DIPARTIMENTO
DI INGEGNERIA
DELL'INFORMAZIONE

UNIVERSITÀ DEGLI STUDI DI PADOVA

SIGNET
signet.dei.unipd.it

WOSS – World Ocean Simulation System

Padova (Italy)

30th of January – 3rd of February 2023

Federico Guerra, Filippo Campagnaro, Michele Zorzi

woss@guerra-tlc.com, filippo.campagnaro@unipd.it

Propagation comparison

Terrestrial radio

- Electro-magnetic wave
- High bandwidth (MHz)
- Short prop. delays (μs)
- Isotropic propagation
- Bandwidth independent of distance
- Typically, white noise
- Required power Tx ≈ Rx (mW)

Underwater acoustic

- Pressure wave
- Low bandwidth (kHz)
- Long prop. delays (s)
- Anisotropic propagation
- Bandwidth dependent on distance
- Freq.-dependent noise
- Required power Tx >> Rx (W)

Propagation delay

- Speed of sound in water: about 1500 m/s
- This means that propagation delays can be significant
- Example for a 1000-bit packet
  - Link of length 1 km
    - propagation delay: 0.66 s
    - transmission time @ 25 kbps: 0.04 s
  - Link of length 10 km
    - propagation delay: 6.6 s
    - transmission time @ 10 kbps: 0.1 s

Current propagation models

- Currently: efforts to develop synthetic channel models, no model largely agreed upon.
- Typical approach for networking studies: use empirical equations.

PROS	CONS
1. Straightforward implementation and evaluation 2. Empirical formulas are very quick to evaluate, allowing longer network simulations	1. Approximations are often inaccurate due to: • deployment scenario • real propagation patterns • sea bottom morphology • bottom reflection/absorption • … 2. No channel variability in time

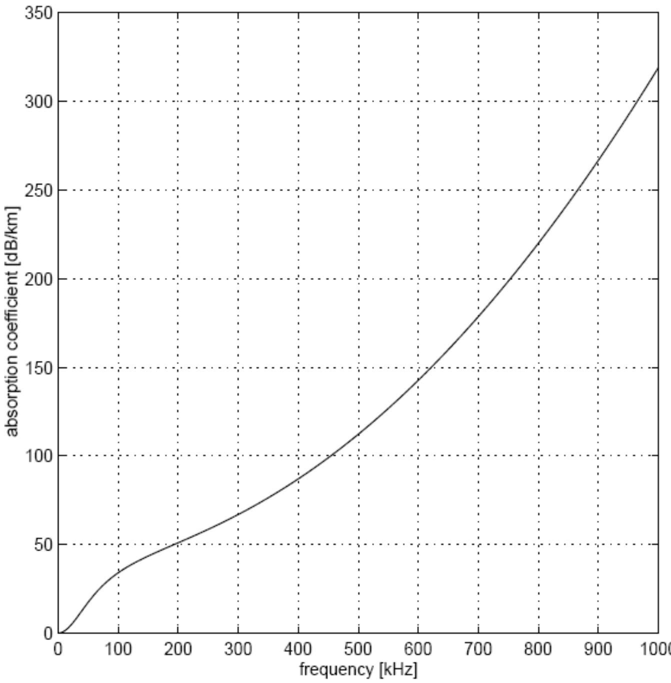
Propagation models - attenuation

- Path loss equation

$$10 \log A(\ell, f) = k \cdot 10 \log \ell + \ell \cdot 10 \log a(f),$$

- Absorption (Thorp's formula)

$$10 \log a(f) = 0.11 \frac{f^2}{1+f^2} + 44 \frac{f^2}{4100+f} + 2.75 \cdot 10^{-4} f^2 + 0.003,$$



(adapted from Stojanovic)

Current propagation models - noise

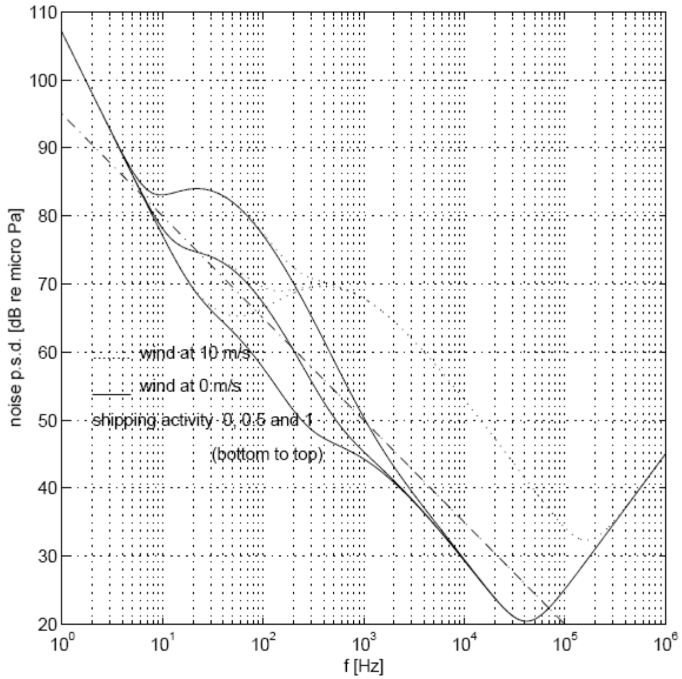
- Sum of four components:

$$N(f) = N_t(f) + N_s(f) + N_w(f) + N_{th}(f)$$

Noise sources:
turbulence, shipping, wind, thermal noise

- where:

$$10\log N_t(f) = 17 - 30\log f$$
$$10\log N_s(f) = 40 + 20(s - 0.5) + 26\log f - 60\log(f + 0.03)$$
$$10\log N_w(f) = 50 + 7.5w^{1/2} + 20\log f - 40\log(f + 0.4)$$
$$10\log N_{th}(f) = -15 + 20\log f,$$



