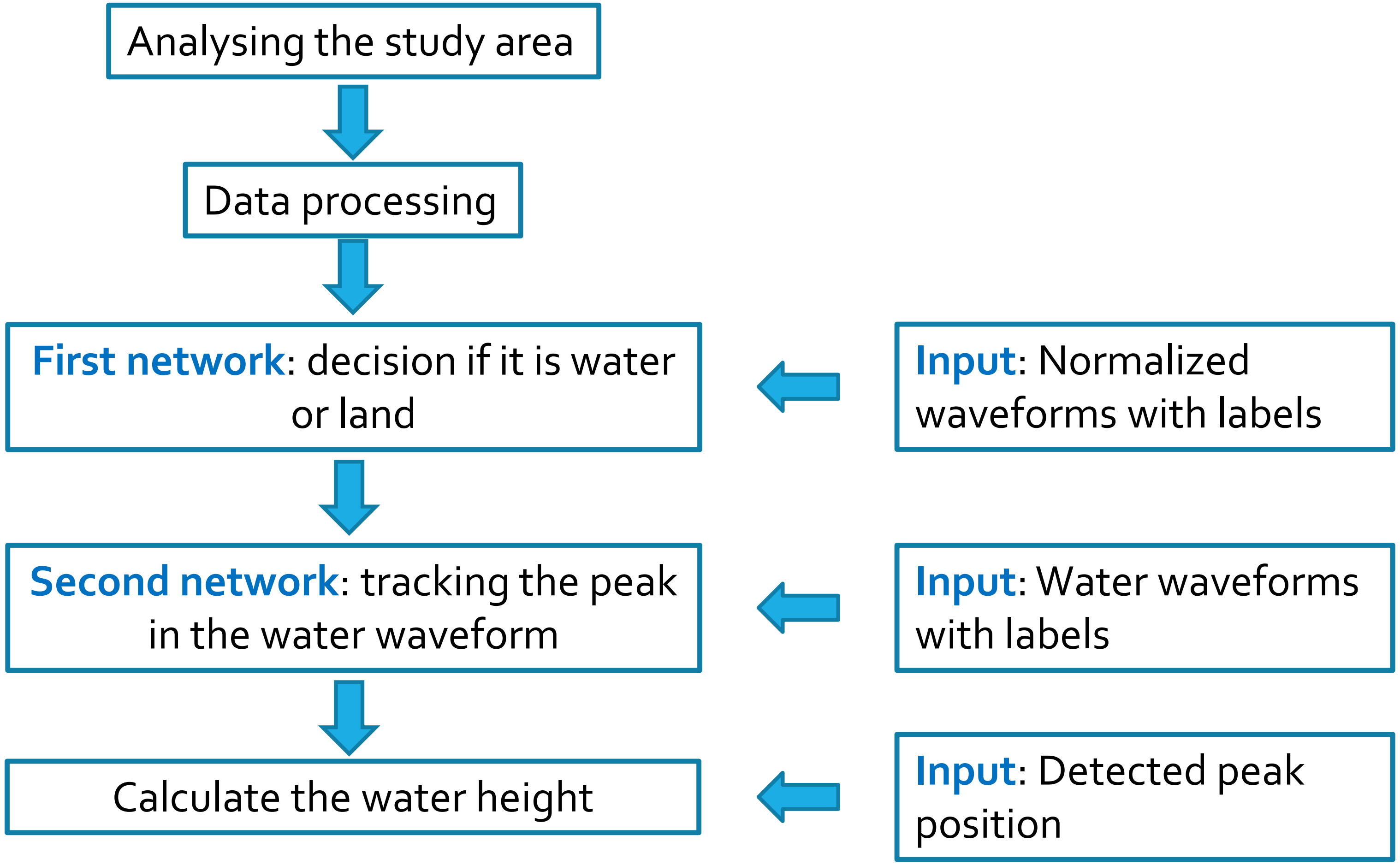
Now we learned a lot about neural networks but what should be done to create such a result?

