Progress in the neural network parameterisation of wave spectra onto nonlinear interaction source terms

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Motivation

- development of operational wave models require improvement of approximative methods for calculation of nonlinear interaction source (S_{nl}) term
- exact solution too time consuming
- a fast yet accurate estimate of S_{nl} term is needed
- Neural Nets (NN) are well suited to parameterise complex functional relations such as the mapping of wave spectra onto S_{nl} terms
- idea first introduced by *Krasnopolsky et al. 2001* (separability in frequency and direction) and *Tolman et al. 2005* (2D EOF for single peaked spectra)

Methodology

- discrete wave spectra are directly mapped onto S_{nl} terms (grid: 25 frequ. X 24 direc. = 600 dim.)
- assumption: there is a continuous mapping with a number of free parameters << 600
- no further assumptions (such as separability or convergence of an expansion series) about wave spectra and S_{nl} terms
- dataset for training of the NN utilises the complexity of wave spectra in an operational wave model

Summary

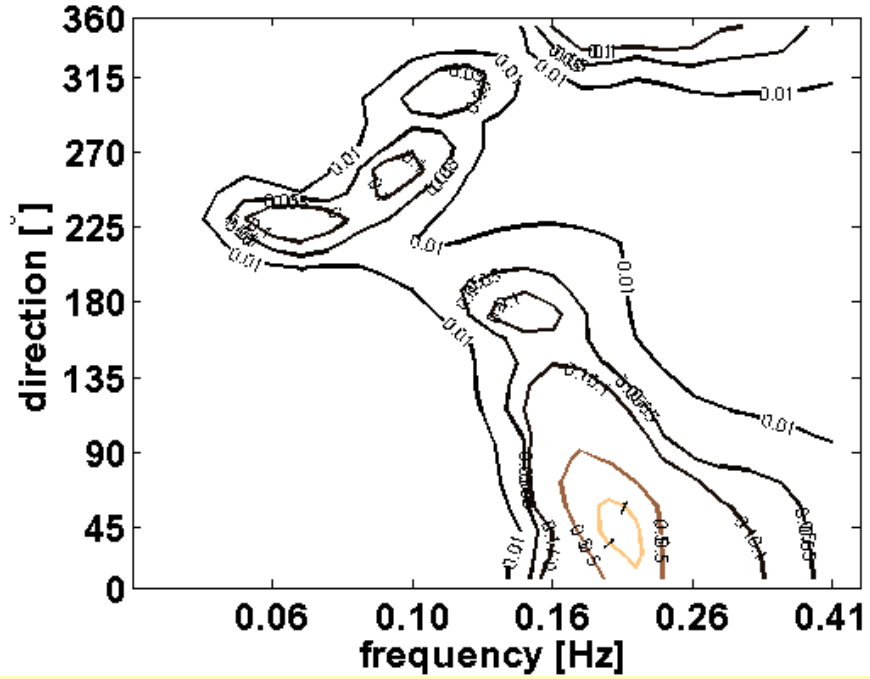
- we (*Wahle et al. 2009)* demonstrated the feasibility of direct mapping of discrete wave spectra onto S_{nl} terms
- number of free parameters of the mapping (intrinsic dimensionality of wave spectra) was found to be ≈ 40
- choices of wave spectra for training of the NN based on automatic classification scheme (cluster analysis)

Dataset for training

- choice of training data essential for NN (interpolation ↔ extrapolation)
- simulated spectra from a hindcast with WAM cycle 4 (> 5 million spectra)
- choose representative subset (wind sea, swell, complex combinations of the two)
- multi-modal spectra should be well presented

→automatic classification of the wave

spectra using a nonhierachical cluster algorithm


direction [°]
360
315
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225
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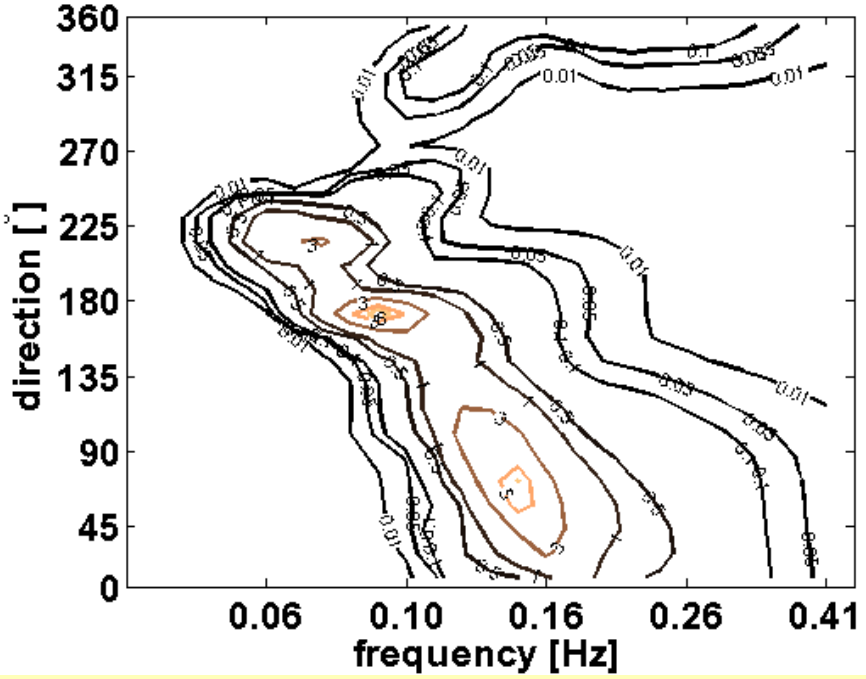
135
90
45
0
0.06
0.10
0.16
0.26
0.41
frequency [Hz]


direction [°]
360
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0.06
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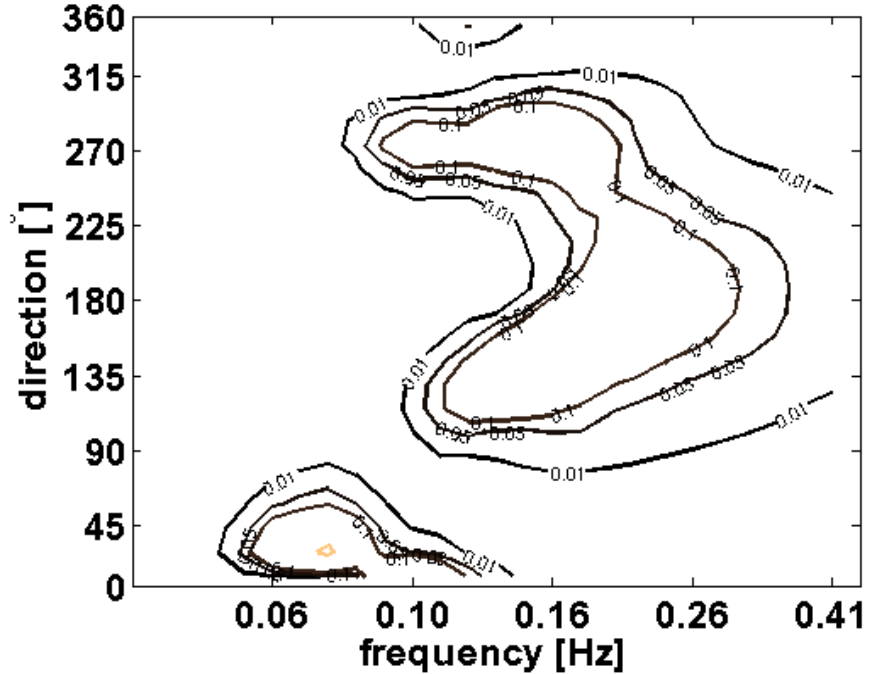
0.16
0.26
0.41
frequency [Hz]