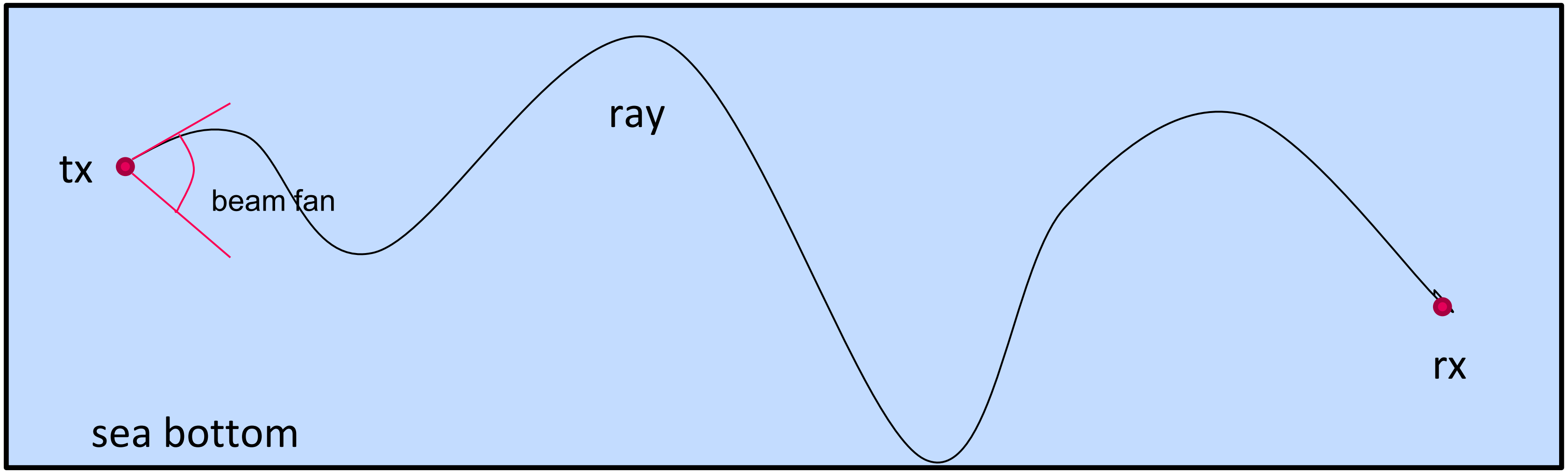
(adapted from Stojanovic)

Actual acoustic propagation

- The propagation path of acoustic waves in water depends on
  - sound speed as a function of depth, i.e.,
    the sound speed profile (SSP), which in turn
    - Depends on salinity, temperature, depth
    - Varies with time (daily/seasonal cycles) and space
  - morphology of the sea bottom (bathymetry)
  - composition of the bottom sediments
  - roughness of the sea surface (altimetry)
  - internal waves
  - …

The ray-tracer tool

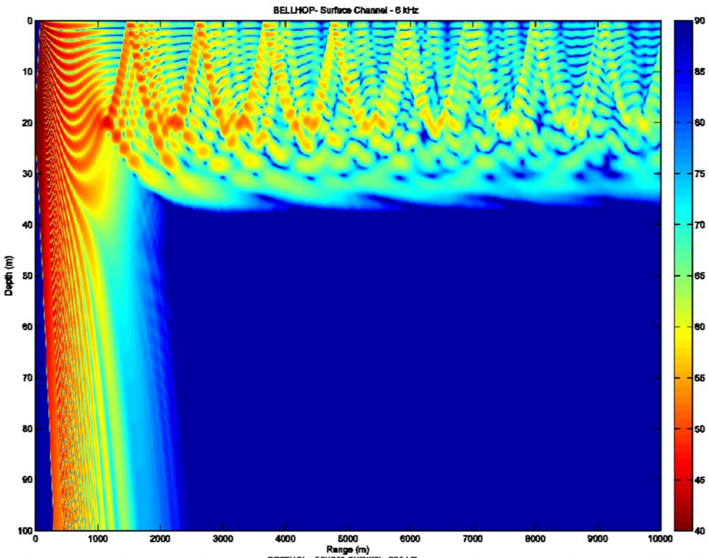
- It is a tool that simulates propagation in the cross-section plane containing the transmitter and the receiver;
- Given the beam fan and the beam number it traces the propagation of each ray, i.e., its reflection and refraction due to the environment;
- Each ray carries a fraction of the transmitter pressure that is attenuated due to absorption, reflection loss … the carried pressure is complex (every reflection introduces a phase shift);
- **The transmission loss** in any point of the plane is the complex sum of all pressure associated to every rays that pass through that point. This value is transformed in dB

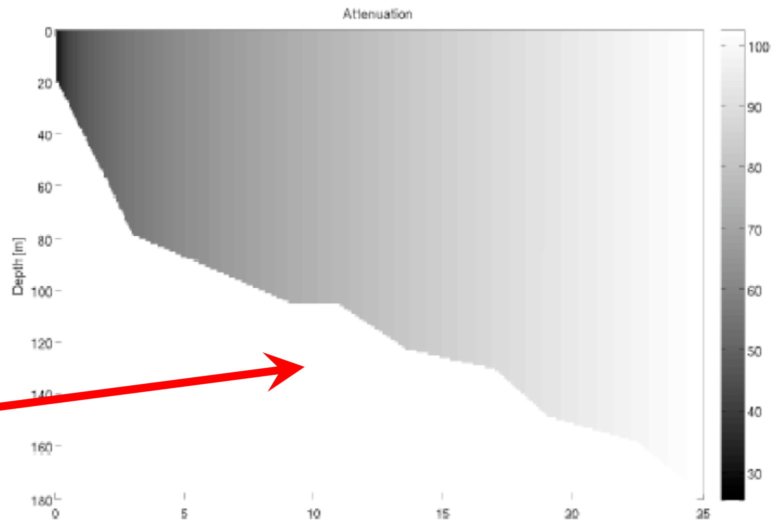


Actual acoustic propagation (examples)

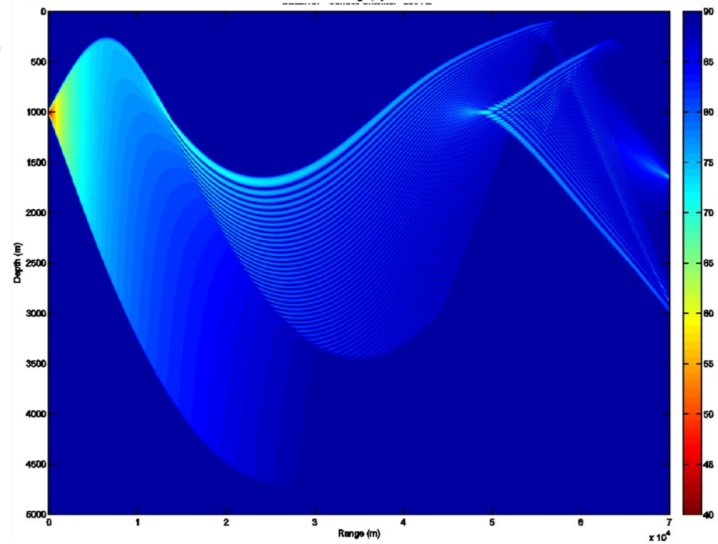
Environmental factors can originate:

- shadow zones
- superficial channels
- convergence zones
- deep sound axis channels…
- short- and long-term fading





