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Single-path acoustic scintillation results from the Shallow Water 2006 Experiment

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- Review of results up to the JASA-EL special issue
- Recent progress
- Summary

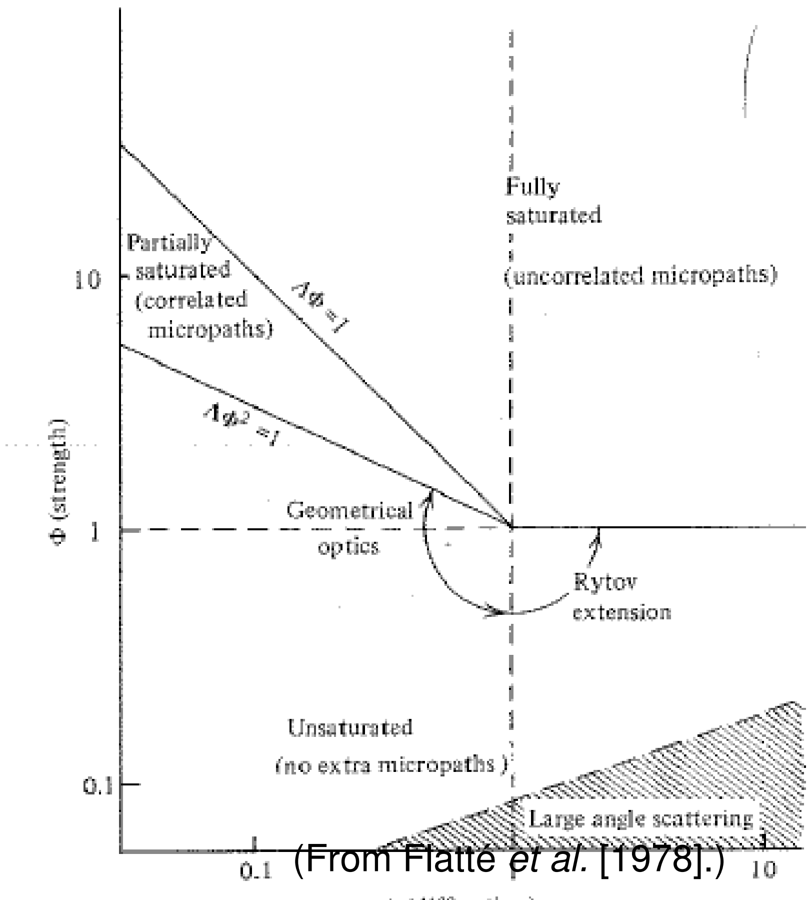
We're operating in the large-phi, large-Lambda region on the plot, but "micromultipathing " isn't consistent with what you're seeing in the data. So you can make the point that new theories must be developed at mid-frequencies in shallow water. " Just as Flatte et al. developed new theories to understand fluctuations in deep water, we must now develop new theories must be developed to understand new problems."

Dan

Motivation

Linear internal waves often are modeled as a background random process introducing random fluctuations in the acoustic field.

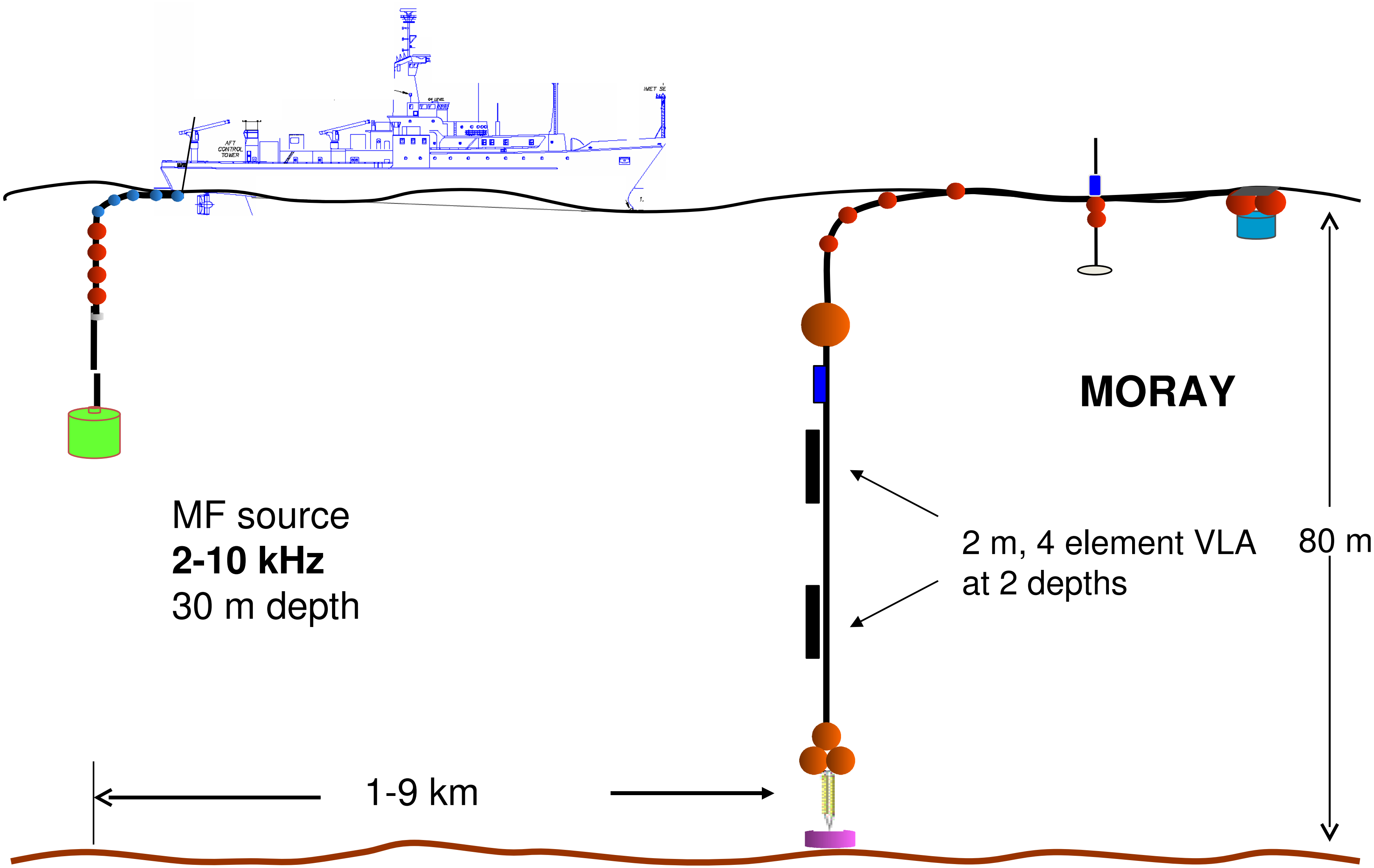
Scattering Theory Regimes



(From Flatté *et al.* [1978].)