direction [°]
360
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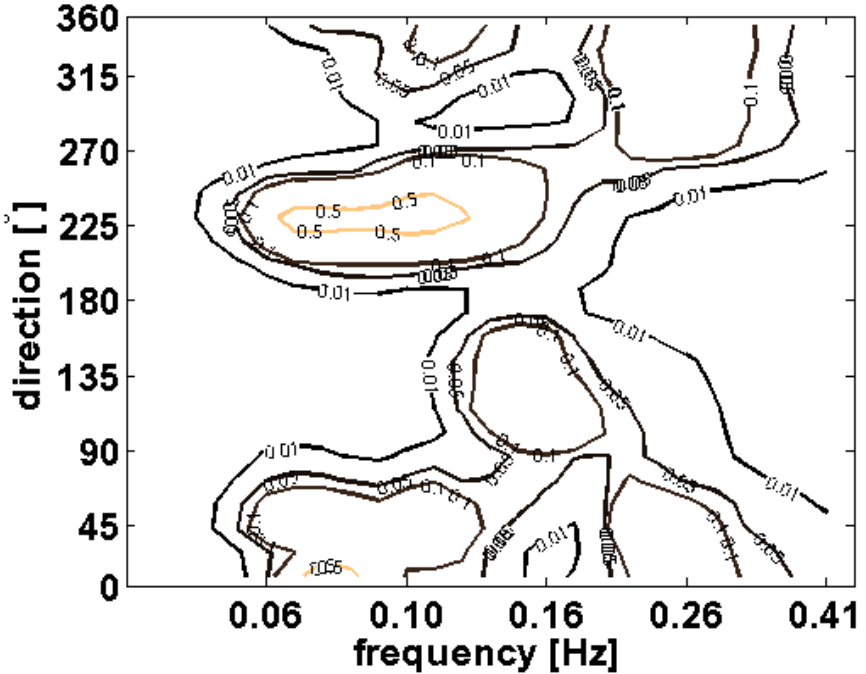
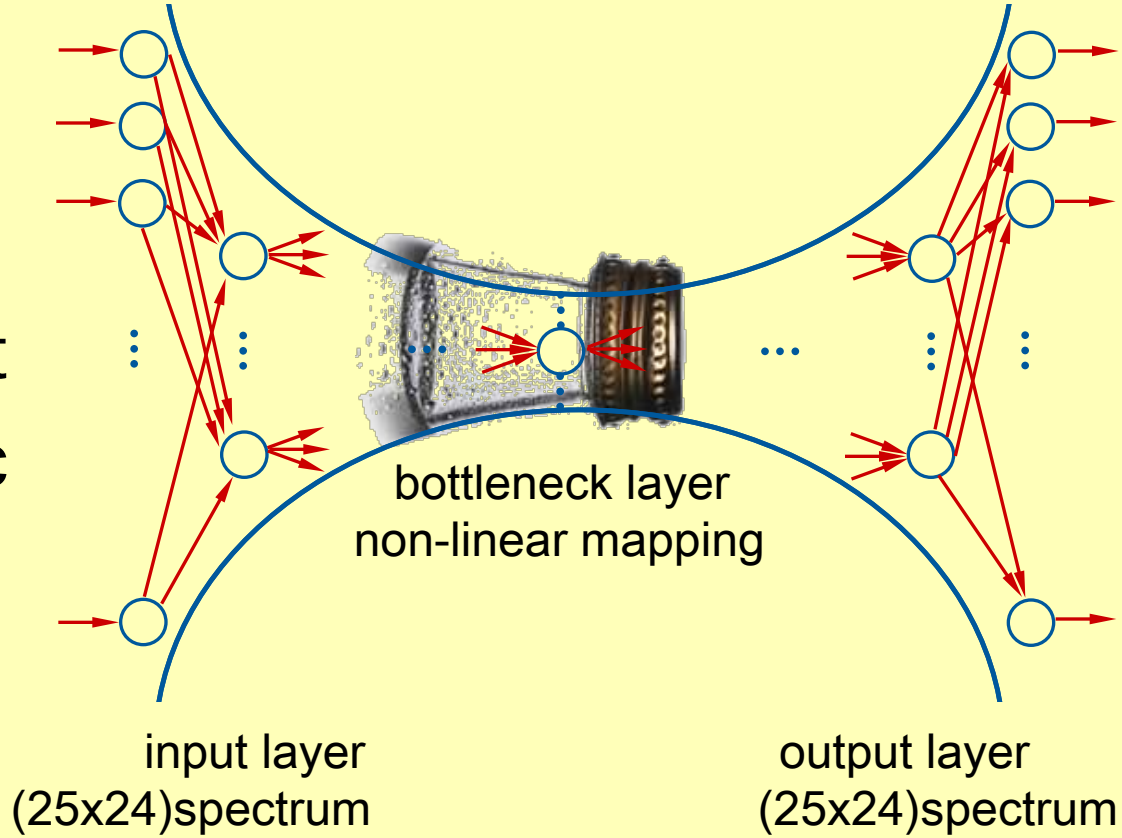
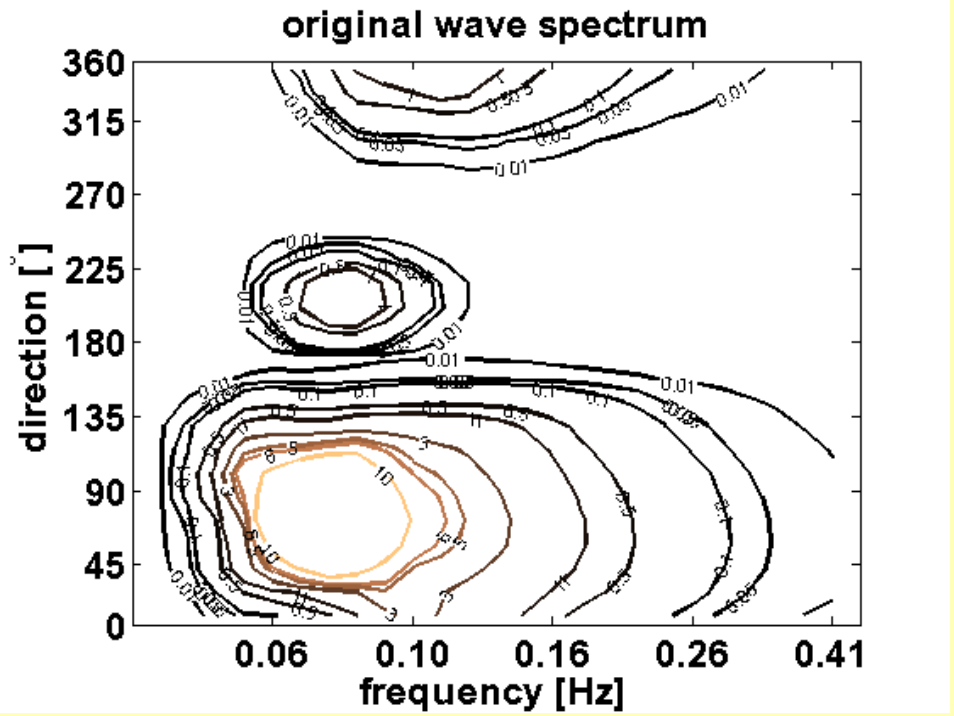
0.06
0.10
0.16
0.26
0.41
frequency [Hz]

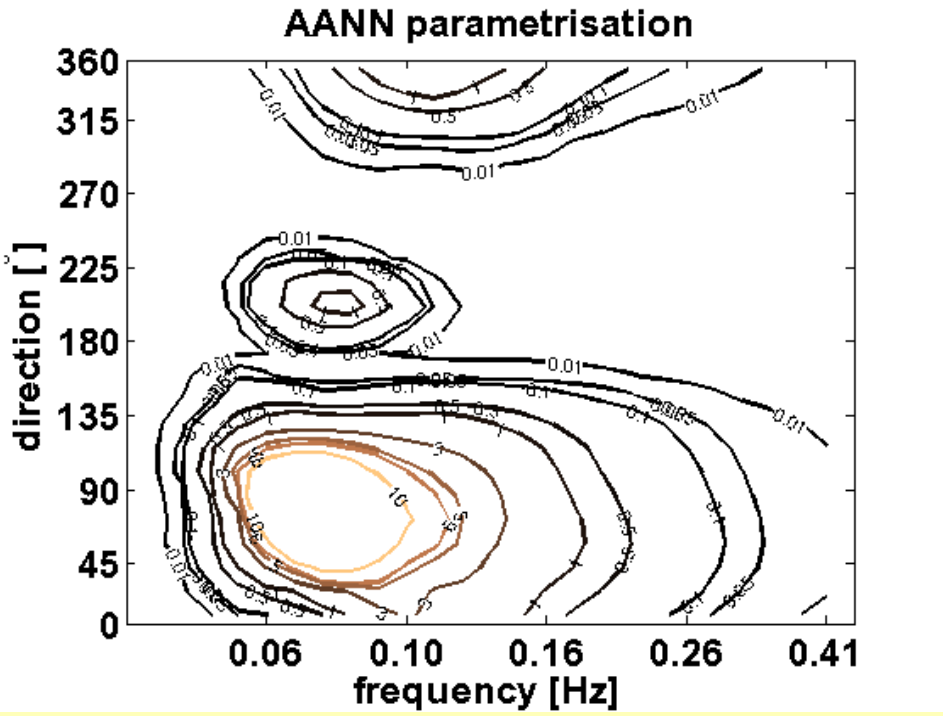

direction [°]
360
315
270
225
180
135
90
45
0
0.06
0.10
0.16
0.26
0.41
frequency [Hz]