For comparison: empirical formulas



WOSS - World Ocean Simulation System

- The *World Ocean Simulation System* (WOSS) is a fully automated framework for integrating channel and network simulation software
- Originally thought as a full-fledged interface to Bellhop ray-tracer…
- …now can be interfaced with *any* channel simulator, to which it can provide all required environmental data

WOSS - World Ocean Simulation System

- What does full-fledged mean here?
  - WOSS Provides a flexible, extendable, technology-independent API for
    - retrieving and manipulating bathymetry, altimetry, Sound Speed Profiles (SSPs) and bottom sediment data from
      - Standard databases
      - User/custom databases
    - manipulate transmission loss or channel power-delay profile as output by the channel simulator and feed it to the network simulator
    - optionally store and retrieve channel simulation outputs in a custom database for later use

WOSS - current capabilities

- The current version provides:
  - Interface implementation and custom NetCDF databases of monthly averaged SSPs taken from the World Ocean Atlas databases (up to the 2018 dataset).
  - Interface implementation for the GEBCO NetCDF bathymetry databases (up to the 2022 version).
  - Interface implementation and custom NetCDF data analysis of the DECK 41 database, for bottom sediments composition and parameters.
  - Fully detailed interface for the Bellhop ray tracing program with custom beam patterns, altimetry etc.
  - Support for time evolution in order to simulate environmental data that changes over time.
  - Support for transducer beam patter modeling to enhance the ray-tracer results.

WOSS – integration in ns

- WOSS is a C++ shared library that can be integrated with any network simulator.
- So far it has been integrated into:
  - ns-miracle and DESERT
  - ns-3

WOSS - integration in ns

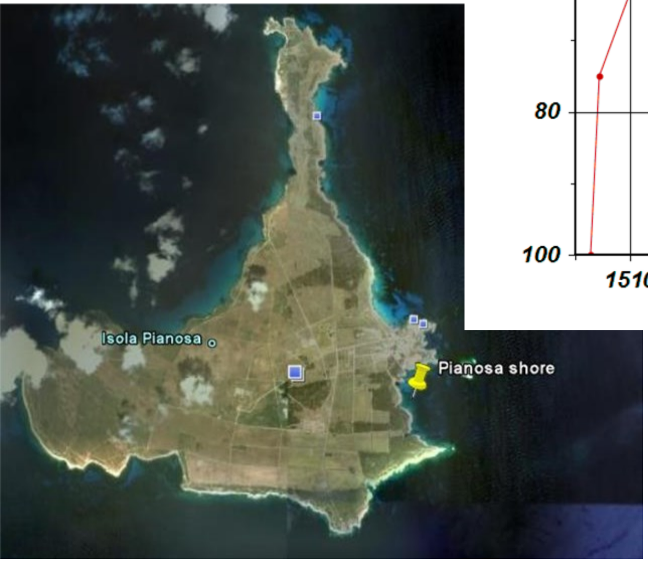
- ns-miracle integration library it is distributed with the main WOSS library, and it contains:
  - wrapper classes that adapt WOSS concepts of time, position, random number generator, within ns-miracle / ns-2 simulator.
  - Propagation and channel classes, that allow ns-miracle and DESERT to properly use WOSS APIs in the simulation for attenuation computation.
  - BPSK class with optional transducer power computations
  - Waypoint position model
  - TCL classes, variables and methods for all the required WOSS C++ classes.
- woss-ns3 integration framework it is distributed as a separated git repository

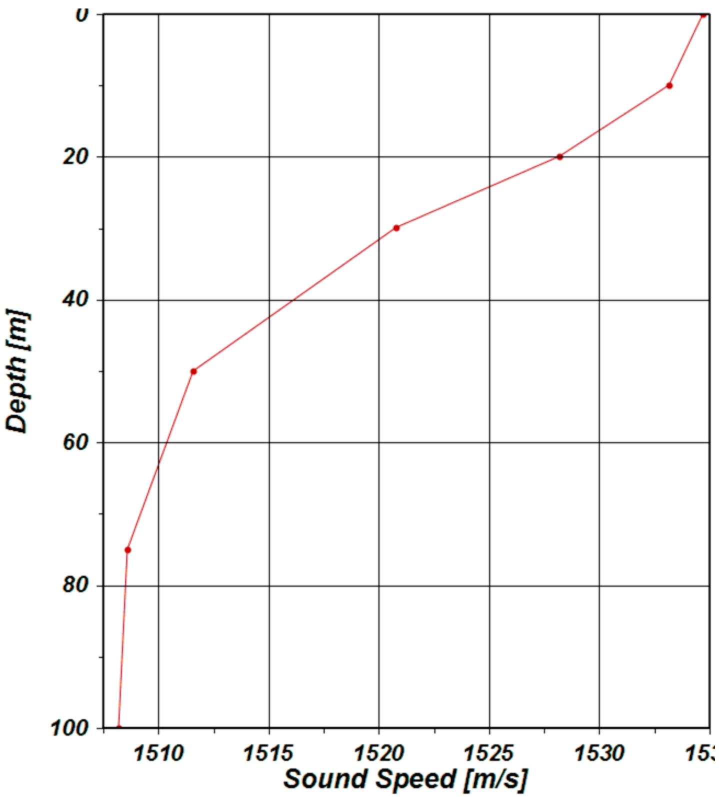
WOSS – website and support

- Where is located
  - https://woss.dei.unipd.it/
- What does the website offer:
  - Technical description
  - Link to the git repository and standalone archive for the main library
  - Link to the git repository for the woss-ns3 integration framework
  - Archives of WOSS software dependencies (NetCDF4, Acoustic Toolbox, etc)
  - Custom made NetCDF databases
  - Support request and bug report: woss@guerra-tlc.com
- **WOSS is also distributed as an add-on of DESERT**