Output of our neural network:

Water = Label 1
Land = Label 2

The tested waveform is **water** with **99.66%**

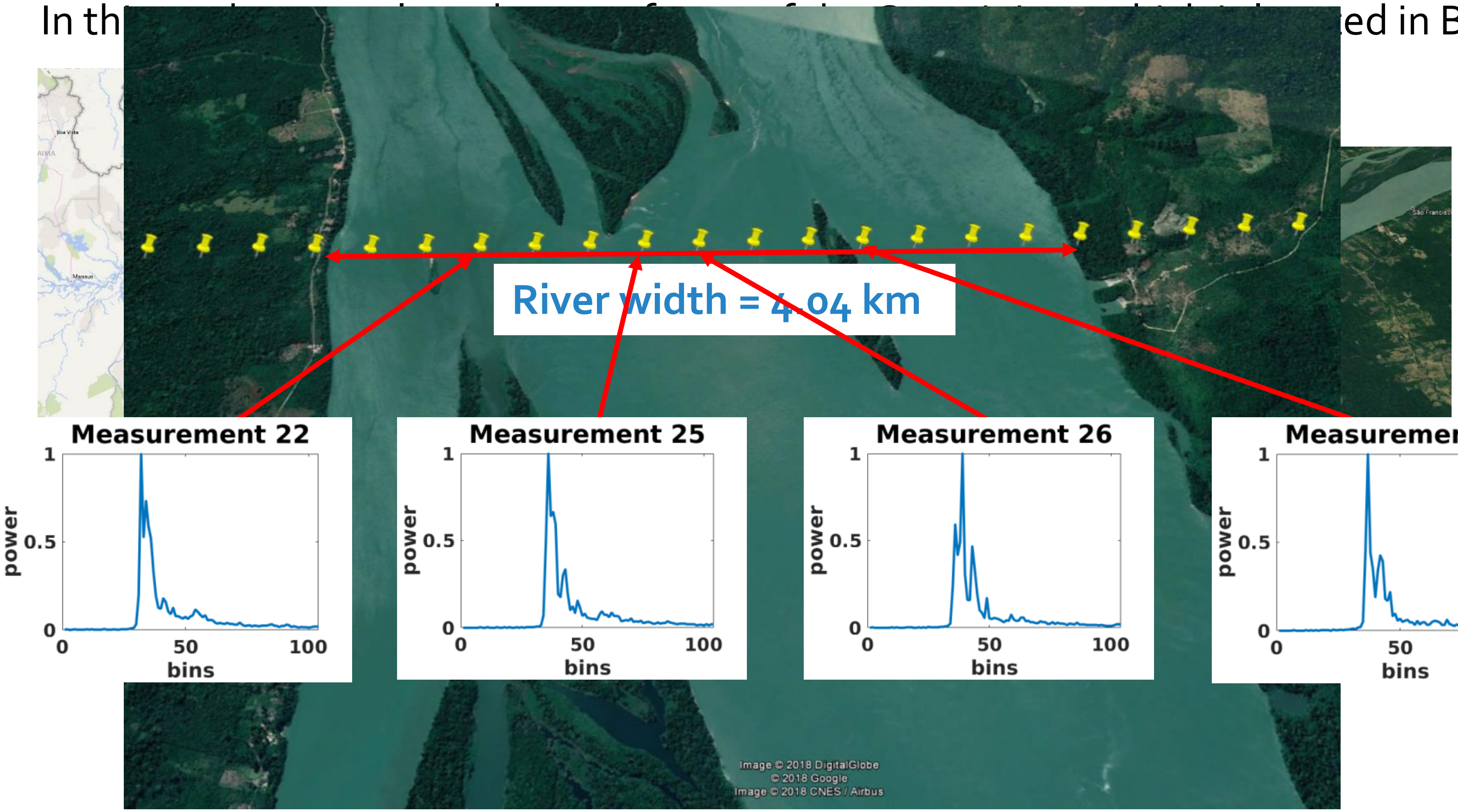
Overview of the developed algorithm



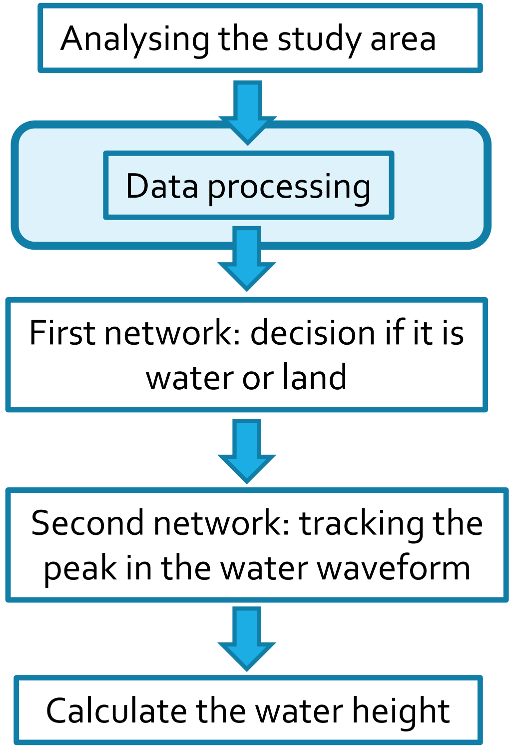
The study area

- Analysing the study area
- Data processing
- First network: decision if it is water or land
- Second network: tracking the peak in the water waveform
- Calculate the water height

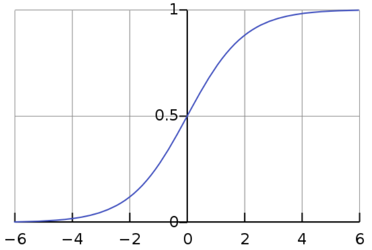