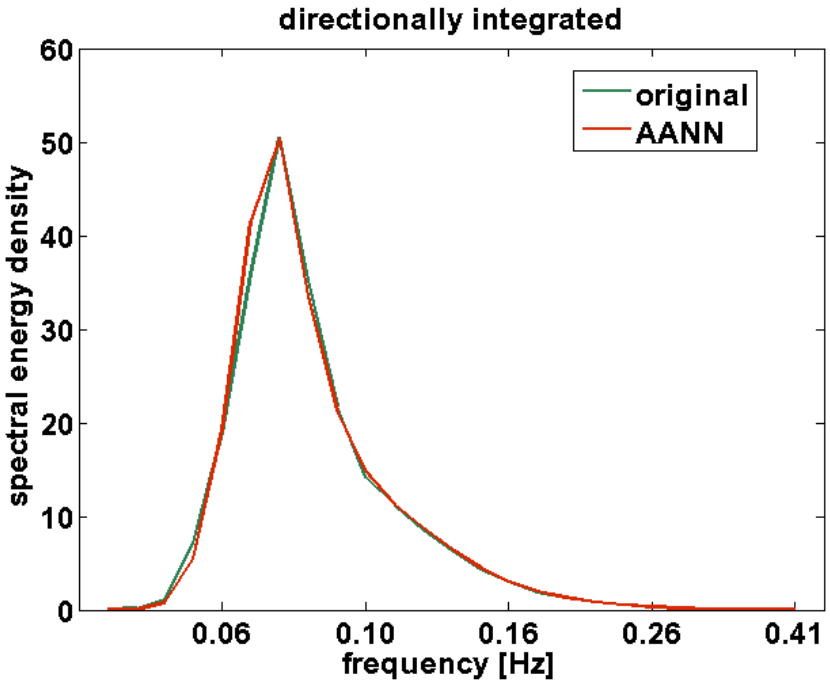
Auto-Associative Neural Net (AANN)

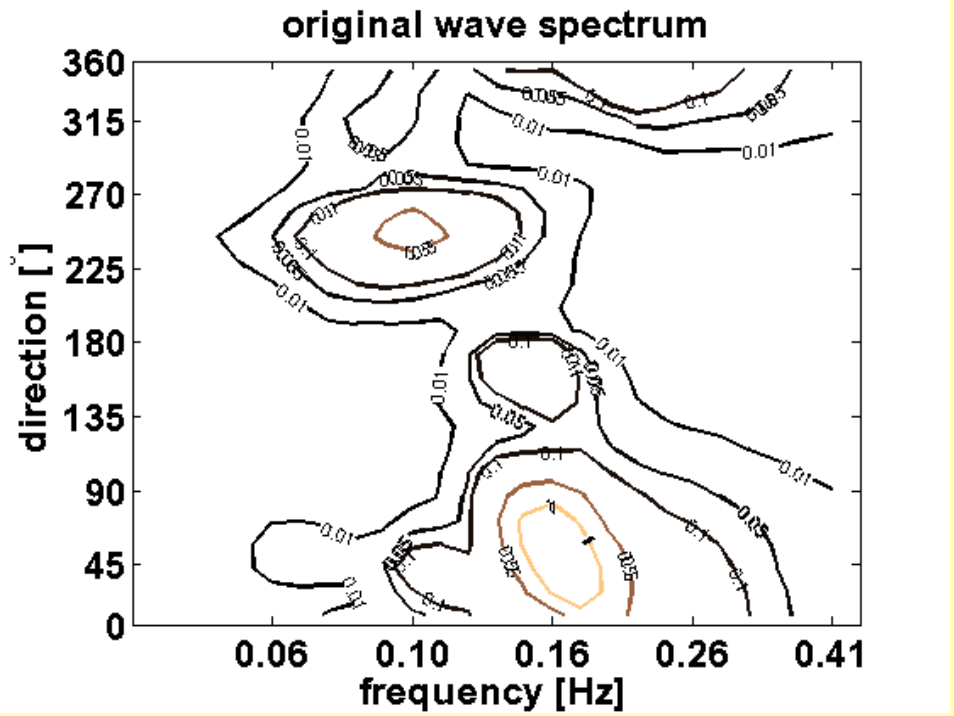
- non-linear reduction mapping of data onto themselves with a Neural Net
- AANN → intrinsic dimensionality
- AANN → non-linear version of PCA

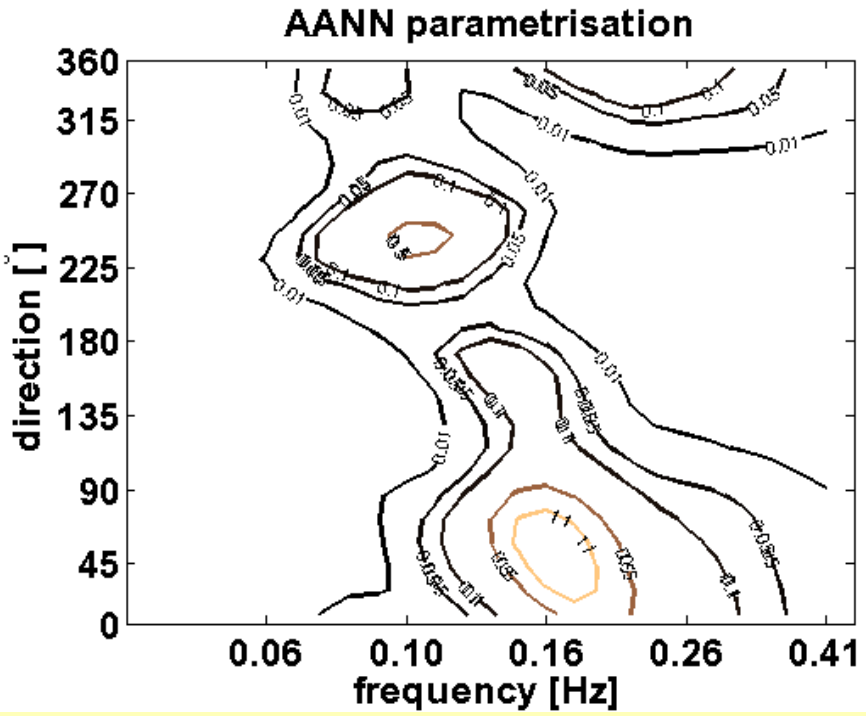


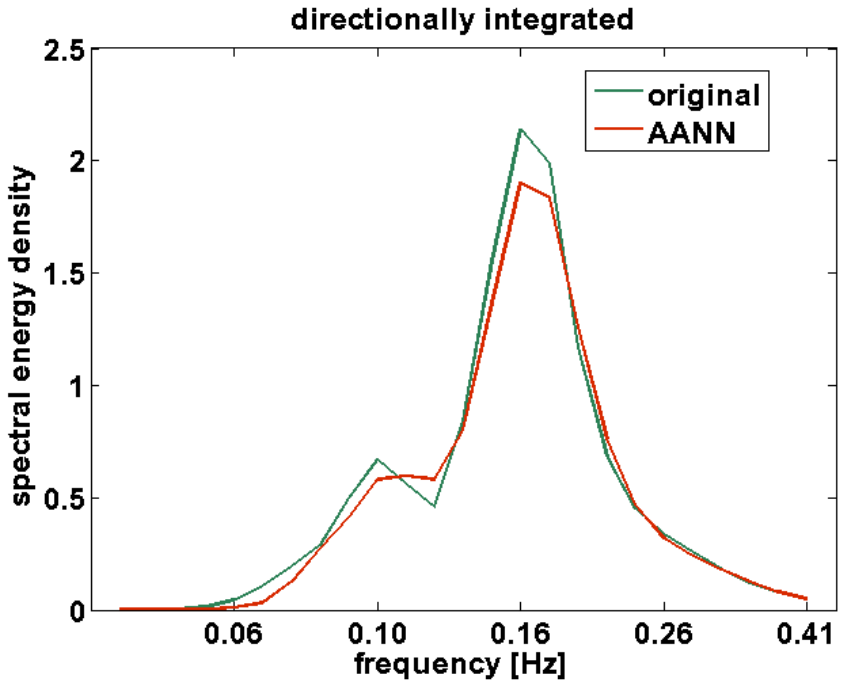

original wave spectrum
direction [°]
360
315
270
225
180
135
90
45
0
0.06
0.10
0.16
0.26
0.41
frequency [Hz]

