A new altimeter waveform retracking algorithm based on neural networks

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Summary

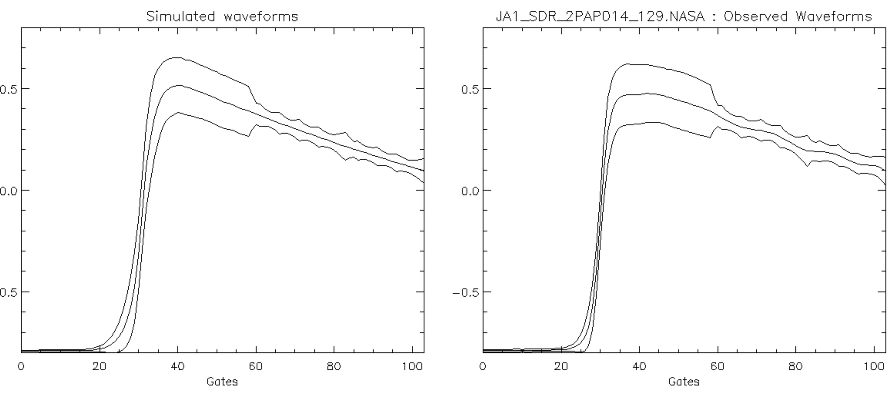
We present a new method for waveform retracking, based on neural network. A set of synthetic Jason-1 waveforms was created according to the Hayne model, taking into account the thermal noise, the telemetry and the data compression used for telemetry, assuming a single gaussian PTR. An appropriate neural network (NN) was determined to retrieve the epoch (range), and the significant wave height from the waveform samples, given a fixed skewness. The obtained NN can be seen like a non-linear mathematical function giving the two parameters (Epoch, SWH) given the 64 waveforms samples: (Epoch, SWH)=F(s1,...,s64).
The NN was applied to simulated and SGDR (Scientific Geophysical Data Records) Jason-1 waveforms.
We show the following results:

- The standard deviation of the NN epoch estimation is equivalent or slightly better than the one obtained with the MLE3 (Maximum Likelihood Estimate) algorithms of the SGDRs.
- **The standard deviation of the NN SWH estimates is reduced by a factor two** in comparison with the MLE3 estimate.

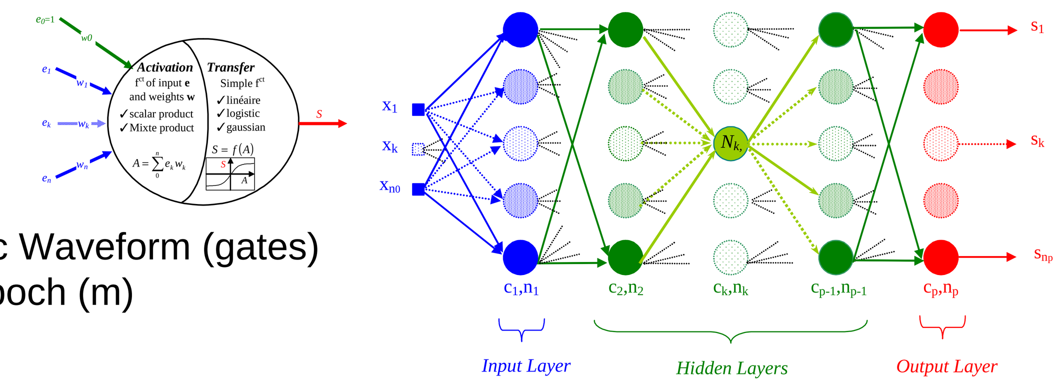
Given the simplified modelling applied in this study, the NN estimate have non-negligible biases, but we demonstrate that this problem can be solved by optimising the NN, using a more sophisticated forward model (Hayne 2nd order) and by creating correction tables.