In th[…]ed in Brazil



Processing the data

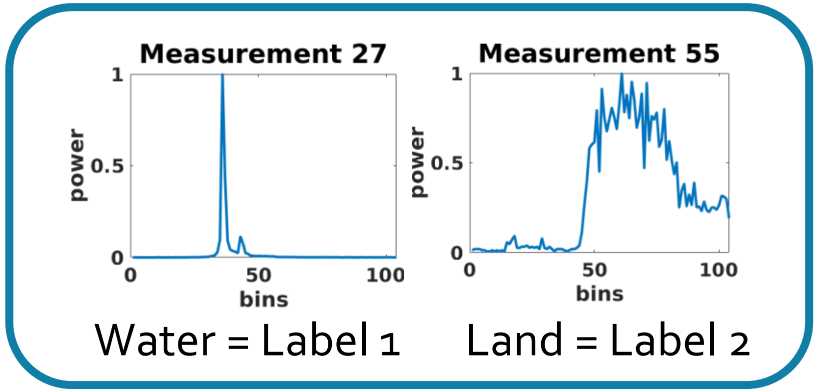


- Because the sigmoid function is in a range between 0 and 1, the input data also has to be in that range ➔ Waveforms have to be **normalized**



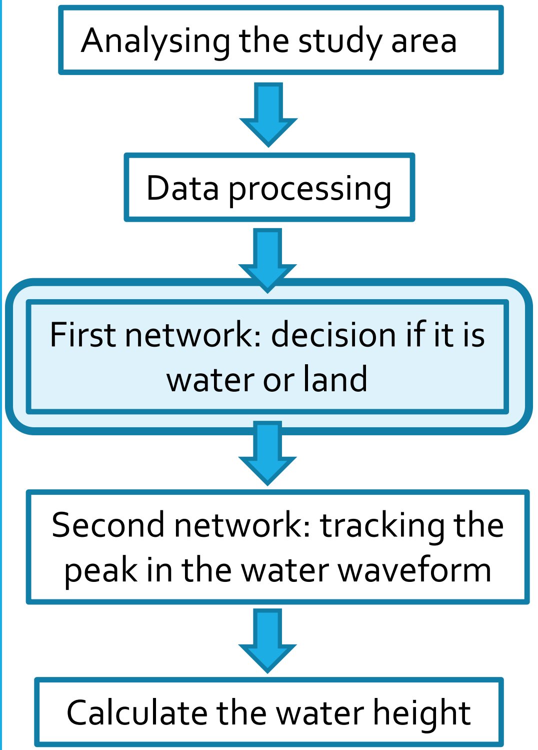
Source:
https://commons.wikimedia.org/w/index.php?curid=4310325

- That the neural network can learn the characteristics, the datasets have to be **labelled:**