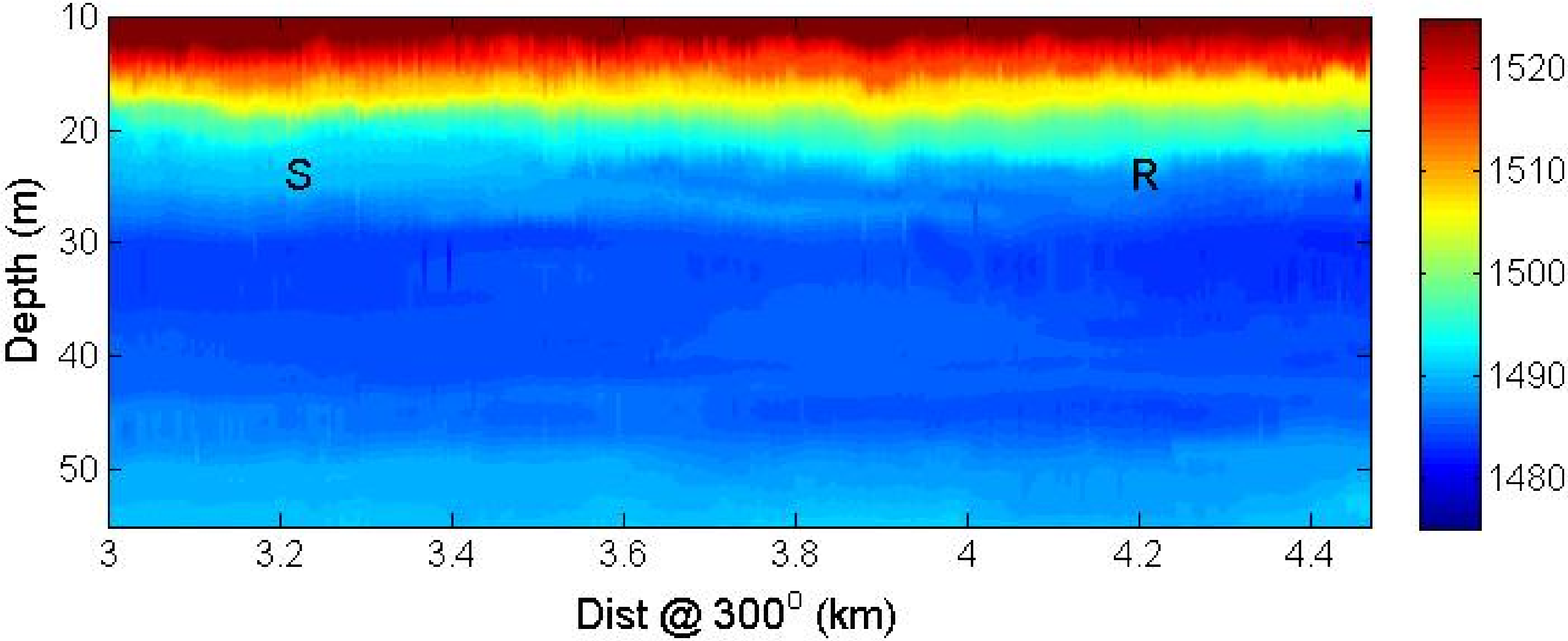
Acoustic fluctuations may be examined using WPRM theory:

Acoustic measurement configuration

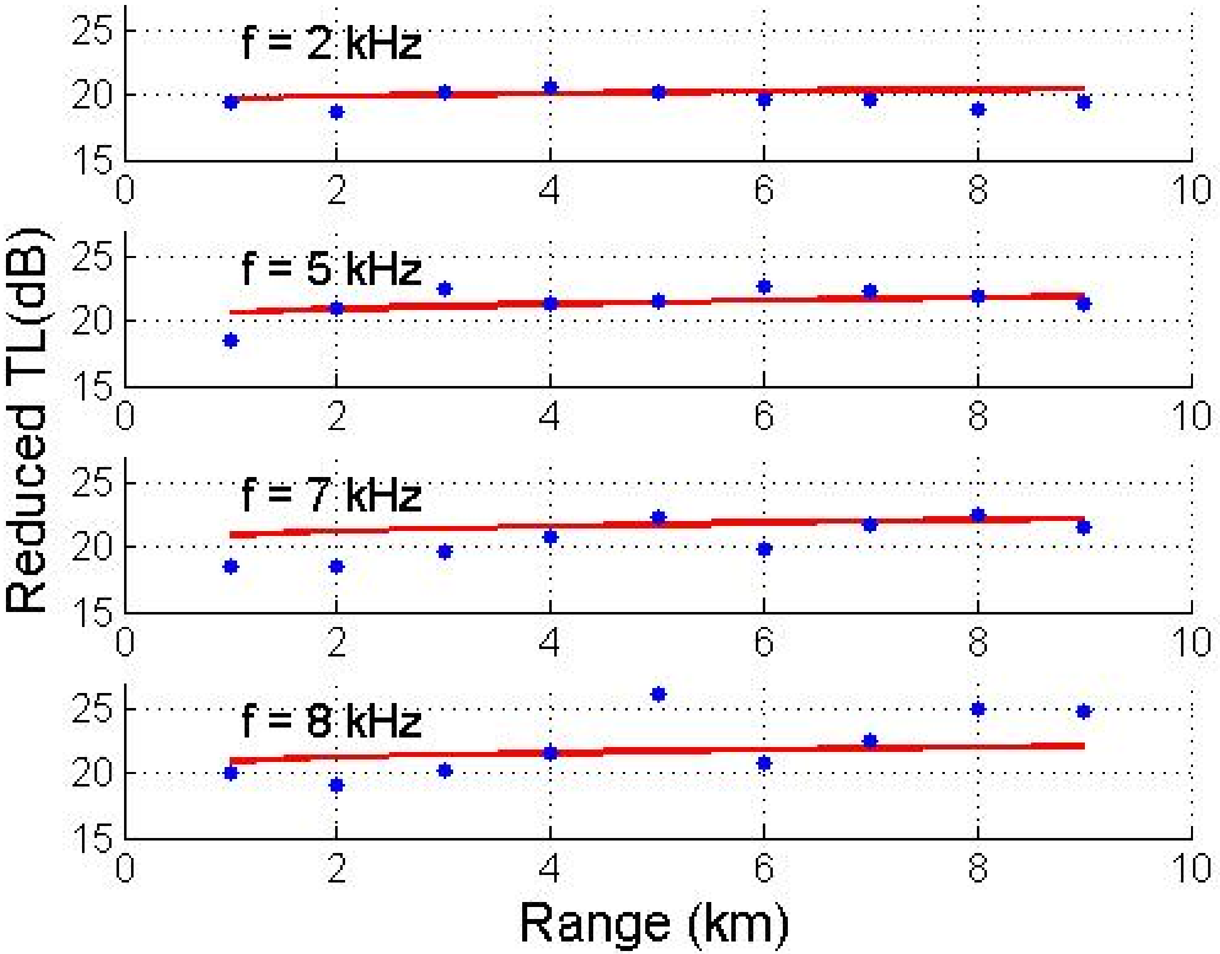


Goal: Predictability and uncertainty of mid-frequency propagation

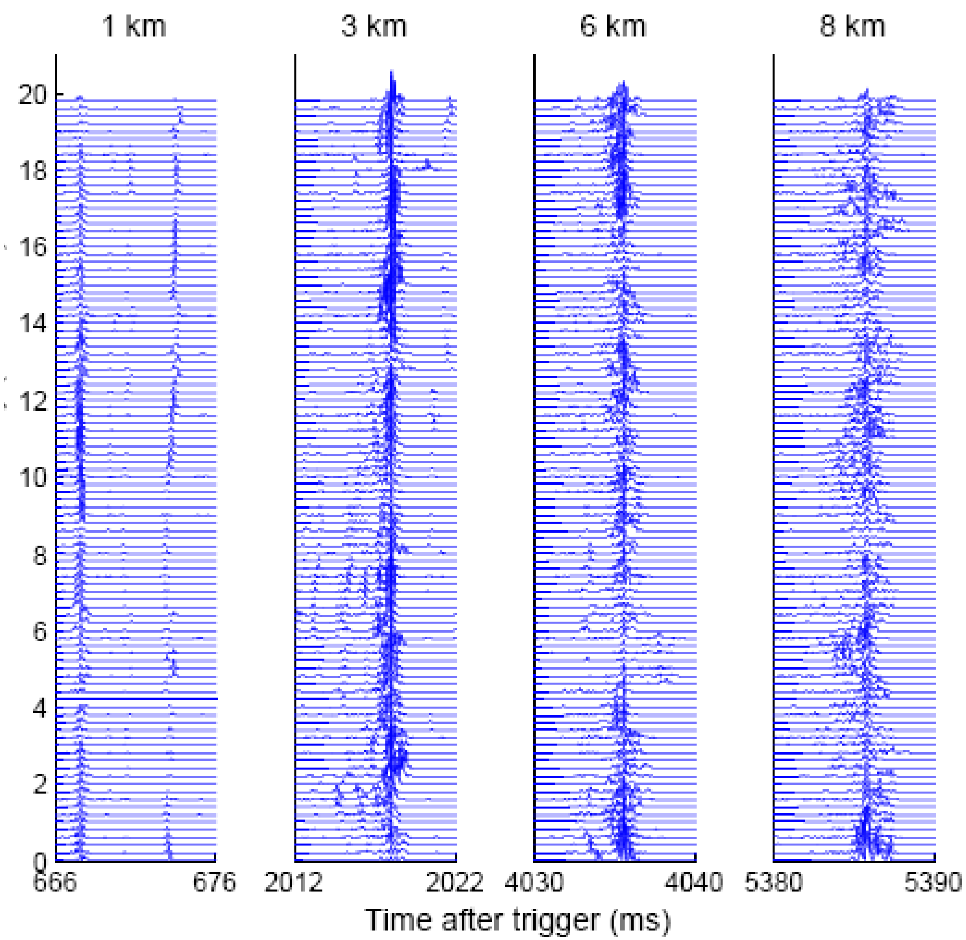
The water column environment:
Thermocline near surface and warm layer near bottom
Data from towed CTD chain



Result:
Mean intensity over frequency and range well modeled using mean SSP and SAMS bottom parameters



Observation of 100 pings 20 s apart:
2.Large intensity fluctuation for all frequency and range, as compared to that of deep water
3.Deep broadband fades over time