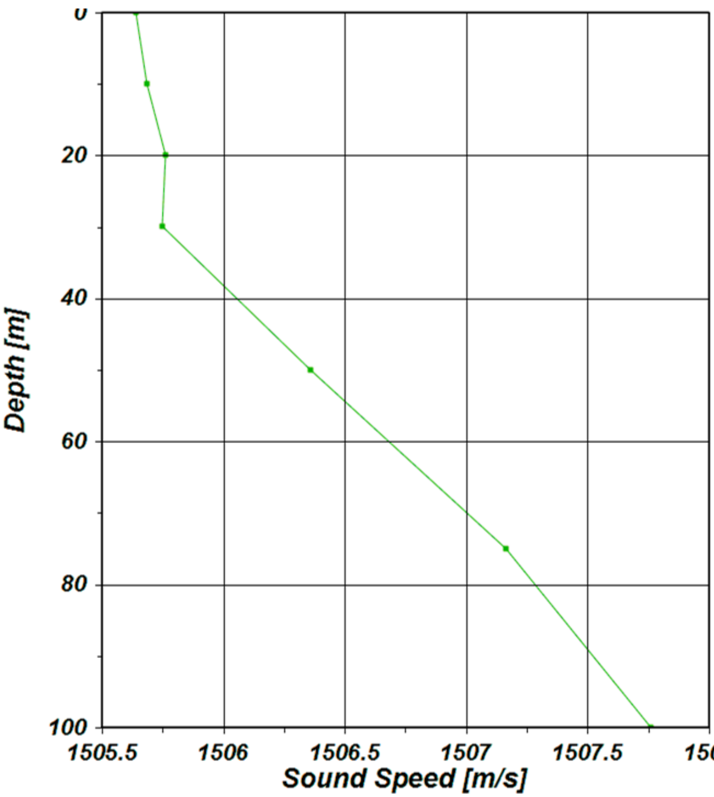
WOSS – some simple results

Example
transmission at
4 kHz, from the shore
of the Italian island
of Pianosa (42.585°N,
10.1°E)
Tx depth: 4m
Rx depth: 115 m
Rx range: 19999.84 m