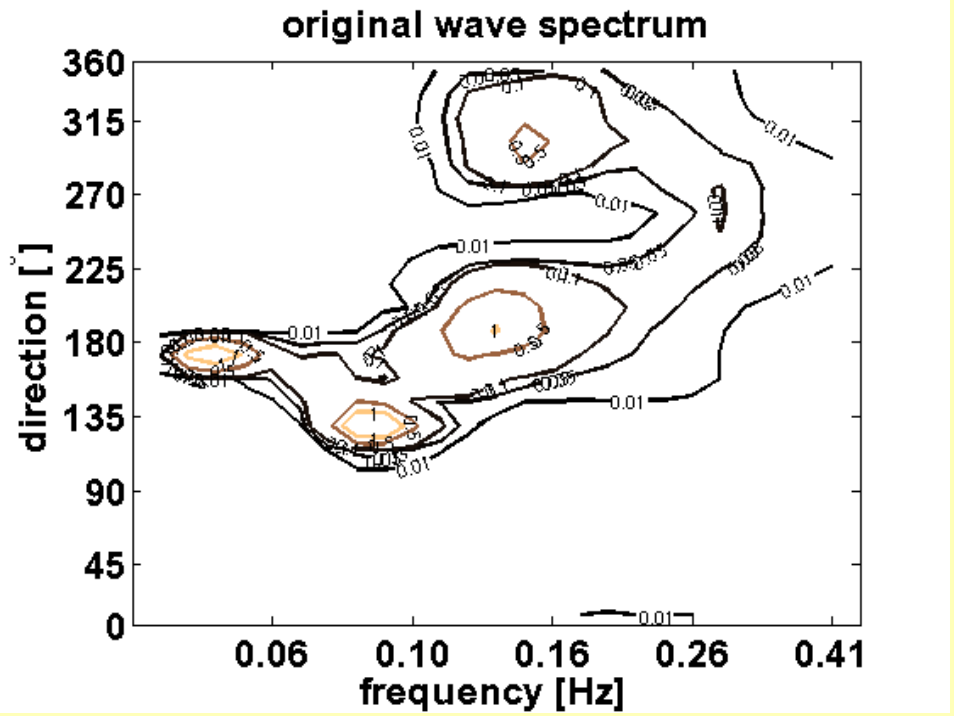

AANN parametrisation
direction [°]
360
315
270
225
180
135
90
45
0
0.06
0.10
0.16
0.26
0.41
frequency [Hz]

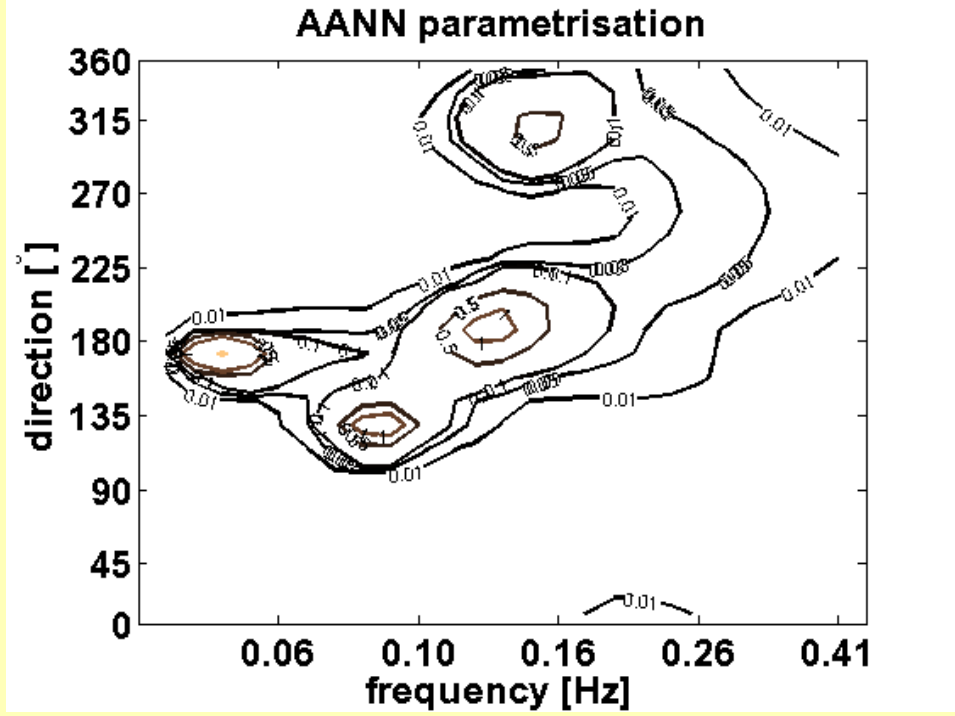

directionally integrated
original
AANN
spectral energy density
60
50
40
30
20
10
0
0.06
0.10
0.16
0.26
0.41
frequency [Hz]

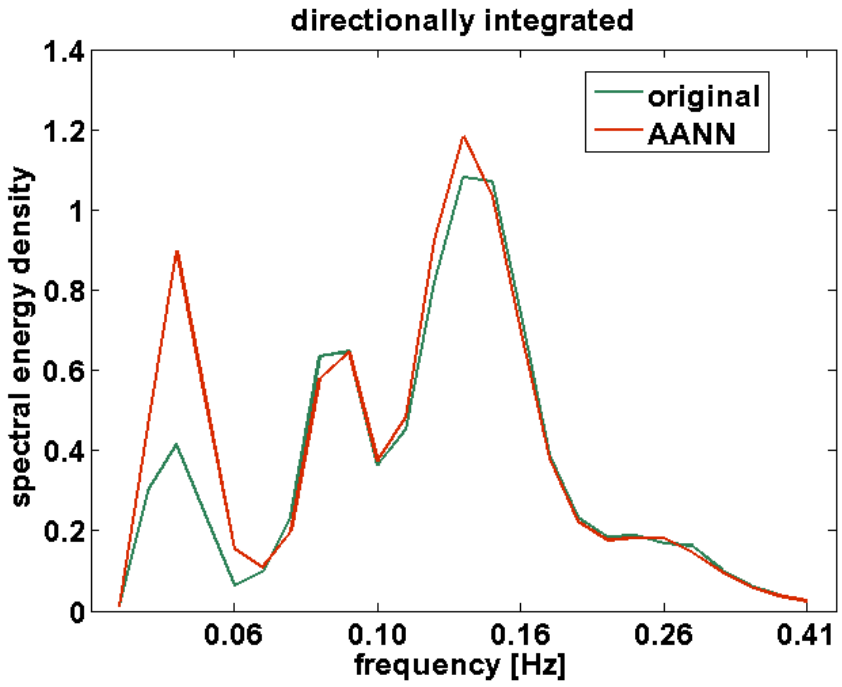

original wave spectrum
direction [°]
360
315
270
225
180
135
90
45
0
0.06
0.10
0.16
0.26
0.41
frequency [Hz]


AANN parametrisation
direction [°]
360
315
270
225
180
135
90
45
0
0.06
0.10
0.16
0.26
0.41
frequency [Hz]

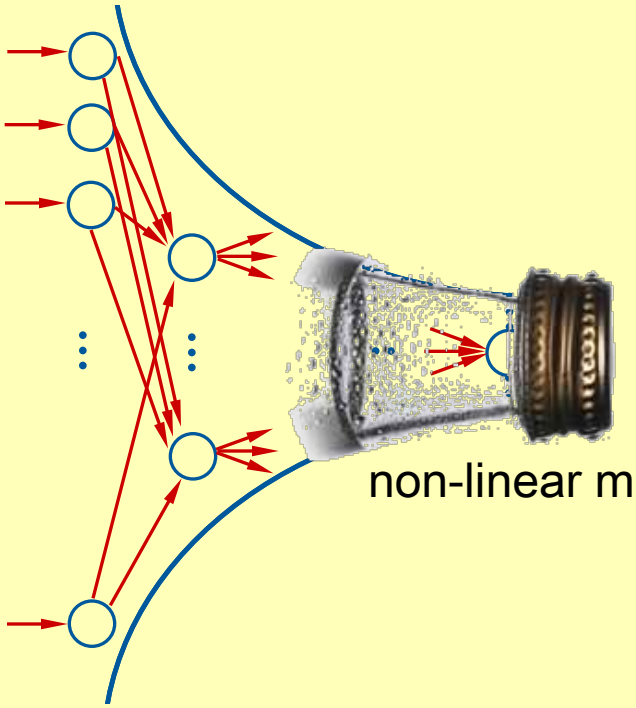

directionally integrated
original
AANN
spectral energy density
2.5
2
1.5
1
0.5
0
0.06
0.10
0.16
0.26
0.41
frequency [Hz]


original wave spectrum
direction [°]
360
315
270
225
180
135
90
45
0
0.06
0.10
0.16
0.26
0.41
frequency [Hz]


AANN parametrisation
direction [°]
360
315
270
225
180
135
90
45
0
0.06
0.10
0.16
0.26
0.41
frequency [Hz]


directionally integrated
original
AANN
spectral energy density
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.06
0.10
0.16
0.26
0.41
frequency [Hz]