Input for the first neural network

Analysing the first results
The first neural network



- The network will label all waveforms in water and land
- The advantage is, that above the water area are very clear peaks

Label	Detection rate
Water	100 %
Land	20,07 %

- The land area shows very different pattern which are difficult to detect for the network

Analysing the first results
The second neural network

Analysing the study area

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Data processing

↓

First network: decision if it is water or land

↓

Second network: tracking the peak in the water waveform

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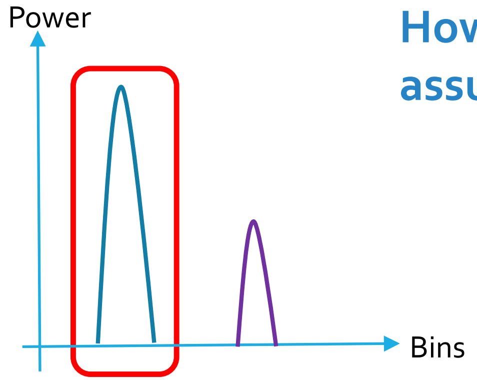
Calculate the water height

- The useful water waveforms are now detected
- To find the correct peak, we need more informations than only the label



How we can select the assumed water peak?

The output gives us the **probability** for each **label**

Analysing the first results
The second neural network – Methodology 1

Analysing the study area

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Data processing

↓

First network: decision if it is water or land

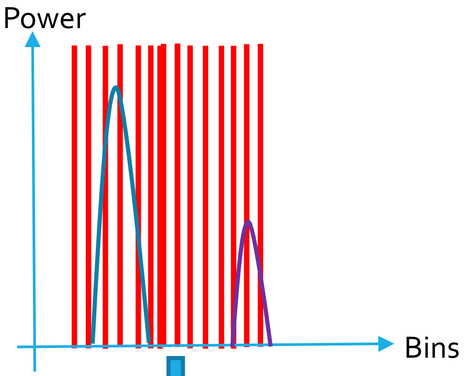
↓

Second network: tracking the peak in the water waveform

↓

Calculate the water height

1. Create a window with the size of 23 bins which defines the input for the network
2. Save the label and probability from the output
3. Move the window 2 bins and repeat it



2. Neural network

Output: Label and probability

➔ **This data is now the input for the next calculation**

+

We count how often each peak is tracked!