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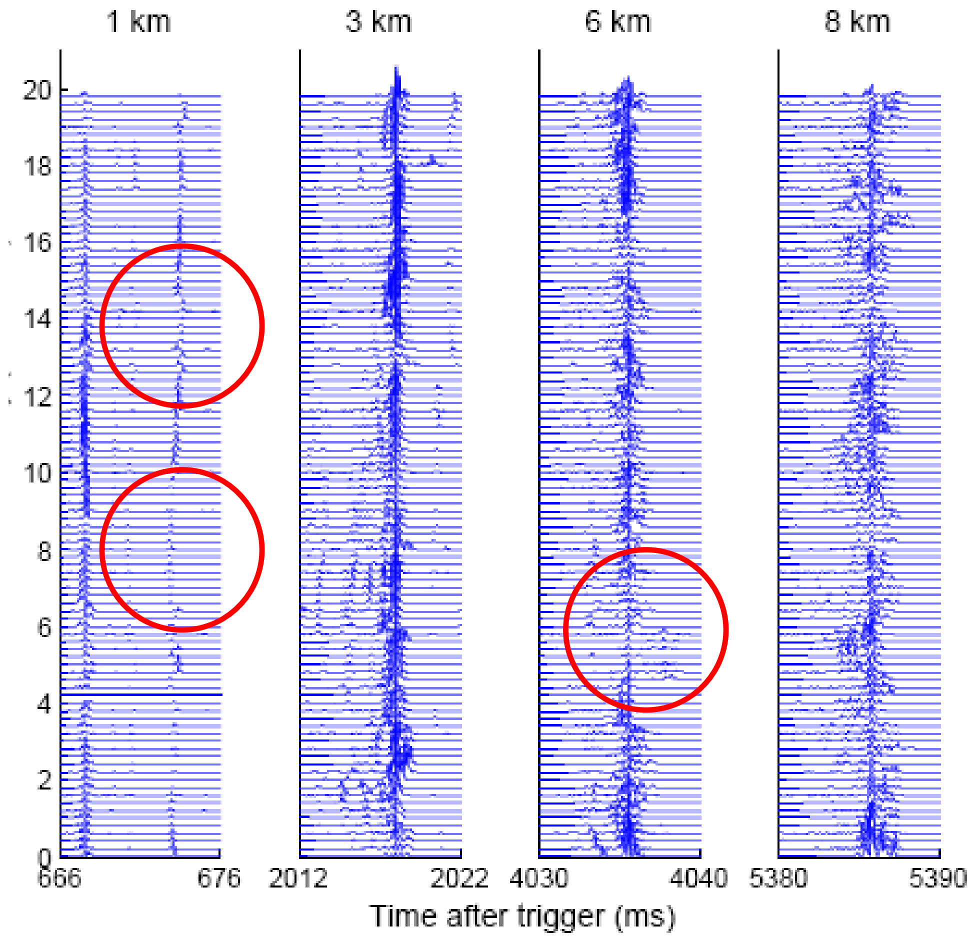
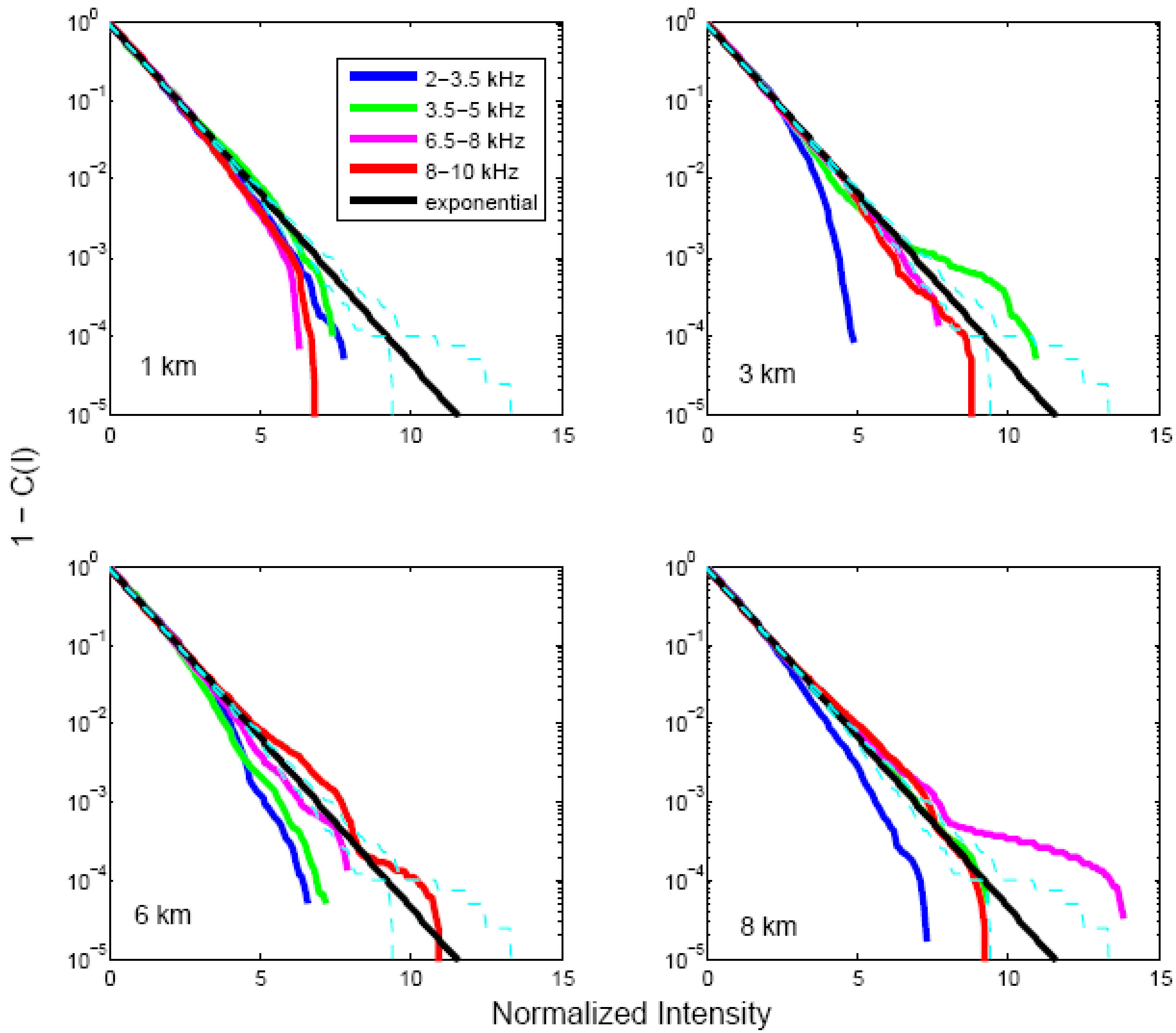


Result: Scintillation index is close to saturation for all frequency, even at a range of 1 km



Significance:

- Though mean TL well modeled, strong fluctuation and deep fades make applications difficult.

- Different from deep ocean, scintillation is much stronger. There is a need to understand why it is so at the basic research level.

- Mid-frequency propagation fluctuations in random media in shallow water are still poorly known and lack empirical observations.

- Quantifying uncertainty depends on understanding of physics causing fluctuations.

Recent progress

Major concern to be addressed:
2.Because the unexpected strong fluctuation, the question is what causes it?

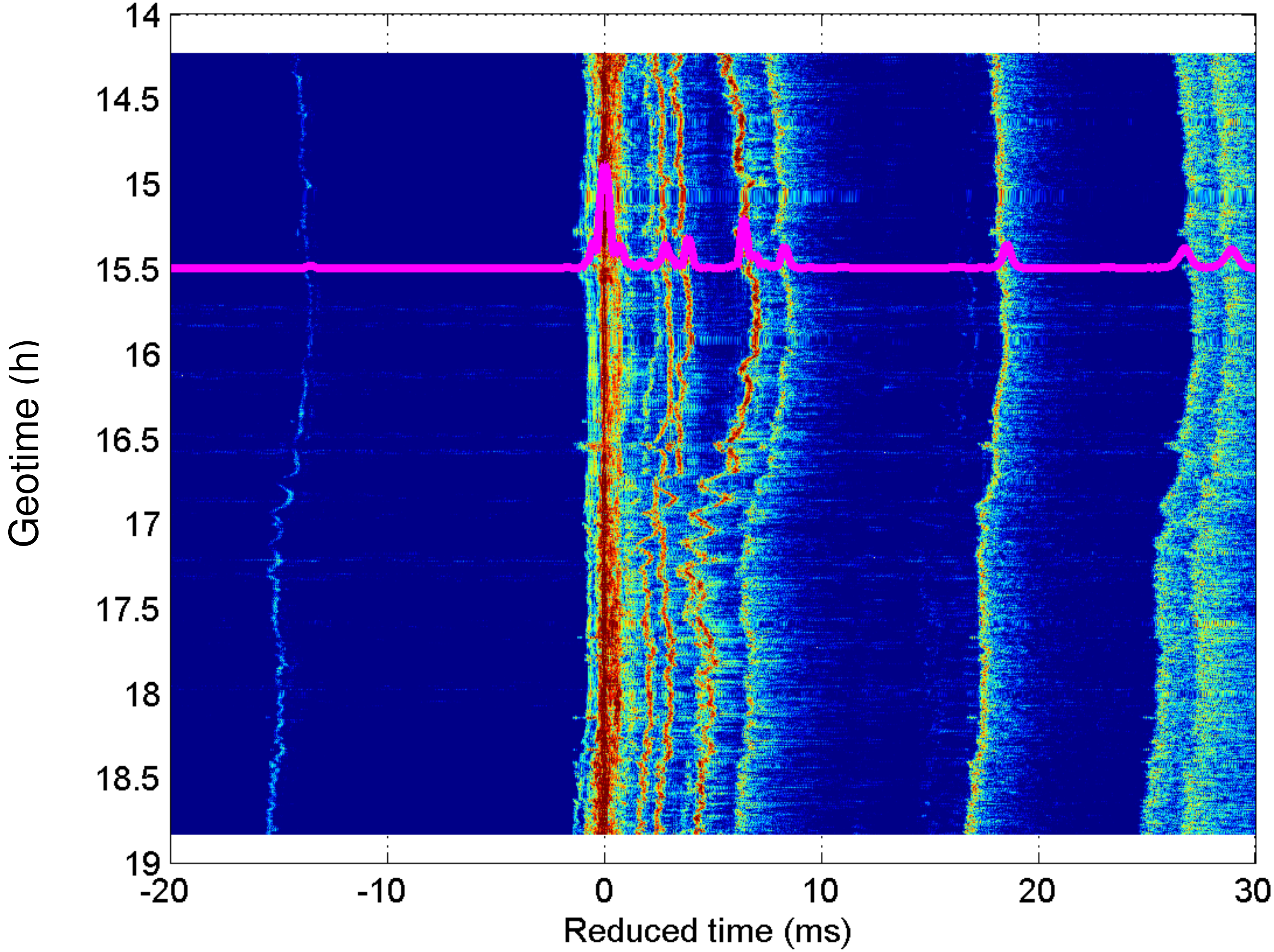
4.Can we find consistent statistical description of the fluctuations to quantify the random waves.