1. Simulated waveforms

- **1st order Hayne Model**
- Single gaussian PTR (0.513T)
- Thermal noise [0,10], FFT(gaussian2)
- Speckle noise (Gaussian, 1/sqrt(90))
- Compression/decompression effects



2. Determination of a Neural Network for data inversion

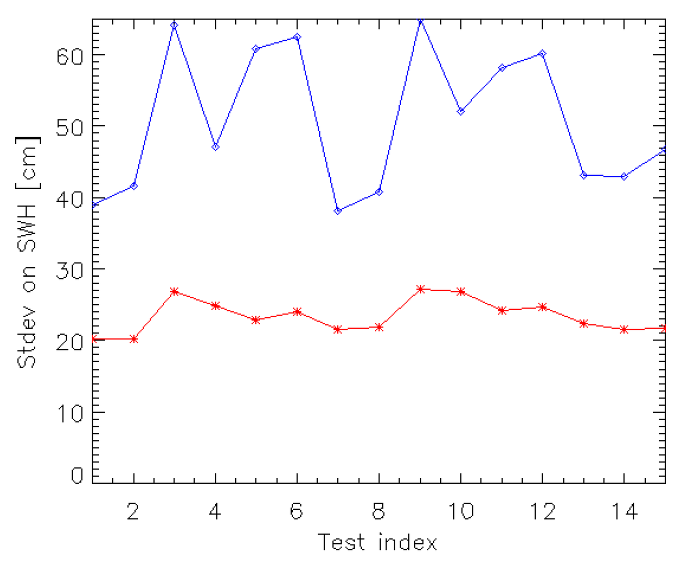


- **Multilayers Perceptron**
  - Input: Ku band Altimetric Waveform (gates)
  - Output:SWH (m) and Epoch (m)
- **Training process**
  - Estimation of weights
  - Train database: SWH ∊ [0;11m] , Epoch ∊ [-0.47;0.47]
- **Optimisation and Validation** of the Network Architecture over an independent database

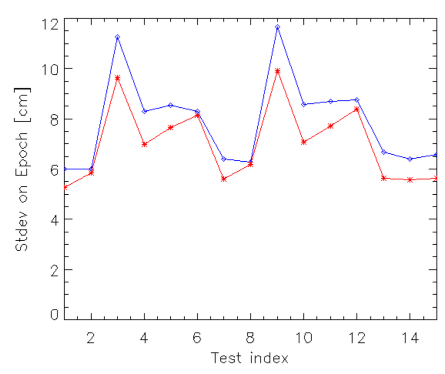
3. Performances with simulated data

- **15 test databases** defined by CNES
- Comparison of **MLE** / **Neuronal** Retracking
- STD of 20Hz estimations:

	SWH	Mispointing Angle	Skew.Waveforms	Skew.Rtk	PTR
Test 1	2 m	0°	0.1	0.1	Single Gaussian
Test 2	2 m	Linear between 0 to 0.3°	0.1	0.1	Single Gaussian
Test 3	6 m	Linear between 0 to 0.3°	0.1	0.1	Single Gaussian
Test 4	Linear between 1 to 6m	0°	0.1	0.1	Single Gaussian
Test 5	Linear between 1 to 6m	0.3°	0.1	0.1	Single Gaussian
Test 6	Linear between 1 to 6m	Linear between 0 to 0.3°	0.1	0.1	Single Gaussian
Test 7	2 m	0°	0.1	0.1	Full PTR
Test 8	2 m	Linear between 0 to 0.3°	0.1	0.1	Full PTR
Test 9	6 m	Linear between 0 to 0.3°	0.1	0.1	Full PTR
Test 10	Linear between 1 to 6m	0°	0.1	0.1	Full PTR
Test 11	Linear between 1 to 6m	0.3°	0.1	0.1	Full PTR
Test 12	Linear between 1 to 6m	Linear between 0 to 0.3°	0.1	0.1	Full PTR
Test 13	2 m	0°	0	0	Full PTR
Test 14	2 m	0°	0	0.1	Full PTR
Test 15	2 m	0°	0.1	0	Full PTR