Analysing the first results
The second neural network – Methodology 2

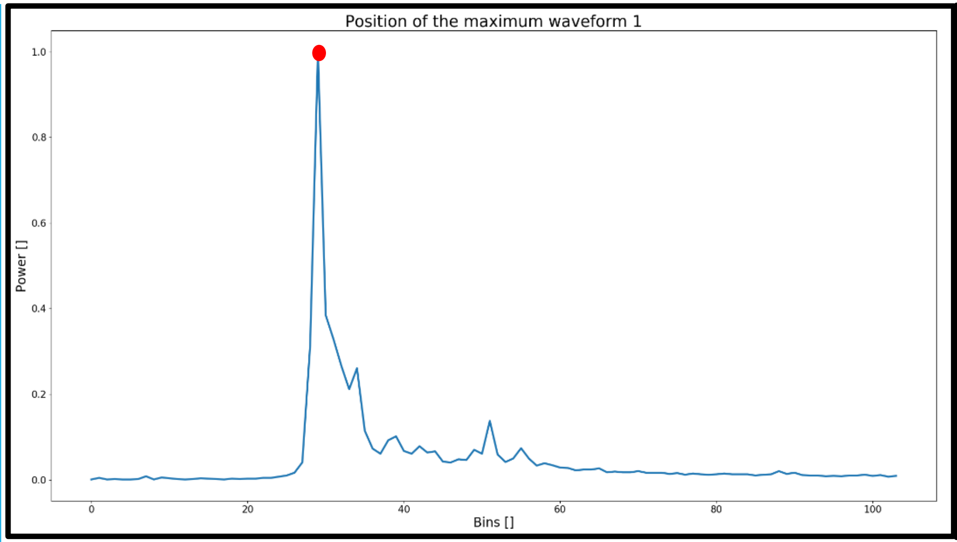
Analysing the study area

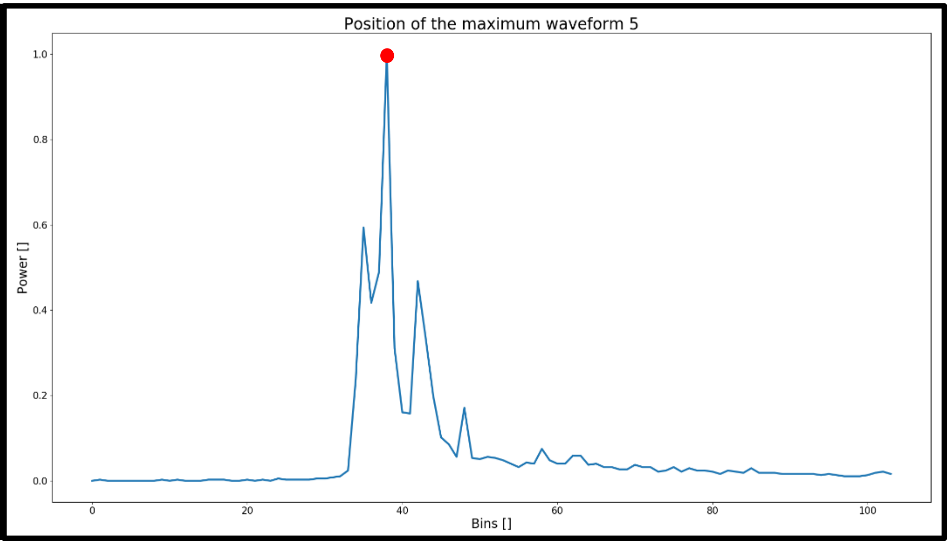
Data processing

First network: decision if it is water or land

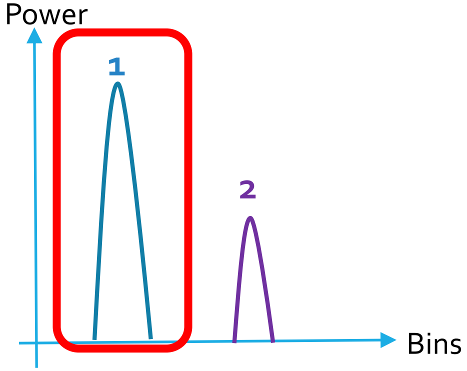
Second network: tracking the peak in the water waveform

Calculate the water height





The tracked peaks are now the input for the water height calculations!



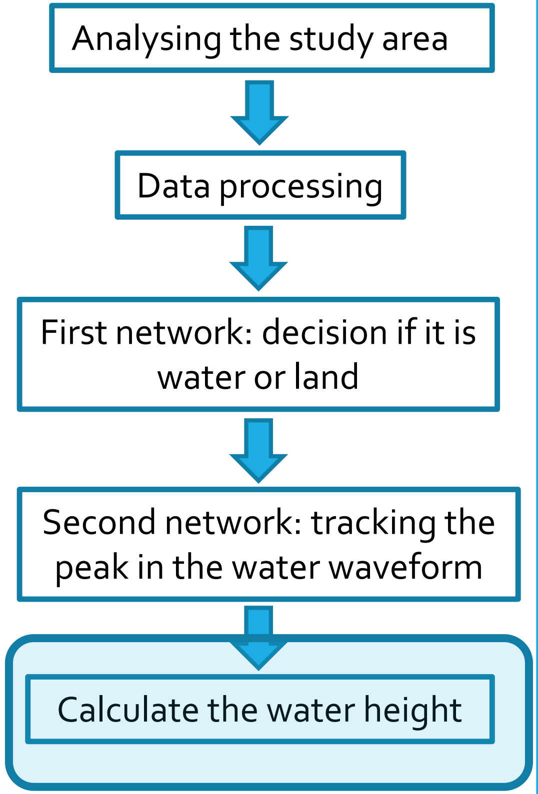
$\bar{P}_1 = 0.9995$ $\bar{P}_2 = 0.9923$