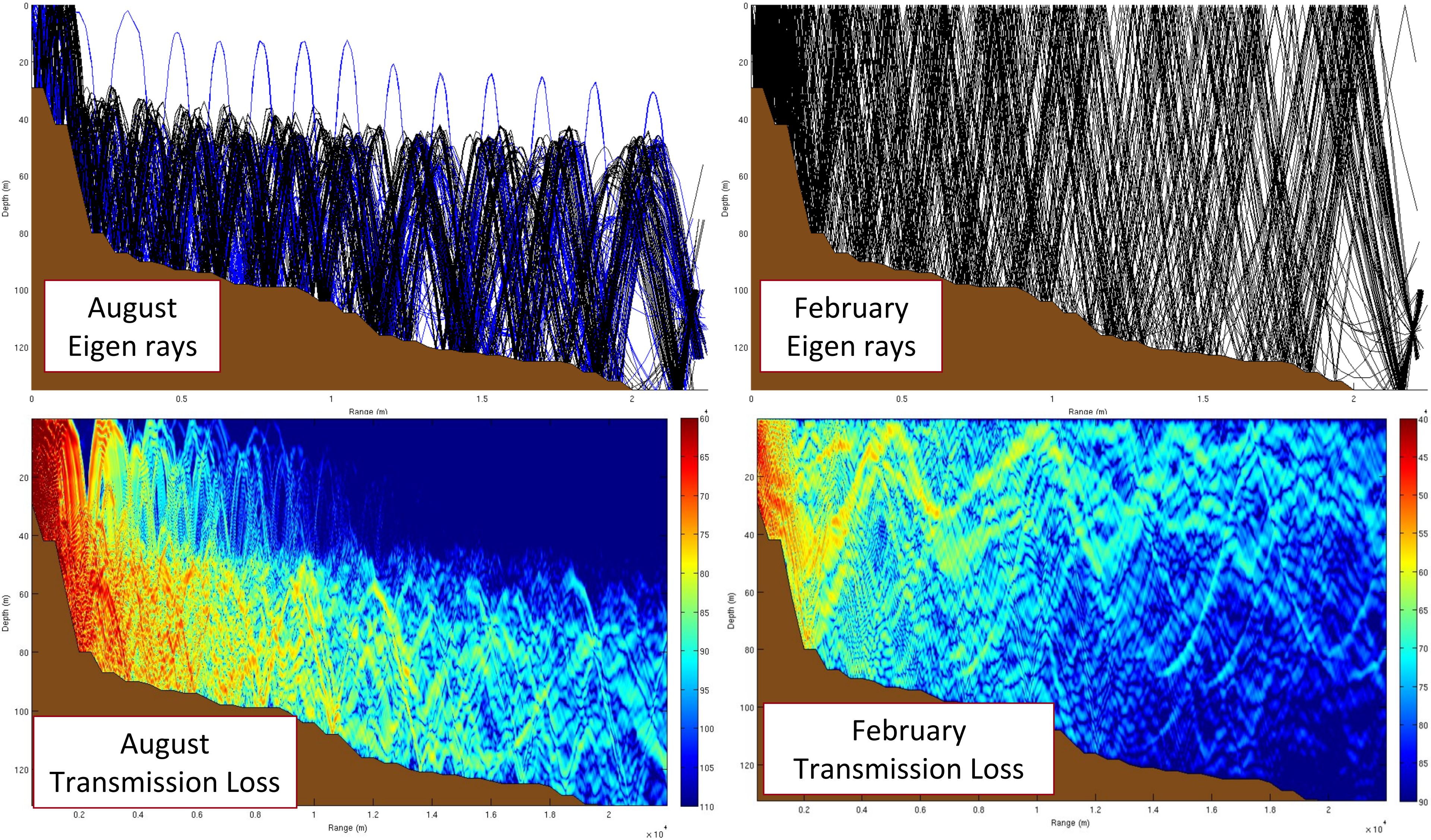


August SSP

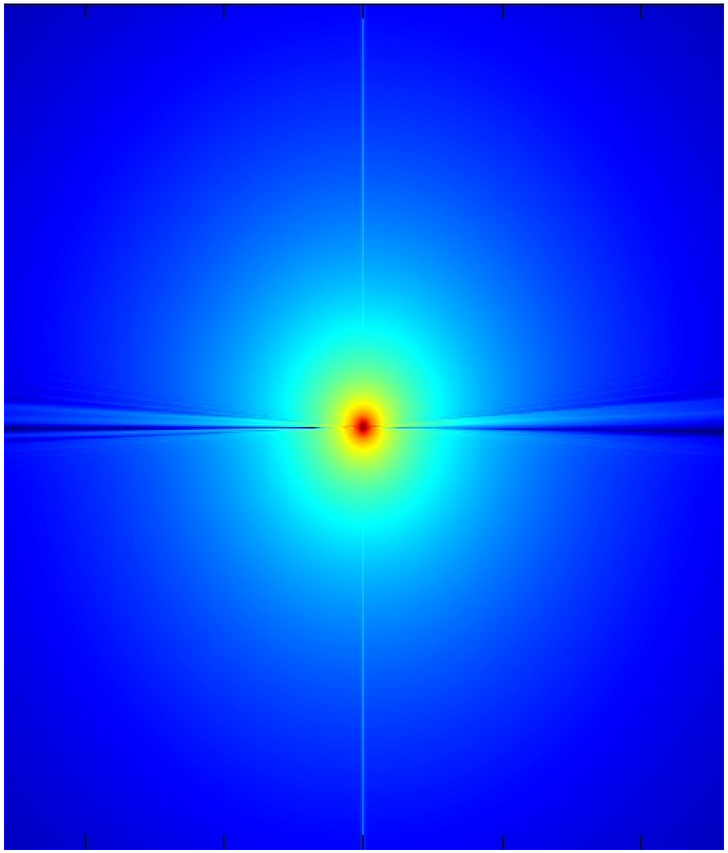


February SSP

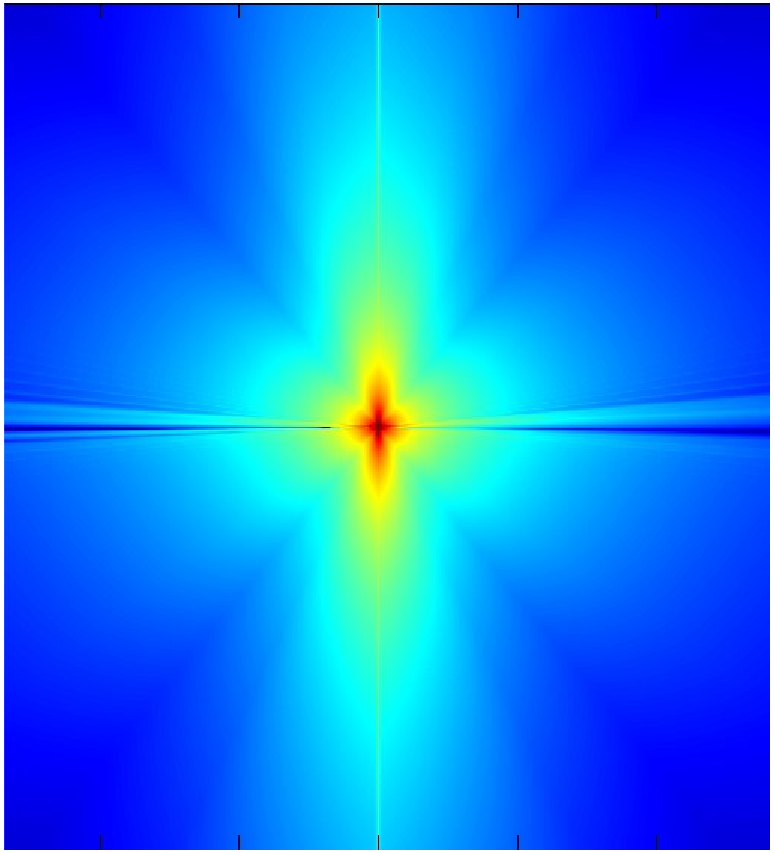
WOSS – some simple results



WOSS – some simple results

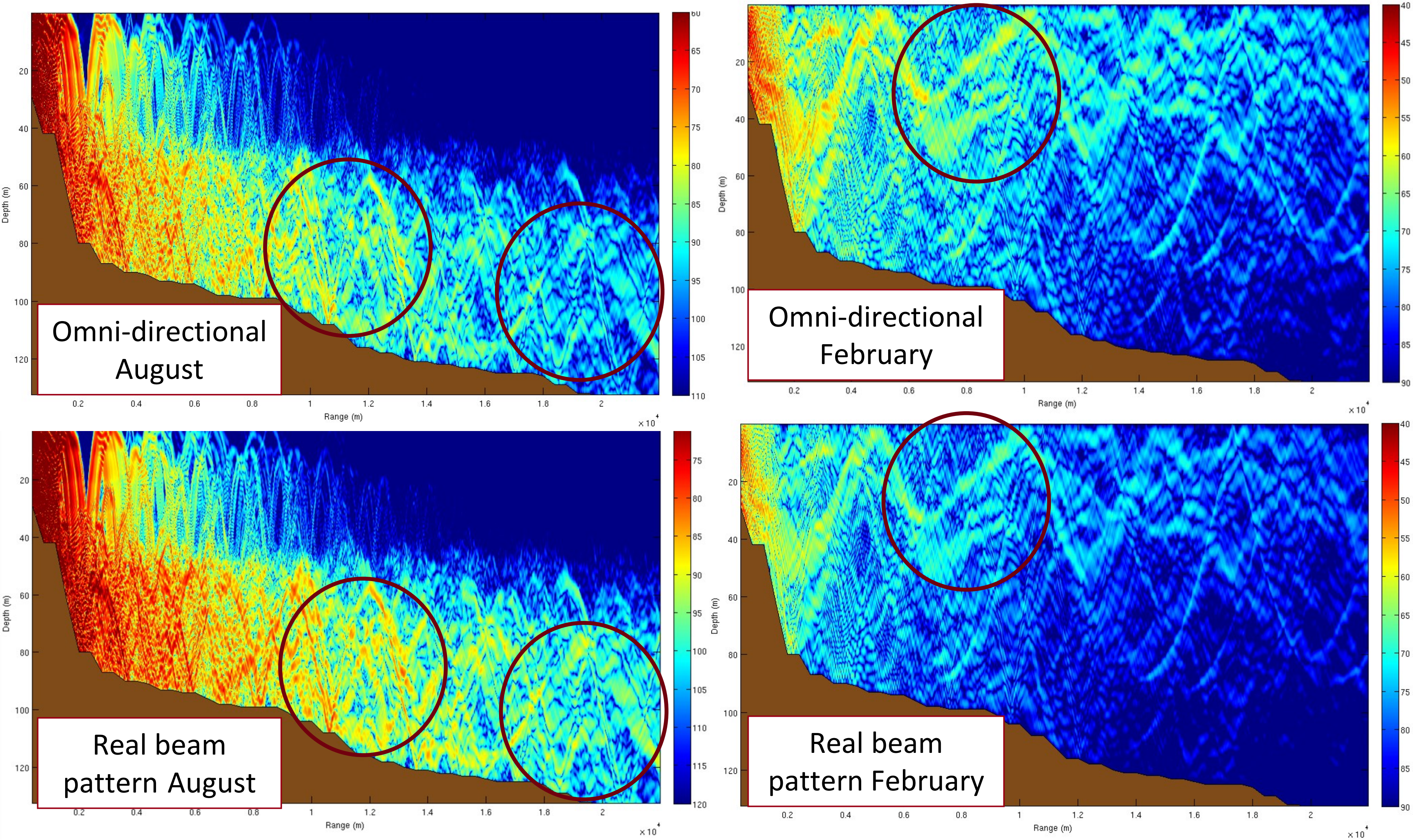


Omni-directional beam pattern

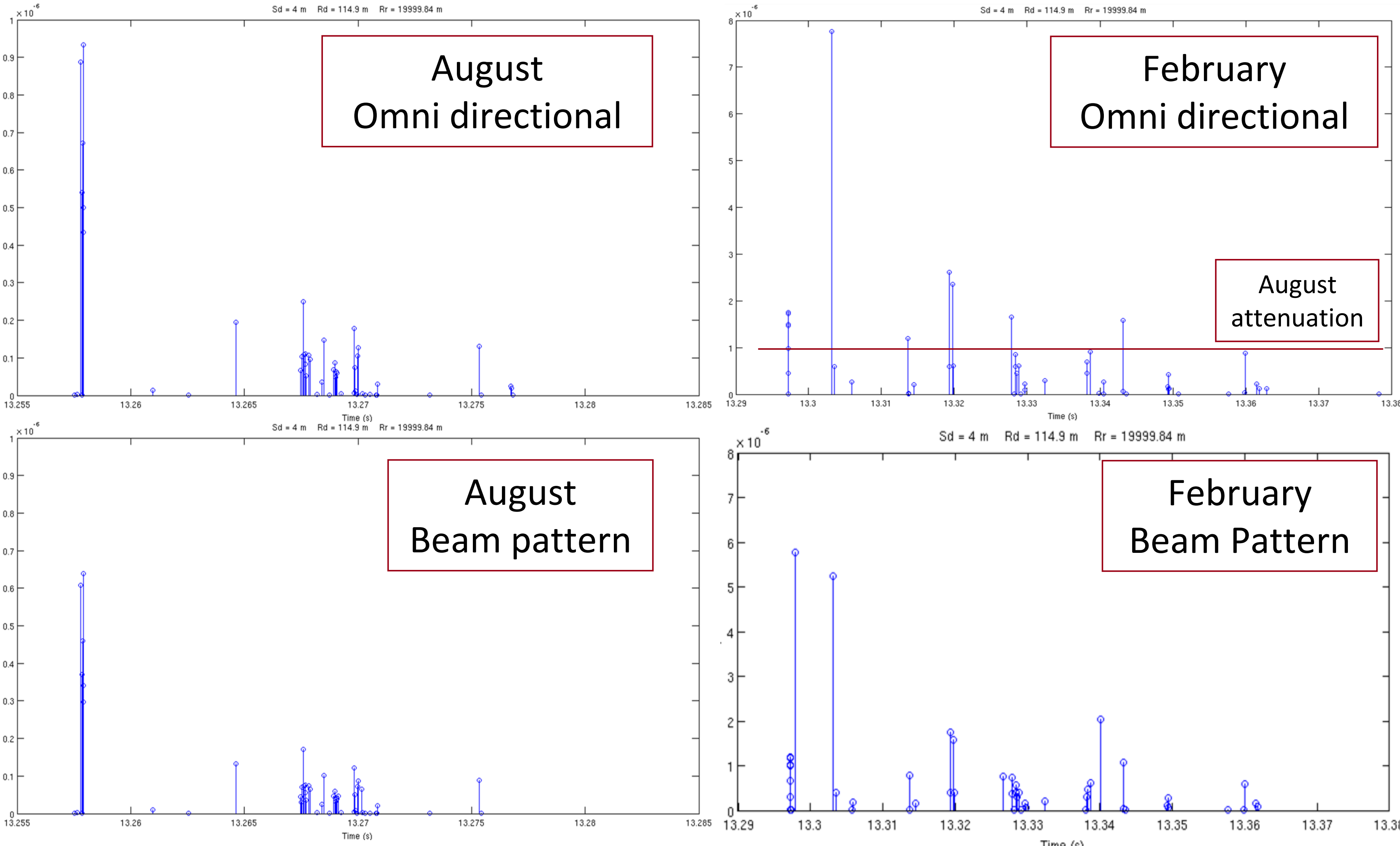