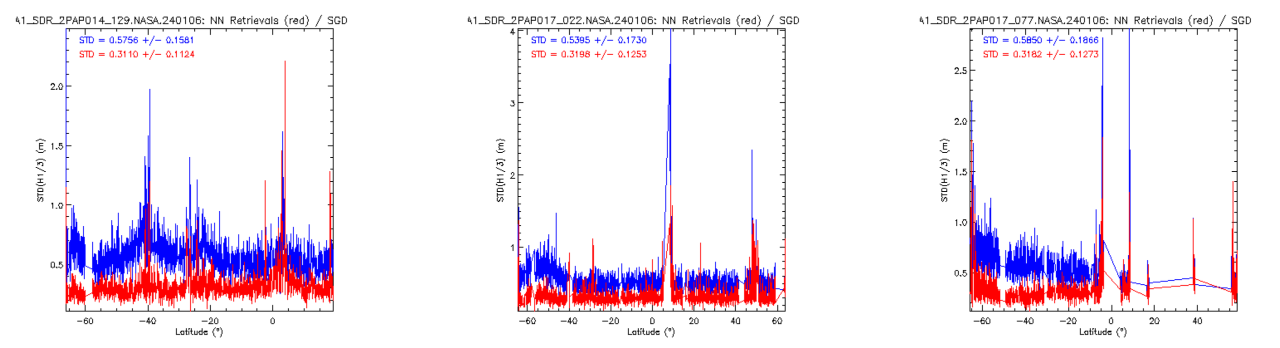
MLE
NN



4. Performances with simulated data

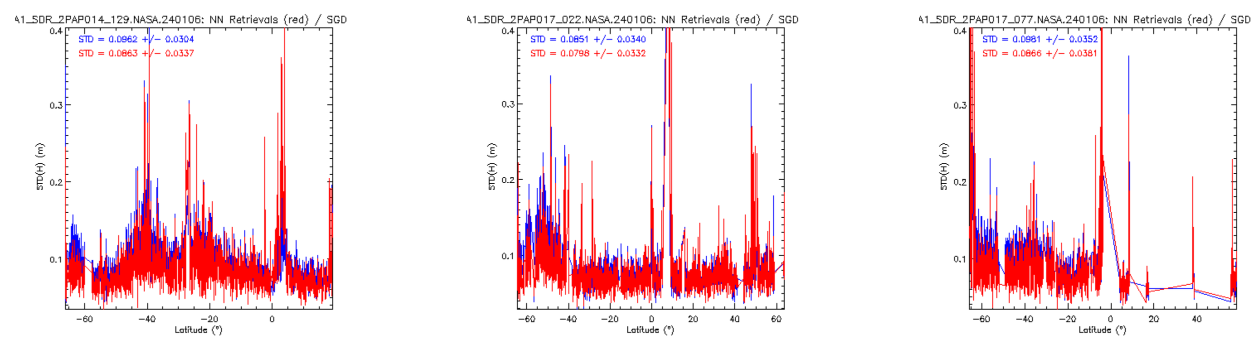
- **Division by 2 of the standard deviation of the SWH estimates: 60cm ⇒ 30cm**

MLE
NN



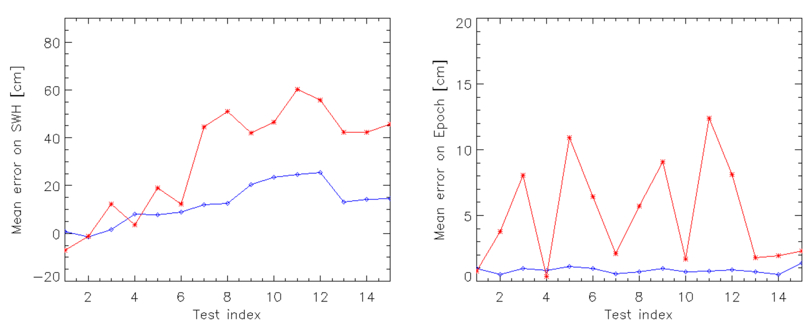
- **Performances of the epoch estimation slightly better: 9cm ⇒ 8cm**