$n_1 = 6$ $n_2 = 3$

➔ $\bar{P}_1 \cdot n_1 = 5.997$

➔ $\bar{P}_2 \cdot n_2 = 2.9769$

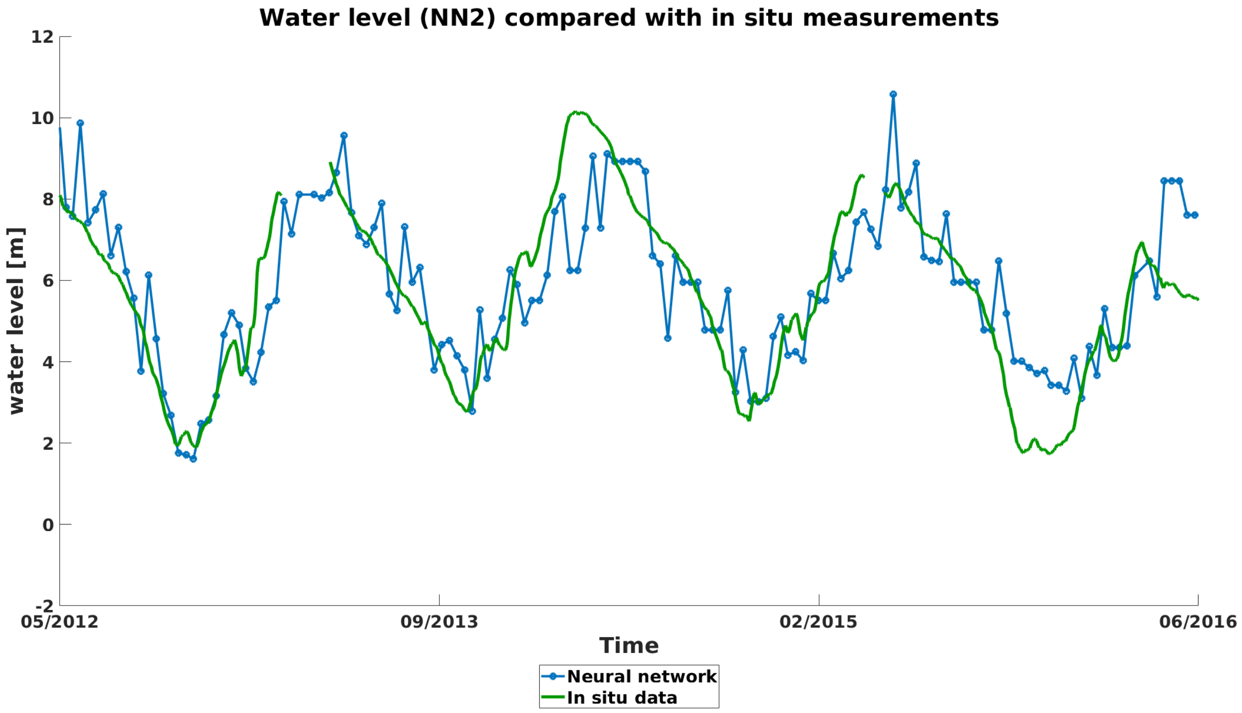
Analysing the first results
Calculation of the water heights



- Comparison of the calculated water level with the water level, measured by in situ stations

$$water\ level = A - (R + \Delta R) + corr$$

A= Altitude of the satellite above the reference ellipsoid
R= measured range
ΔR = Retracked range
$corr$= Applied corrections