Detailed study on statistics of individual arrivals at the 1 km range.

Approach:

- Detailed study on statistics of individual arrivals at the 1 km range.
- Mean field, 2nd , and 4th moments analyzed.

1 km fixed range data, 2-10 kHz, and PE simulation using CTD 13 taken at 15:29 (UTC) . Four distinct arrivals separable, no-surface interaction.



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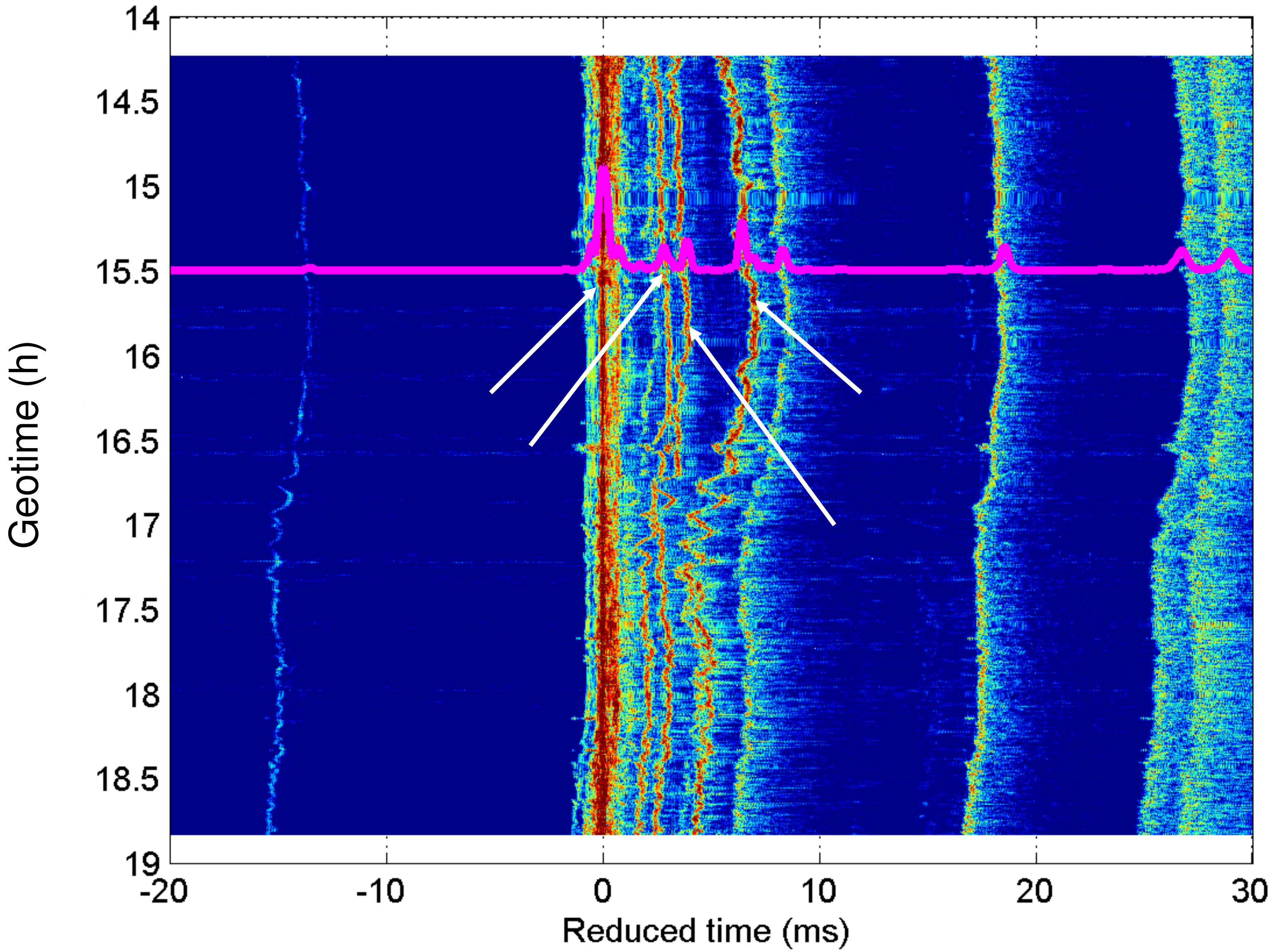
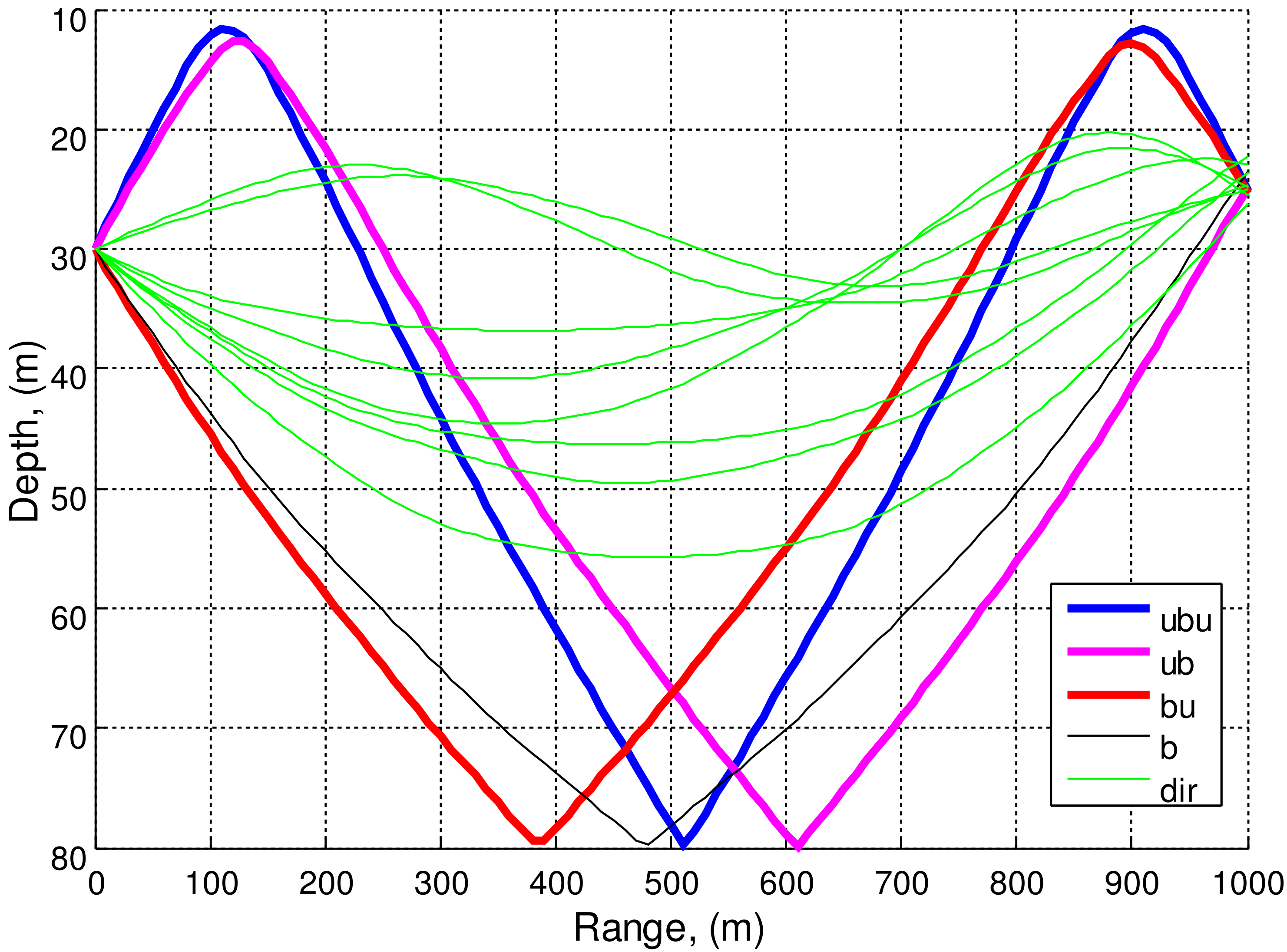
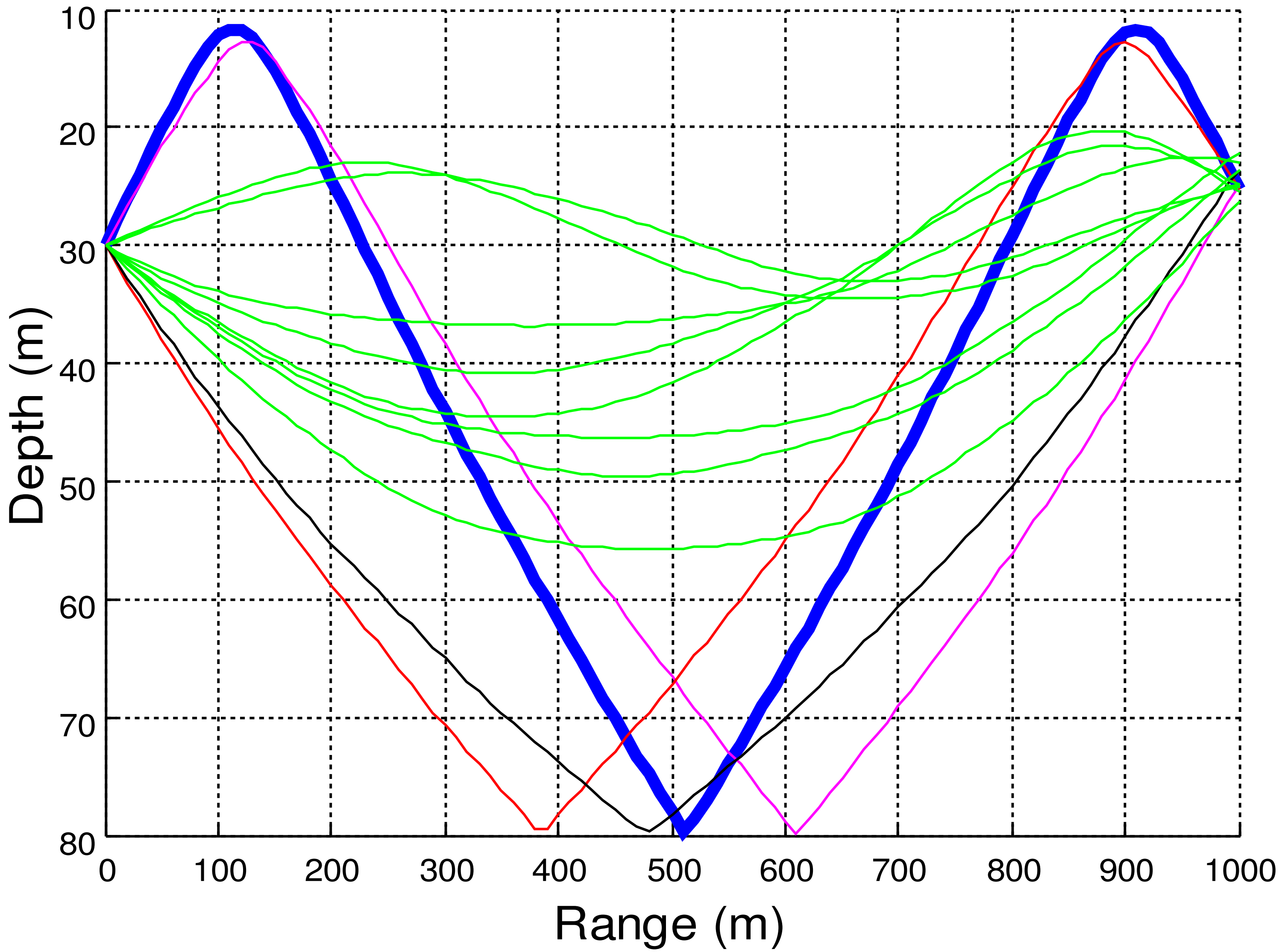