Real transducer beam pattern

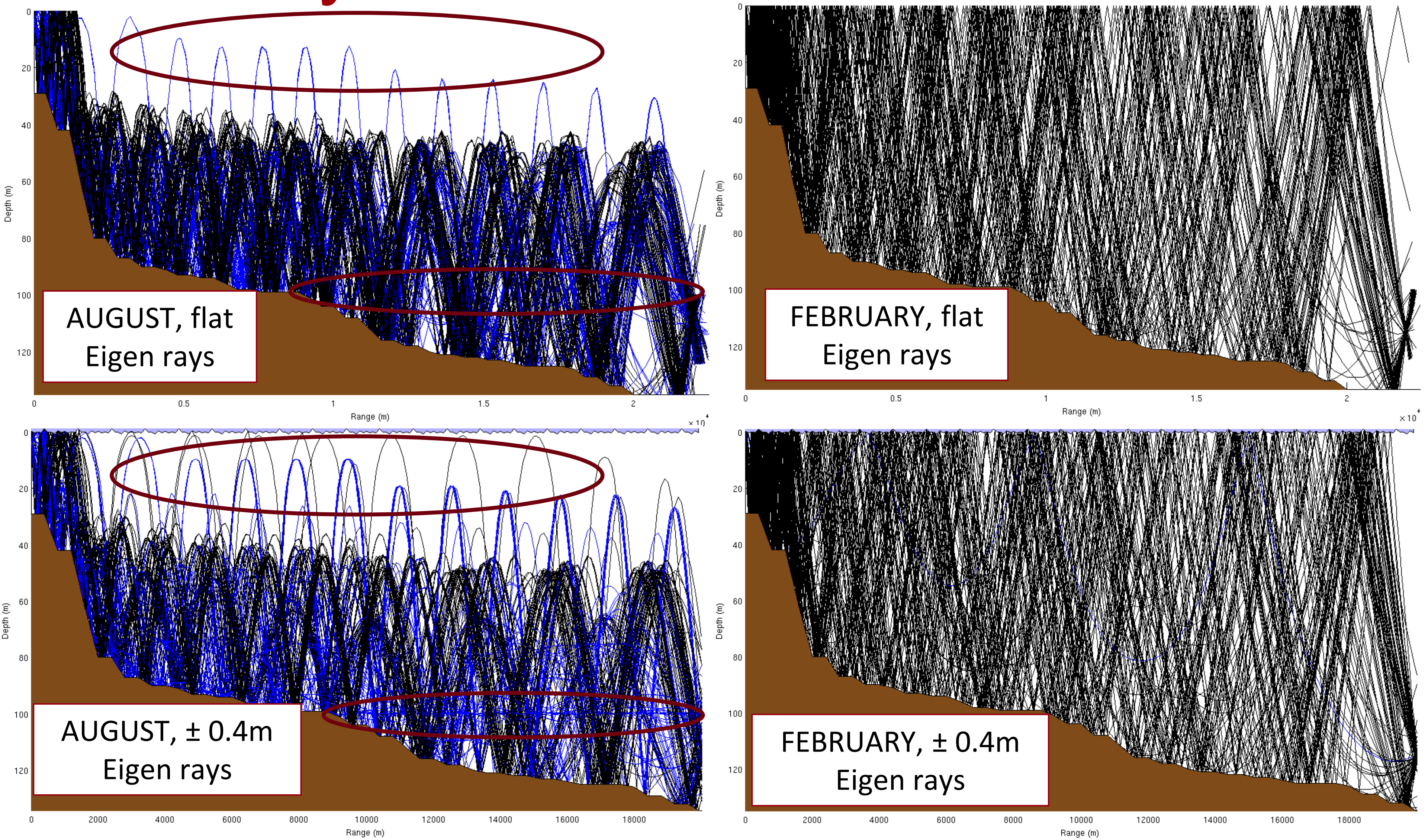
WOSS – some simple results



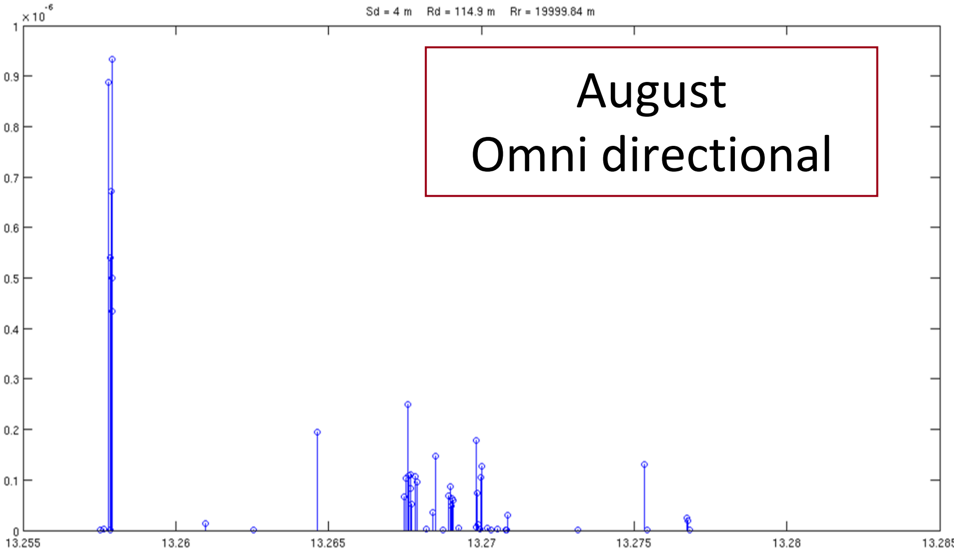
WOSS – some simple results

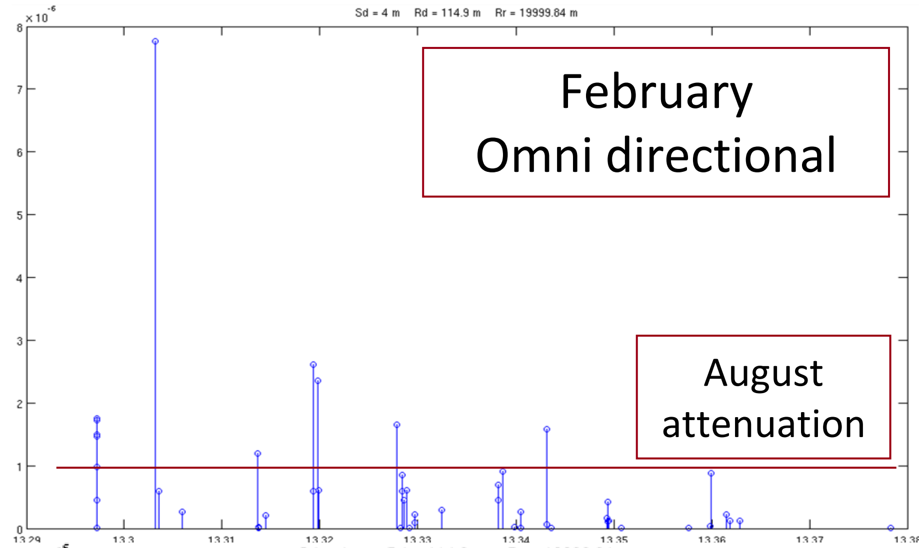


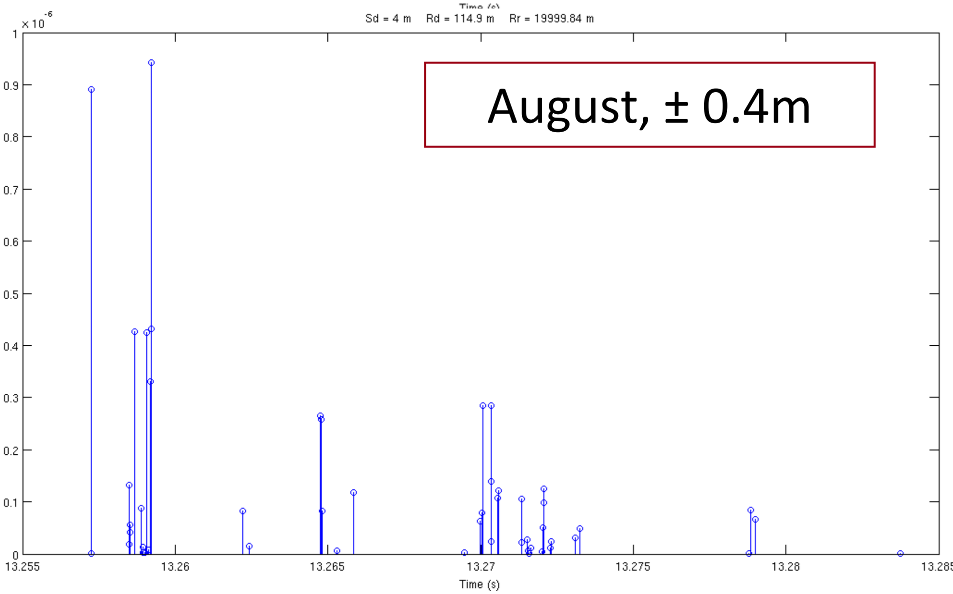
WOSS – some simple results – altimetry

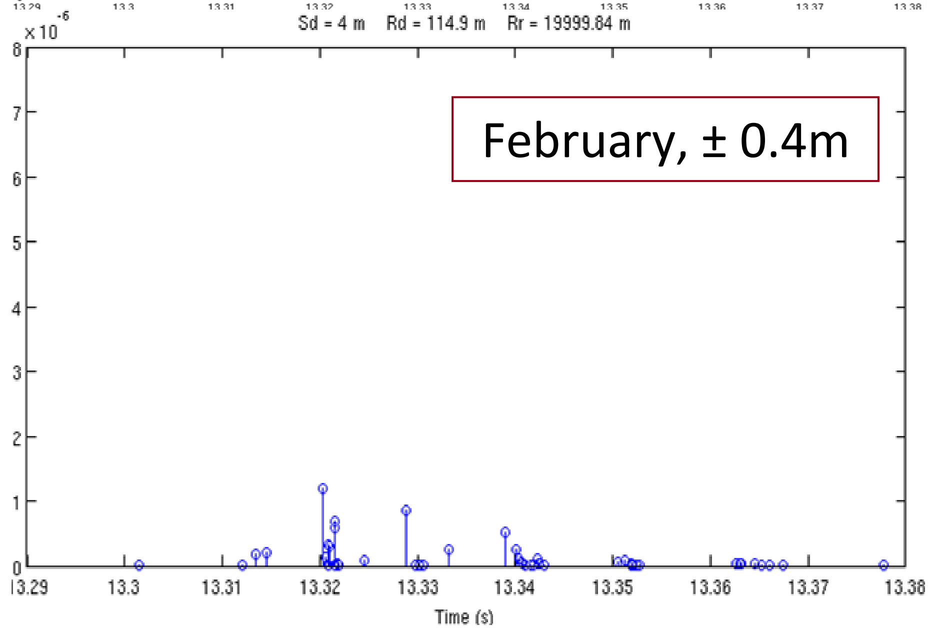


WOSS – altimetry