Analysing the first results
Calculation of the water heights

Analysing the study area

↓

Data processing

↓

First network: decision if it is water or land

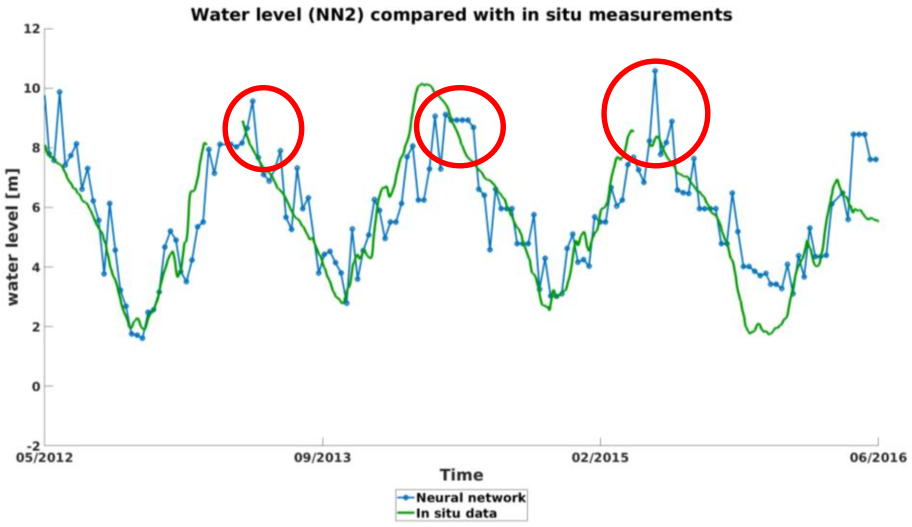
↓

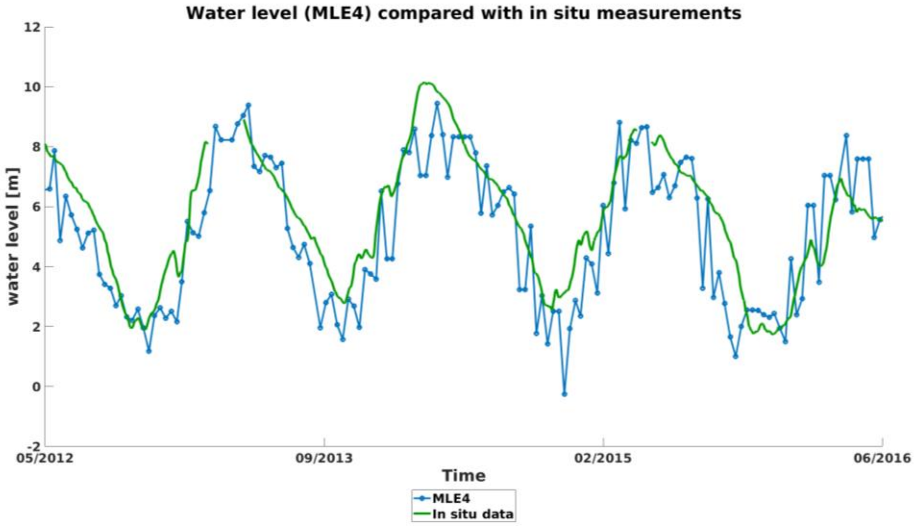
Second network: tracking the peak in the water waveform

↓

Calculate the water height

- Now we compare the water level with water levels, generated by the MLE4 retracker:

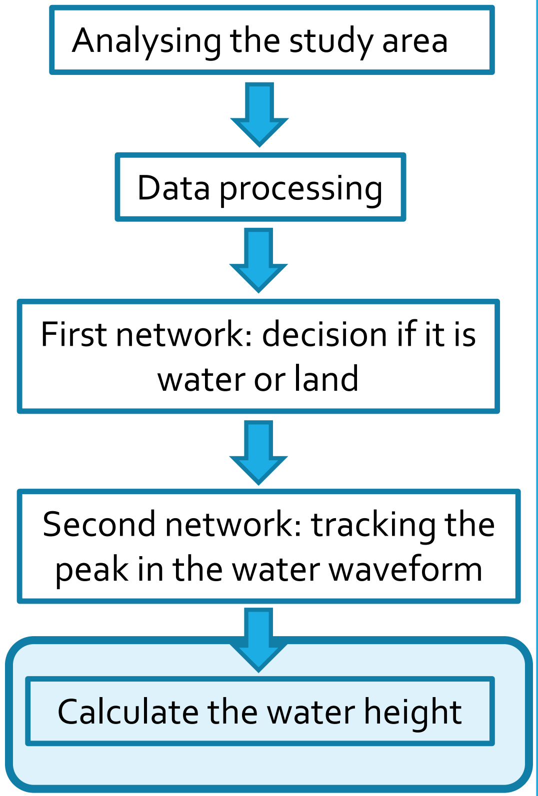




- As it can be seen, there is a delay in the peak maximum compared to the in situ data

➔ **Beside this problem, the main variations of the in situ water level can be reconstructed**