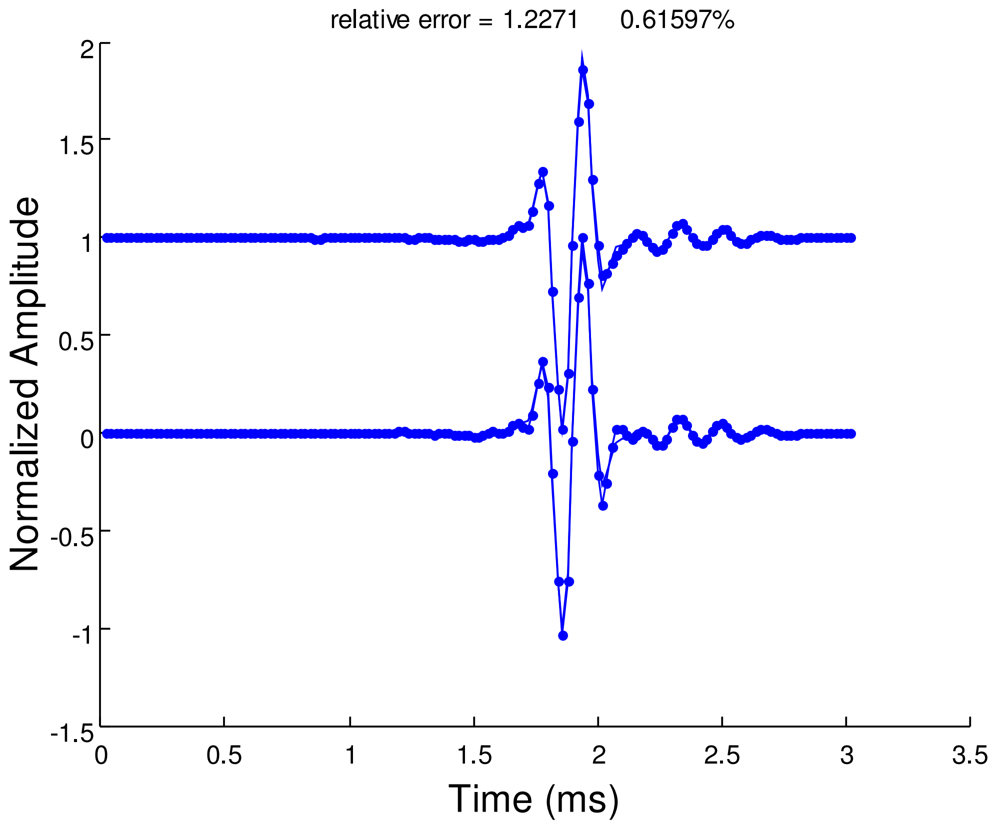


10
20
30
40
50
60
70
80
0
100
200
300
400
500
600
700
800
900
1000
Depth, (m)
Range, (m)
ubu
ub
bu
b
dir