NN mapping of non-linear interaction

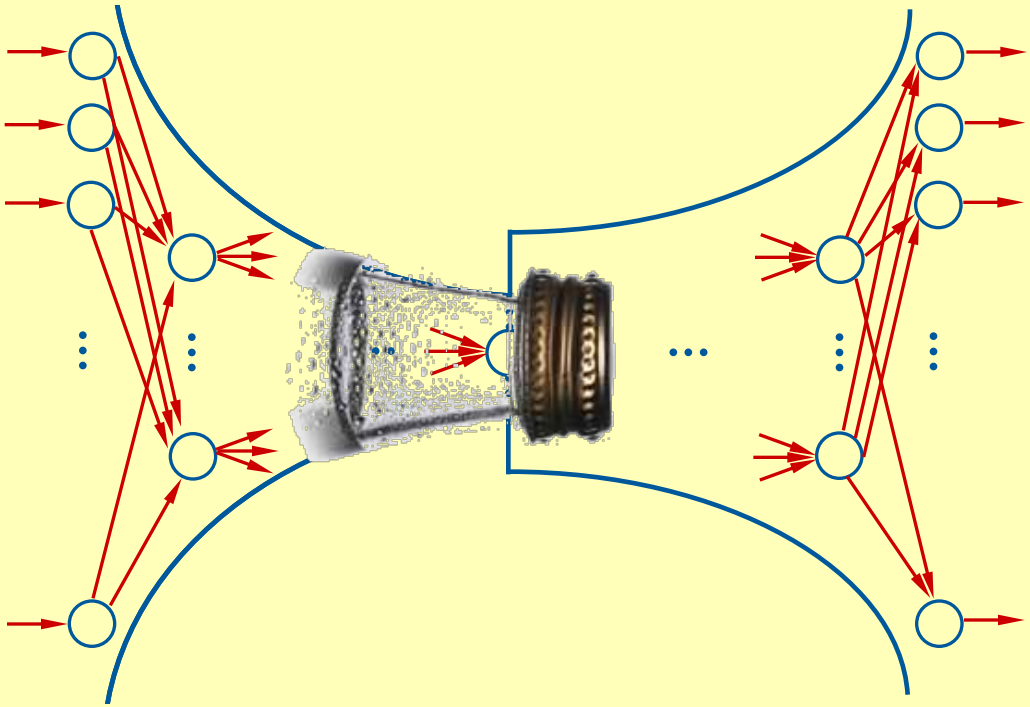


non-linear mapping

(25x24) wave spectrum

(25x24) non-linear interaction source term

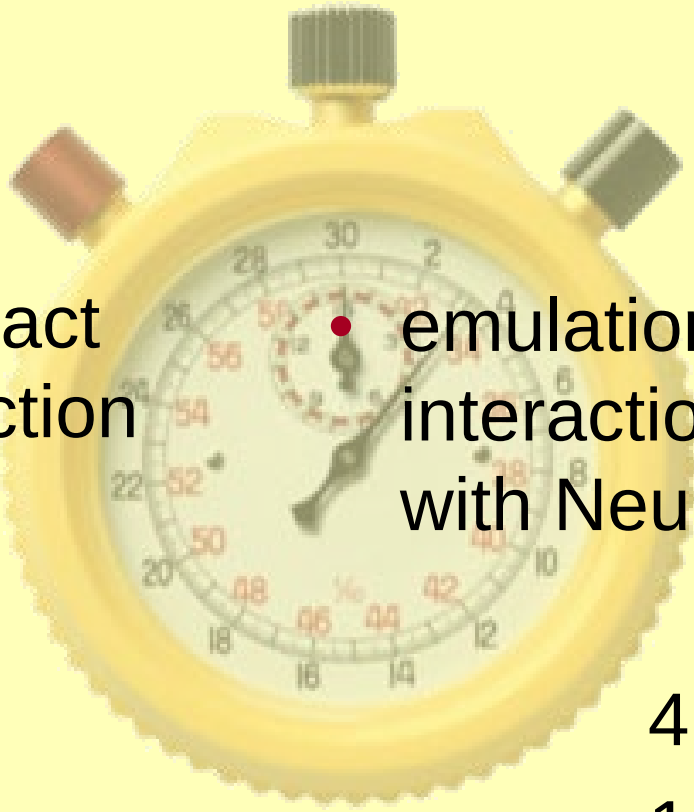
NN mapping of non-linear interaction



(25x24) wave spectrum

(25x24) non-linear interaction source term

Runtime comparison



- calculation of exact nonlinear interaction source terms:

2460 seconds /

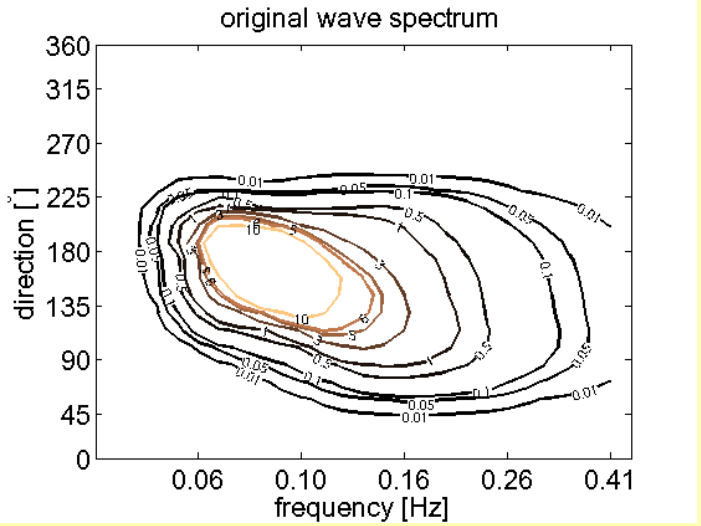
1000 spectra

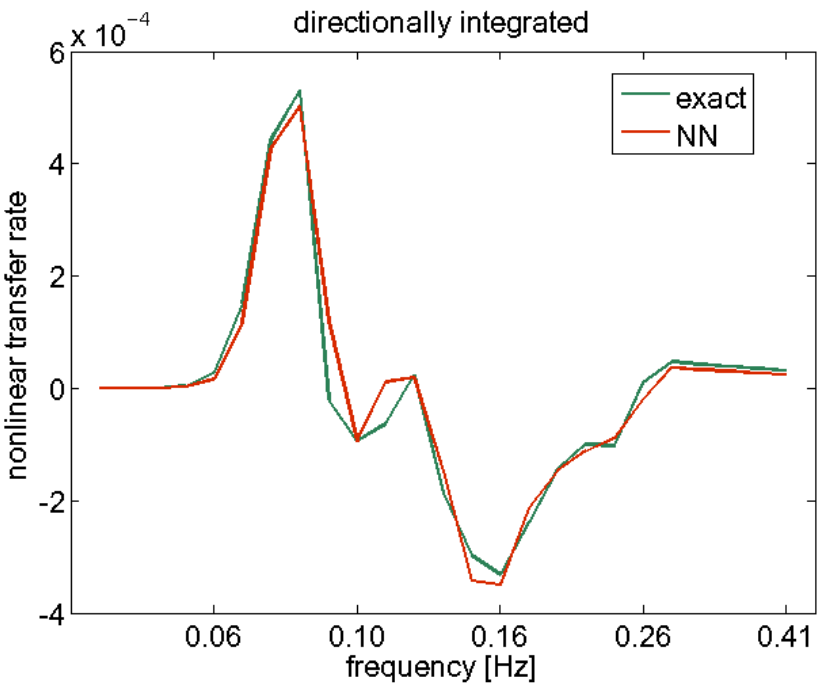
- emulation of nonlinear interaction source terms with Neural Net:

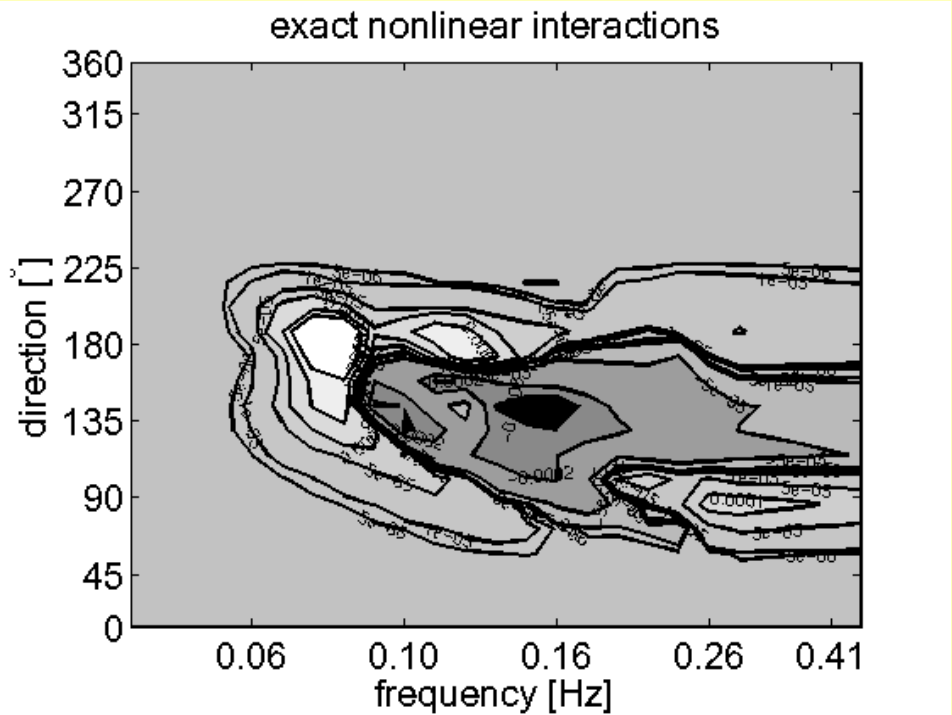
4.1 seconds /

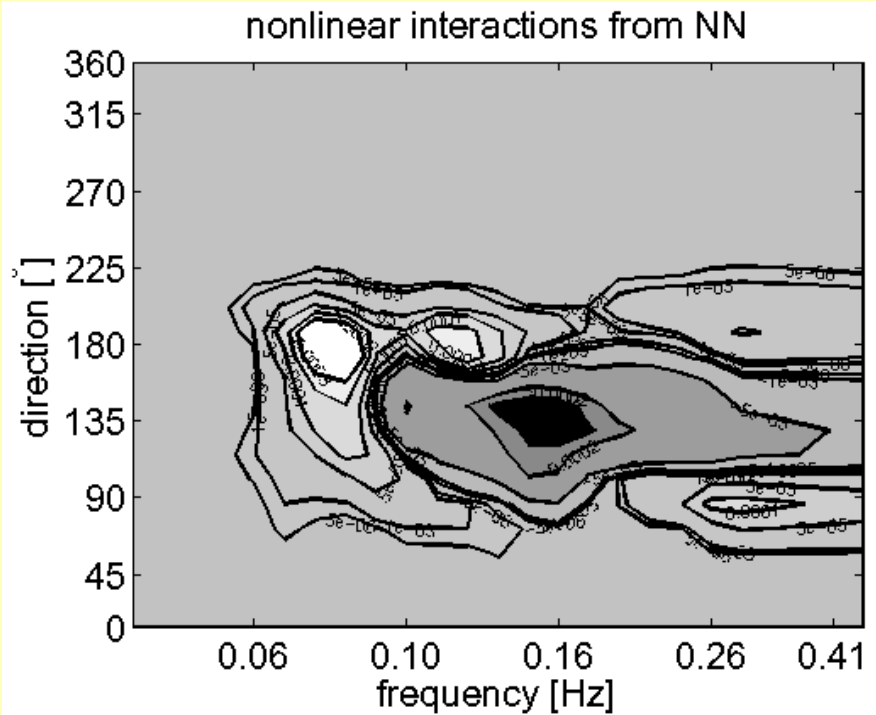
1000 spectra

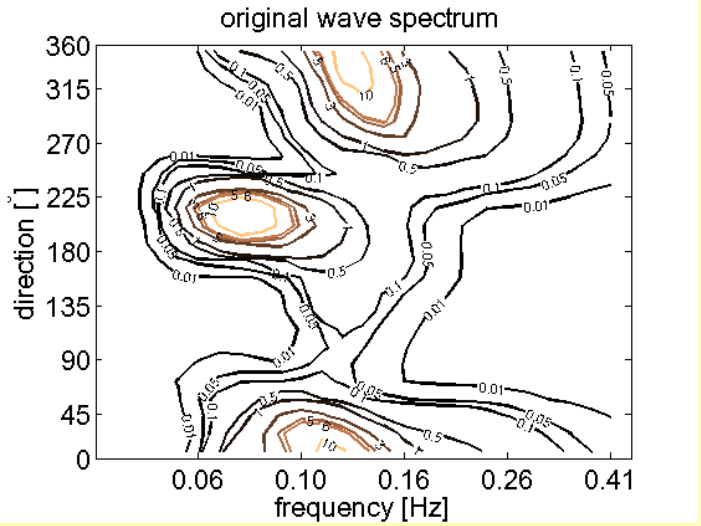
x 600


original wave spectrum
direction [°]
frequency [Hz]
360
315
270
225
180
135
90
45
0
0.06
0.10
0.16
0.26
0.41


directionally integrated
x 10^-4
nonlinear transfer rate
frequency [Hz]
exact
NN
6
4
2
0
-2
-4
0.06
0.10
0.16
0.26
0.41


exact nonlinear interactions
direction [°]
frequency [Hz]
360
315
270
225
180
135
90
45
0
0.06
0.10
0.16
0.26
0.41


nonlinear interactions from NN
direction [°]
frequency [Hz]
360
315
270
225
180
135
90
45
0
0.06
0.10
0.16
0.26
0.41


original wave spectrum
direction [°]
frequency [Hz]
360
315
270
225
180
135
90
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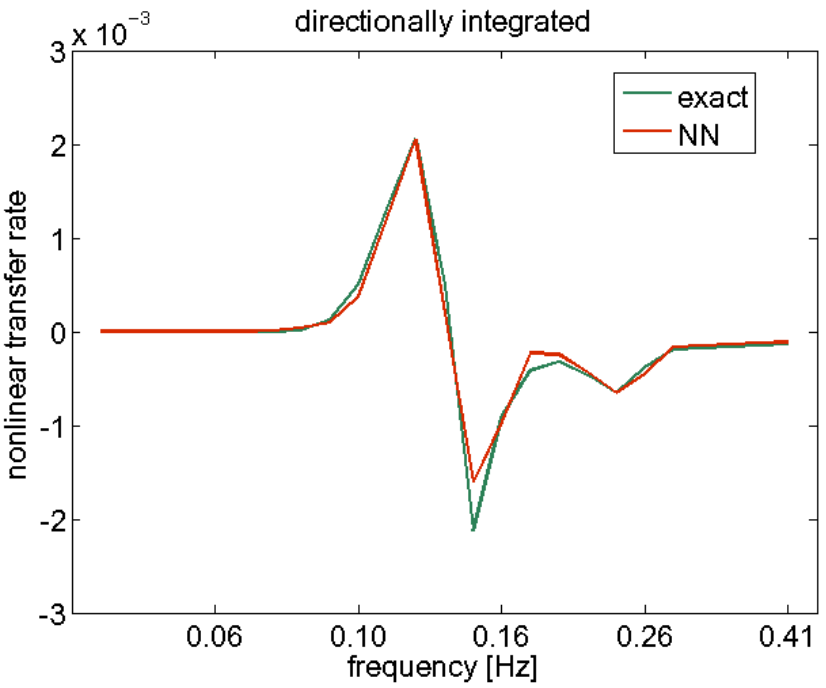
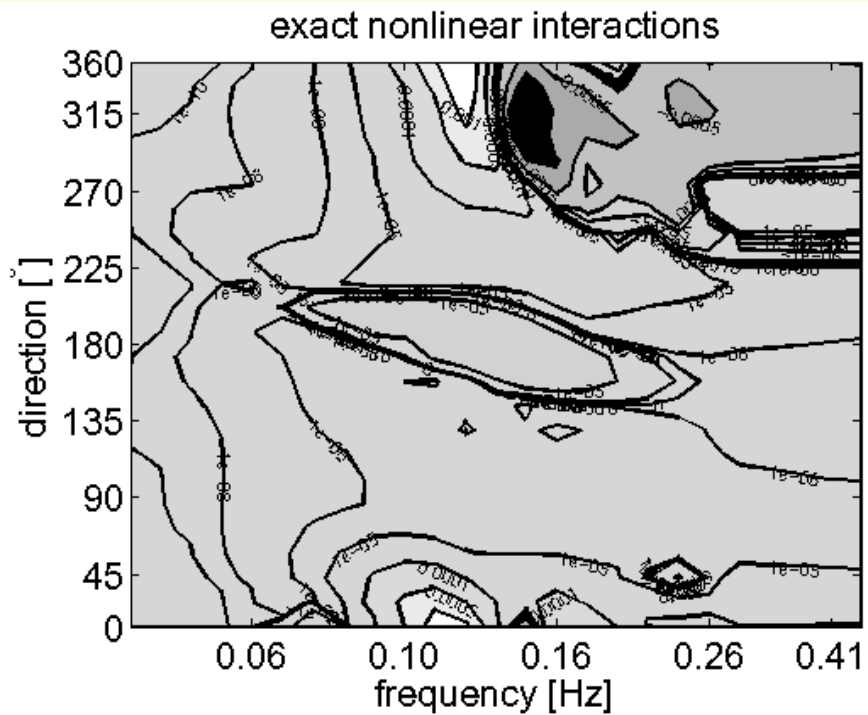
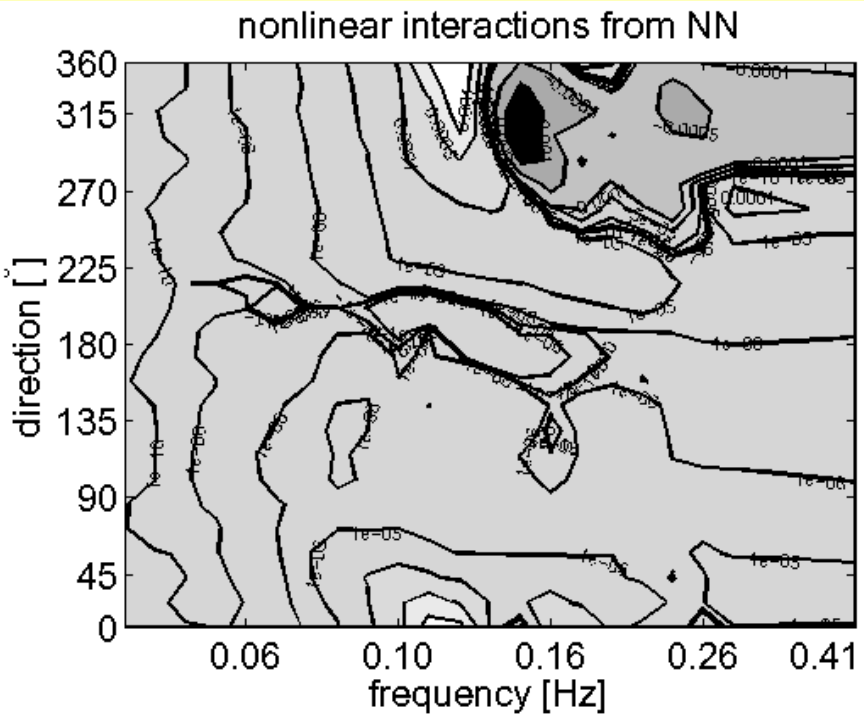
0.06
0.10
0.16
0.26
0.41