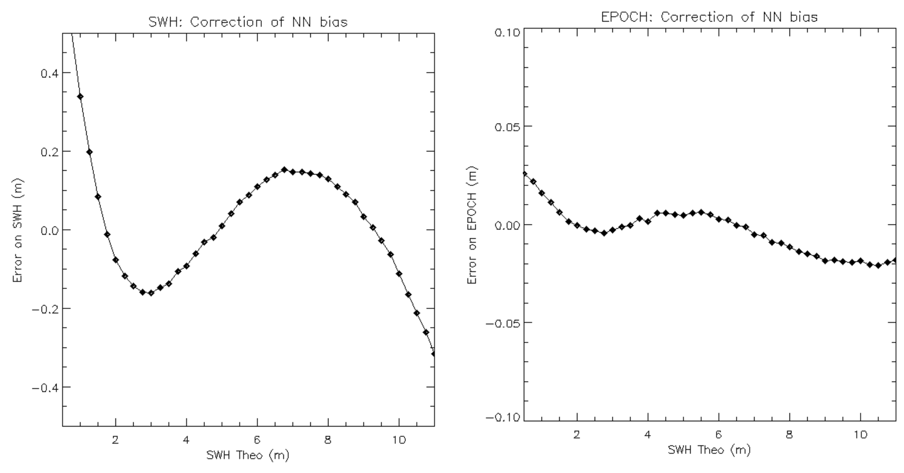
MLE
NN



5. Correction tables

- Estimation of the **Neural network biases**
- Simulation of 10 000 noisy altimetric waveforms / SWH

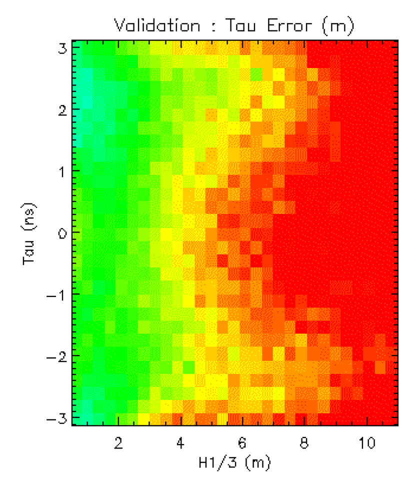




⇒ The NN biases can be corrected

6. Other results

- **Effect of the center gate** (half point of the leading edge): The precision of the epoch depends on the waveform centering
- **Taking into account the mispointing angle** in the training database, without estimation
⇒ Diminution of the neural network biases



Applications

Improvement of a factor 2 of the SWH estimates:

- Applications in meteorology like **sea state forecast** (use of altimeter SWH for assimilation, or validation, in wave models)
- **Sea-state bias correction** for the altimeter products:
  - Sea-state bias studies (relying on the SHW and wind)
  - Improve the precision of the sea-state bias corrections (depending mainly on the SWH)
- **Extreme events** (hurricanes): can extremely high waves be better estimated with this method?

Scientific studies dedicated to **faint geophysical signals** may benefit from improvements of the altimeter data precision:

- Small eddies (<< 100 km)
- Geophysics (small wavelengths of the geoid)

Other perspectives

The **computation efficiency of neural networks** can be valuable for:

- **Computation of the OSDR** (Operational scientific data records, Near-Real Time products) SWH for wave models
- **Massive re-processing** of historical altimeter data: the approach presented here necessitates the determination of waveform invertors specific to each mission.

Inversion of other parameters:

- **Non free Ocean surface**: Sea Ice and Ice Caps…

Conclusions and Perspectives

This short study demonstrated the ability of a method based on neural networks to reach:

- At least **comparable results with MLE, concerning the precision of the epoch** estimation (hence the precision of the range)
- **A significant improvement of the precision on the Significant Wave Height, with a reduction of noise of a factor 2**

One potential advantage of the **method** is that it **considers radar echoes** individually (**20 Hz** for Jason-1), and doesn't assume restricting hypotheses on the proprieties of the sea surface for tens or thousands of kilometers.

Survey

A survey about that subject is in circulation among SWH users. If you want to participate in that study, please contact M. Arnaud Quesney (coordinates in up-right corner).