Analysing the first results
Calculation of the water heights



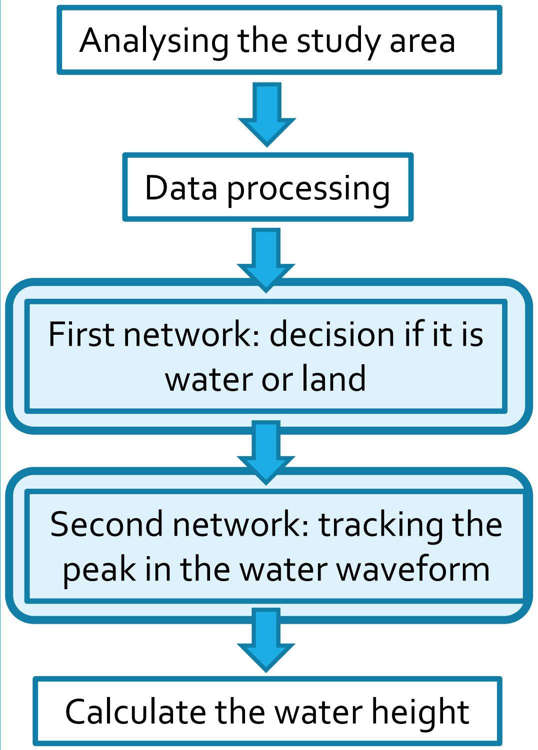
- At least, the residuals can be calculated to determine the standard deviation and the mean value from it:

$$res = waterLevel_{InSitu} - waterLevel_{Retracked}$$

	Water level with 2. NN [m]	Water level with MLE4 [m]
Standard deviation of the residuals	1.2872	1.1886
Mean value of the residuals	0.9549	1.0420

- Reagrding this statistics the results are comparable with each other

Analysing the first results
Summary

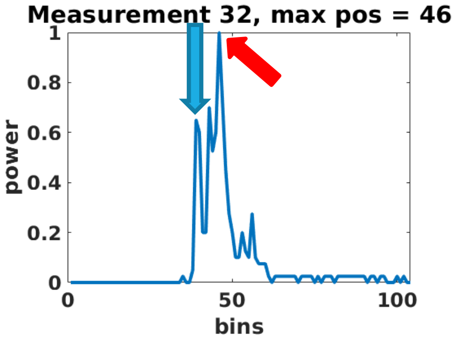


- There are good results by using a neural network for the classification of waveforms (**first neural network**)
- We have still several problems by using a neural network for the retracking but already good results (**second neural network**)

➔ **Neural networks show a big potential for further studies in this area**

Future work

Until now, it is not possible to handle noisy datasets, where we have multipeaks close to each other:

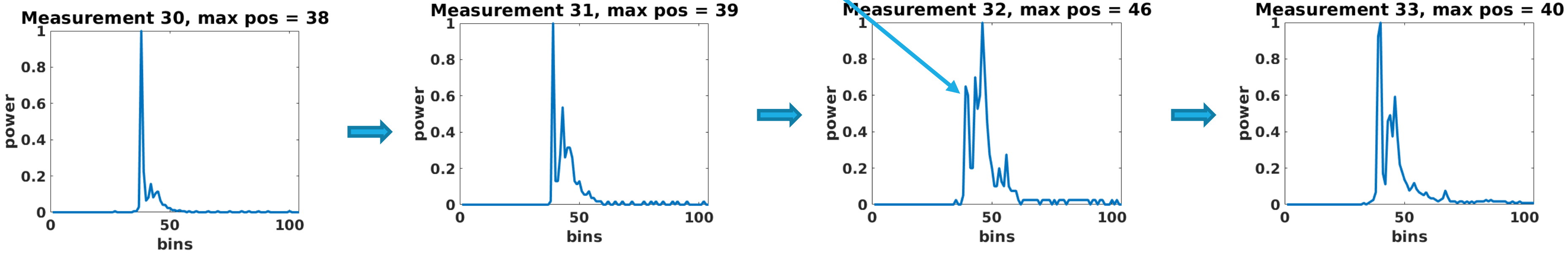


Which peak is from the water signal?

Recurrent neural networks can predict the position of a signal by regarding the **previous** signals

Solution is regarding the time aspect:

Position 39



Thank you very much for your attention!