directionally integrated
x 10^-3
nonlinear transfer rate
frequency [Hz]
exact
NN
3
2
1
0
-1
-2
-3
0.06
0.10
0.16
0.26
0.41


exact nonlinear interactions
direction [°]
frequency [Hz]
360
315
270
225
180
135
90
45
0
0.06
0.10
0.16
0.26
0.41


nonlinear interactions from NN
direction [°]
frequency [Hz]
360
315
270
225
180
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0.06
0.10
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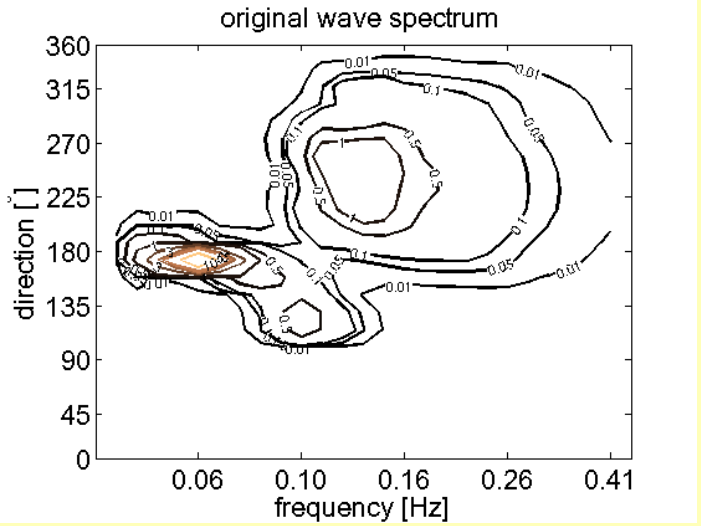
0.41


original wave spectrum
direction [°]
frequency [Hz]
360
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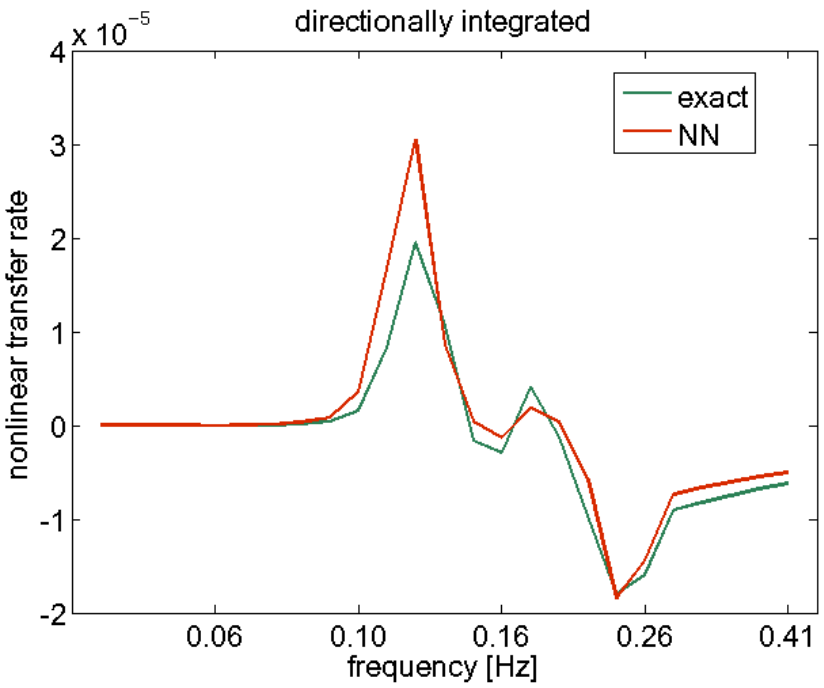
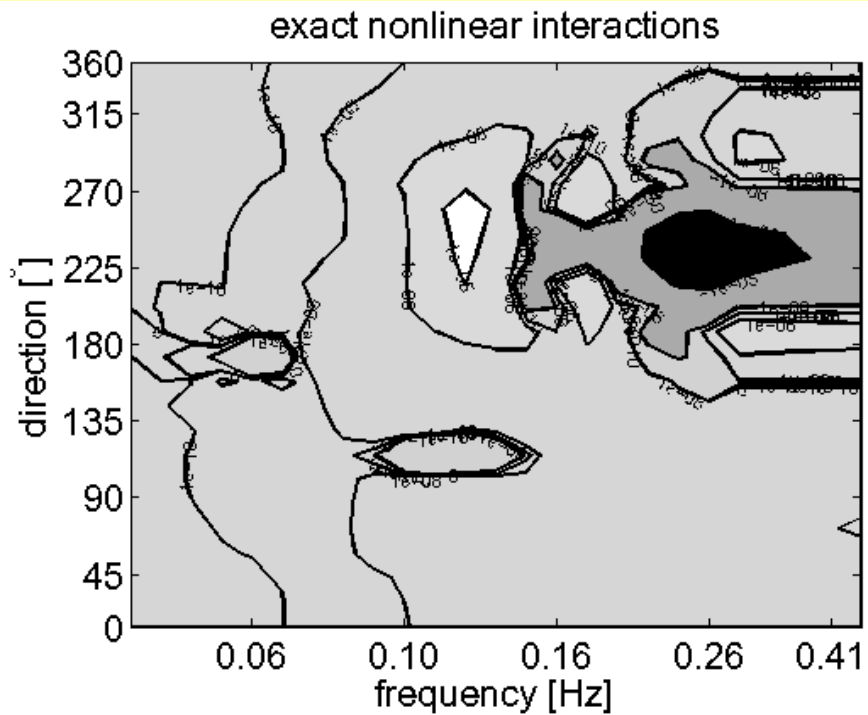
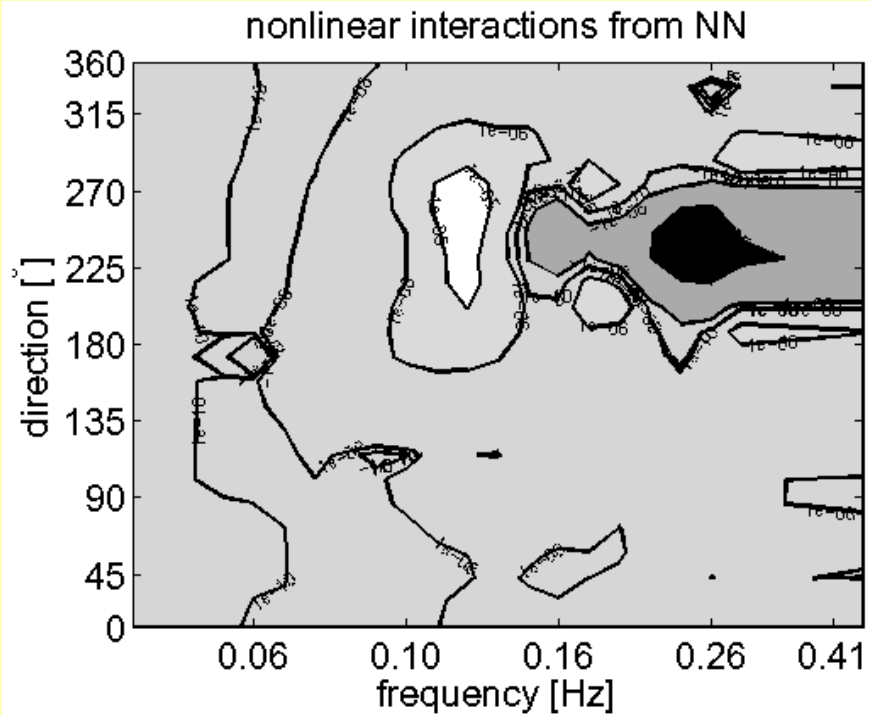
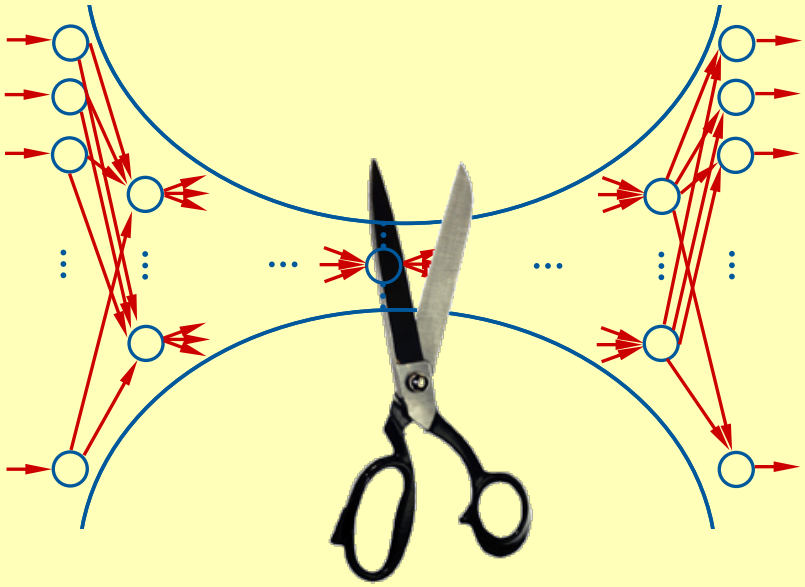
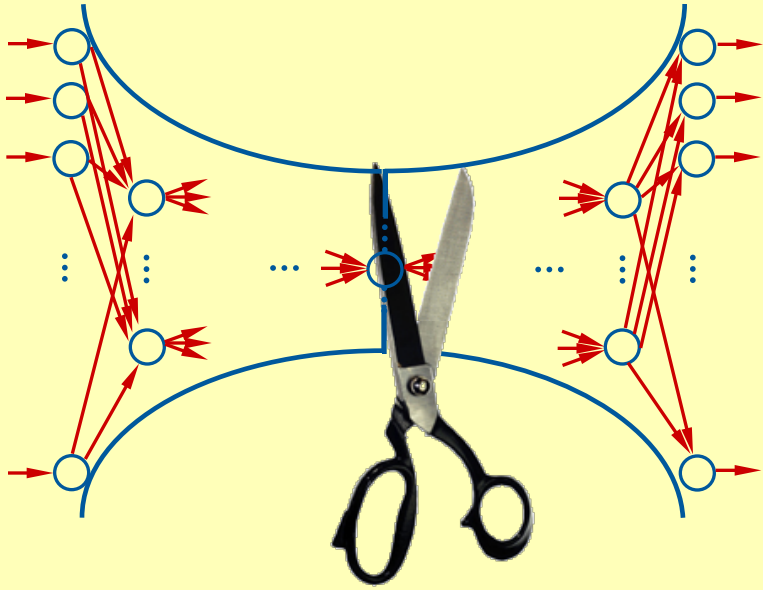