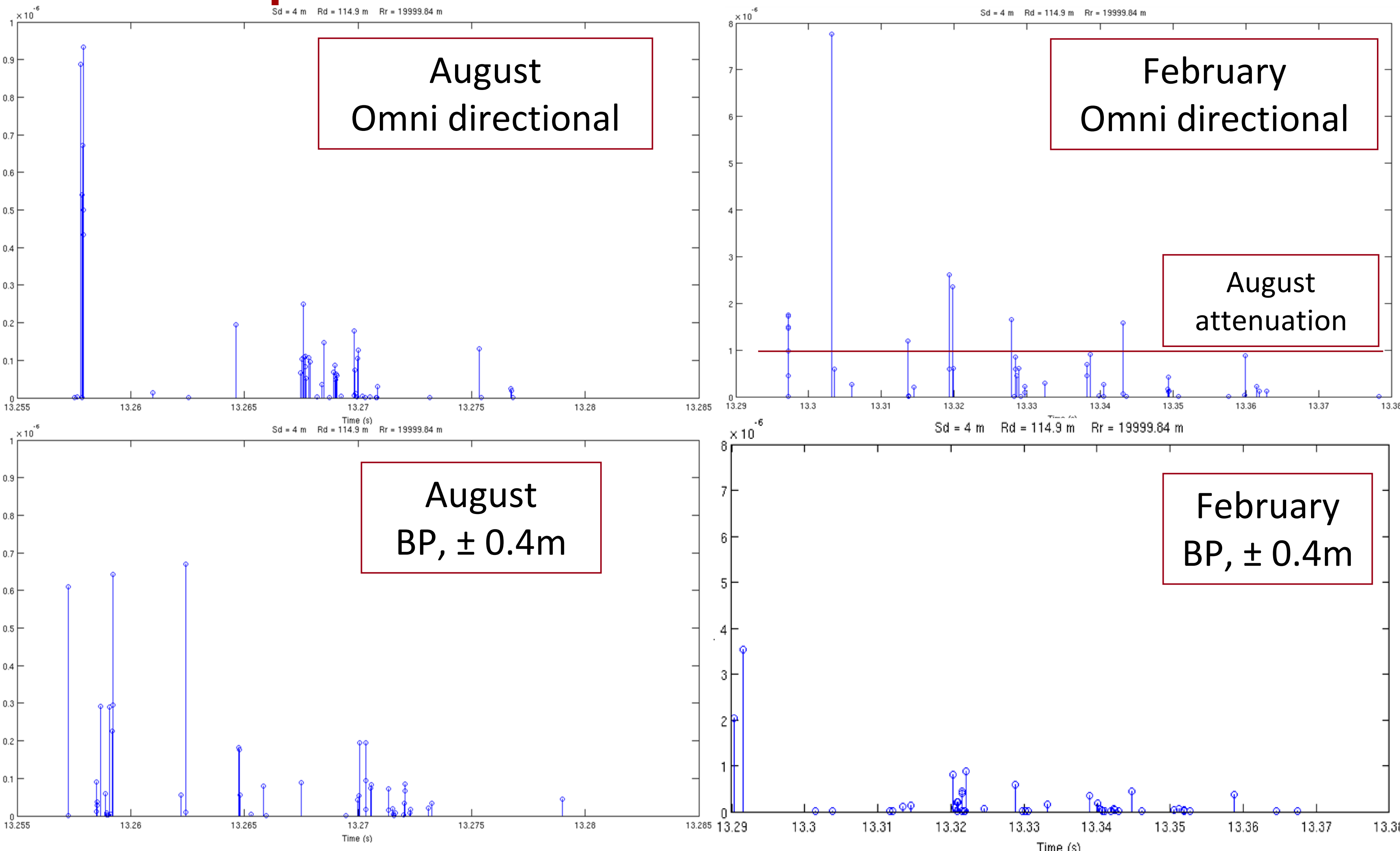








WOSS – altimetry + transducer beam pattern



WOSS – CBR results: PER

	MONTH	OMNI	BP	ATI	ATI + BP
CBR PER	August	$\approx 4 \bullet 10^{-1}$	$\approx 6 \bullet 10^{-1}$	$\approx 5 \bullet 10^{-1}$	$\approx 7 \bullet 10^{-1}$
CBR PER	February	$\approx 5 \bullet 10^{-5}$	$\approx 2 \bullet 10^{-4}$	$\approx 1 \bullet 10^{-1}$	$\approx 1 \bullet 10^{-2}$

- BPSK modulation, PHY rate 4800 bps, packet size 64 bytes, CBR period 60 s;
- In August, the transmitter beam pattern and the altimetry introduce a result worsening;
- in February, the altimetry results in a higher PER, while the beam pattern actually improves the error rate.