directionally integrated
x 10^-5
nonlinear transfer rate
frequency [Hz]
exact
NN
4
3
2
1
0
-1
-2
0.06
0.10
0.16
0.26
0.41


exact nonlinear interactions
direction [°]
frequency [Hz]
360
315
270
225
180
135
90
45
0
0.06
0.10
0.16
0.26
0.41


nonlinear interactions from NN
direction [°]
frequency [Hz]
360
315
270
225
180
135
90
45
0
0.06
0.10
0.16
0.26
0.41

Concluding remarks

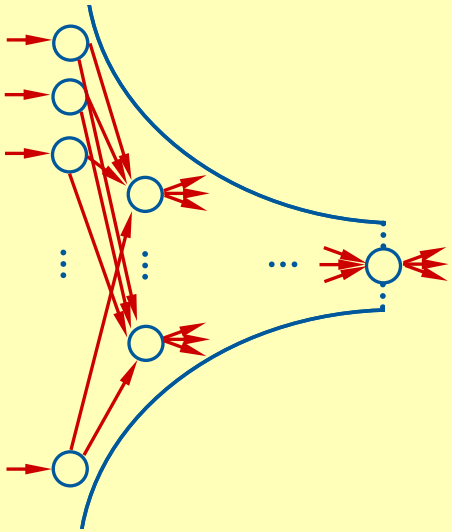


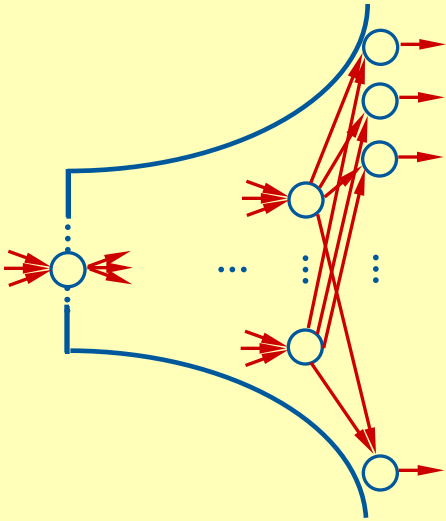


- nonlinear reduction mapping of wave spectra onto themselves

- nonlinear reduction mapping of S_{nl} terms onto themselves

Concluding remarks

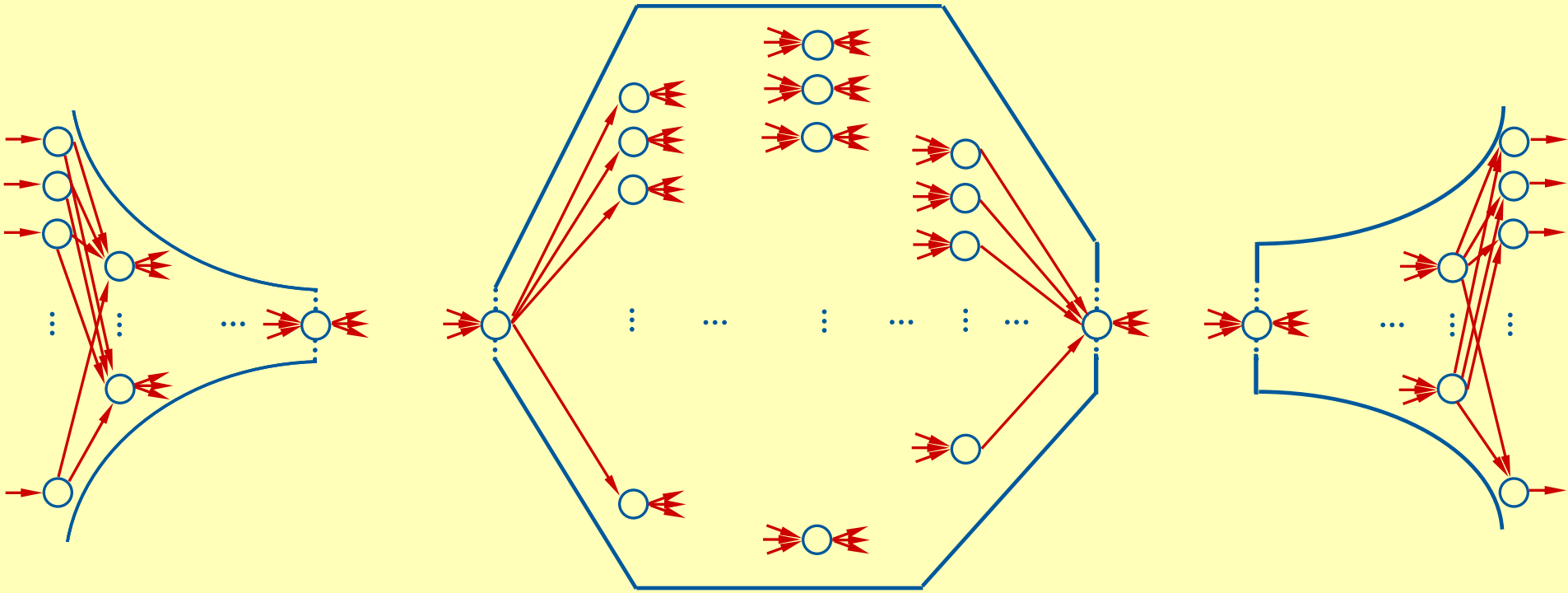




- (24x25) wave spectra
  → compressed (39 dim.) wave spectra

- compressed (50 dim.) S_{nl} terms
  → (24x25) S_{nl} terms

Concluding remarks



→ map compressed representations onto each other

\+ more complex NN architectures

\+ independent of wave model resolution

References

- *Krasnopolsky V.M., Chalikov D.V., Tolman H.L., (2001). Using neural network for parameterization of nonlinear interactions in wind wave models. In: International Joint Conference on Neural Networks, 15--19 July, 2001, Washington DC, pp. 1421-1425, ISBN 0-7803-7044-9.*
- *Tolman H.L., V. M. Krasnopolsky, Chalikov D.V. (2005). Neural network approximation for nonlinear interactions in wind wave spectra: direct mapping for wind sea in deep water. Ocean Modelling 8 , 253-278 .*
- *Wahle K., Günther H., Schiller, H., (2009). Neural network parameterisation of the mapping of wave spectra onto nonlinear four-wave interactions. Ocean Modelling 30, 48-55.*

Thank you

for your attention!