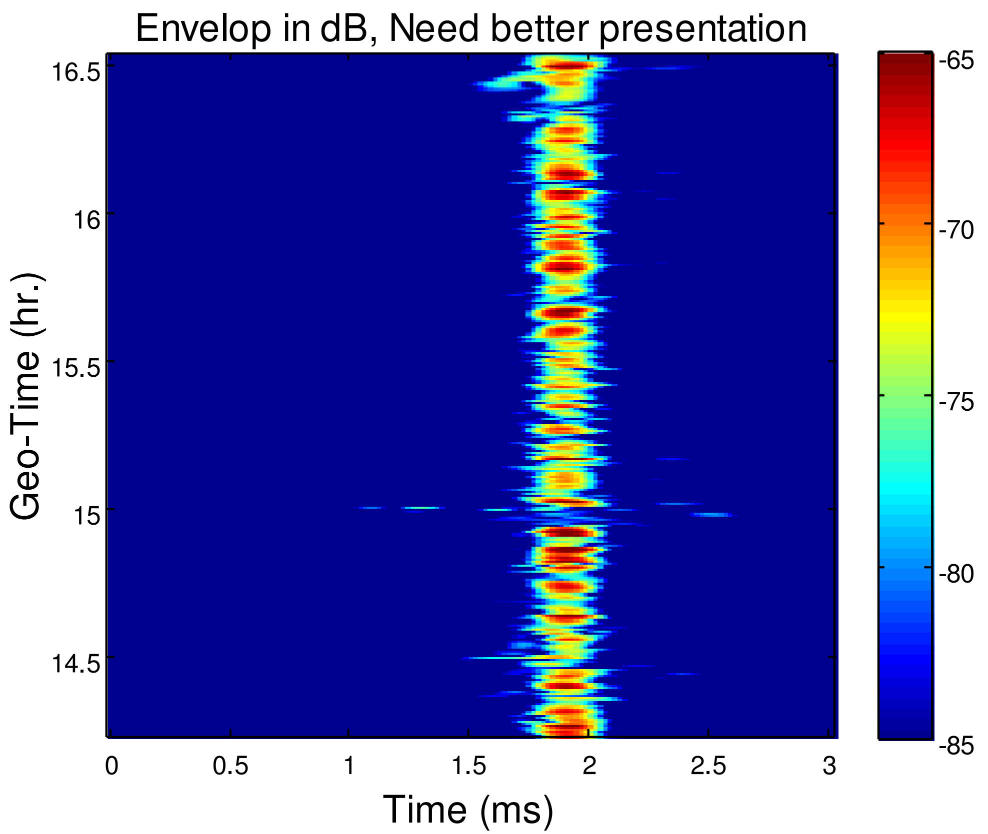
Report concentrates on this arrival

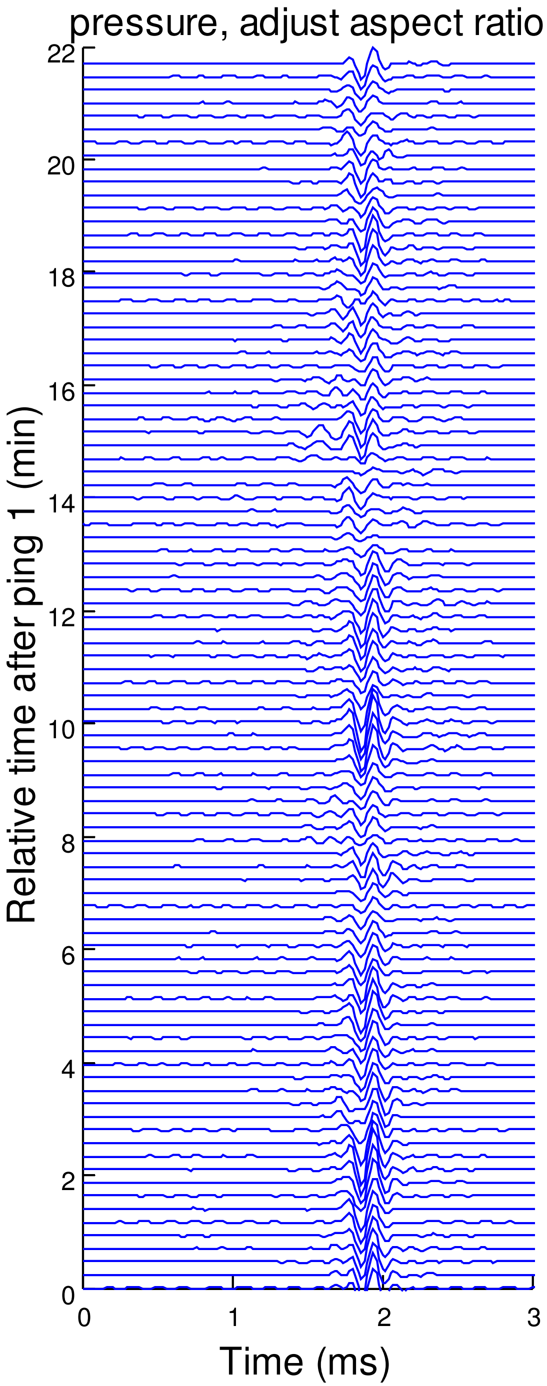


Stable local means-- 225 ping (31minute) average over 3 hours (blue) and overall mean (pink)



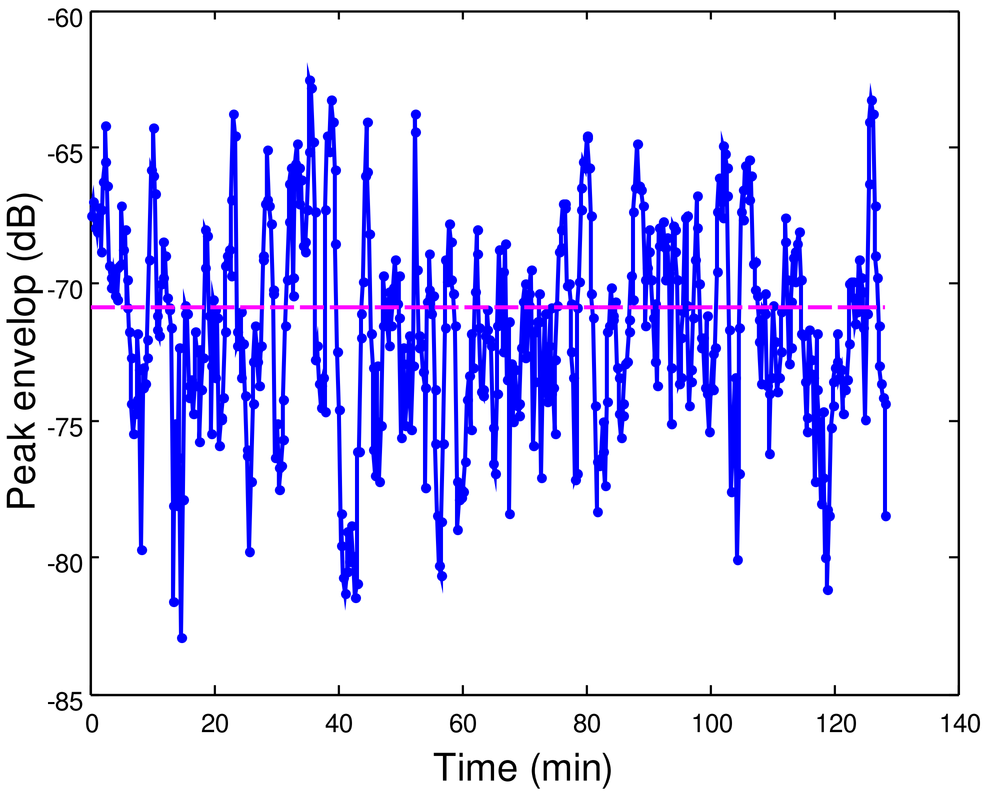
Intensity fluctuation and deep fades even for single path
The next three figures show different aspect of strong fluctuations.





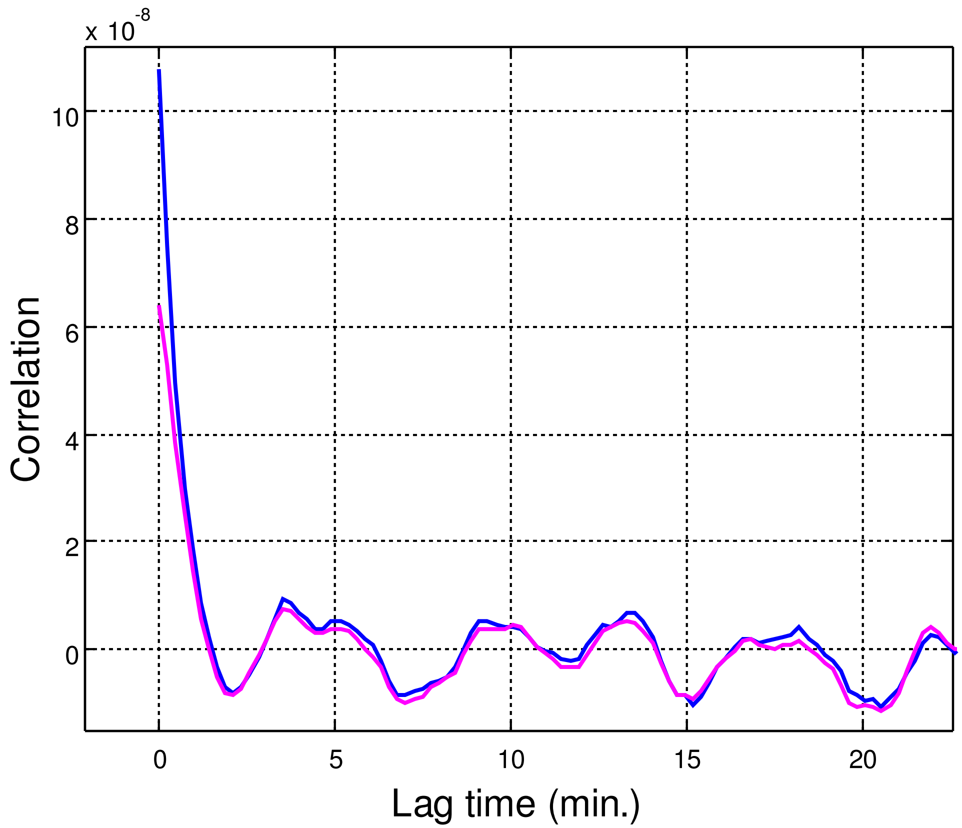
Lined up pressure field vs. time
– fades and spread

Peak intensity envelope varies 10 dB.
Oscillation over ~ 5 minutes

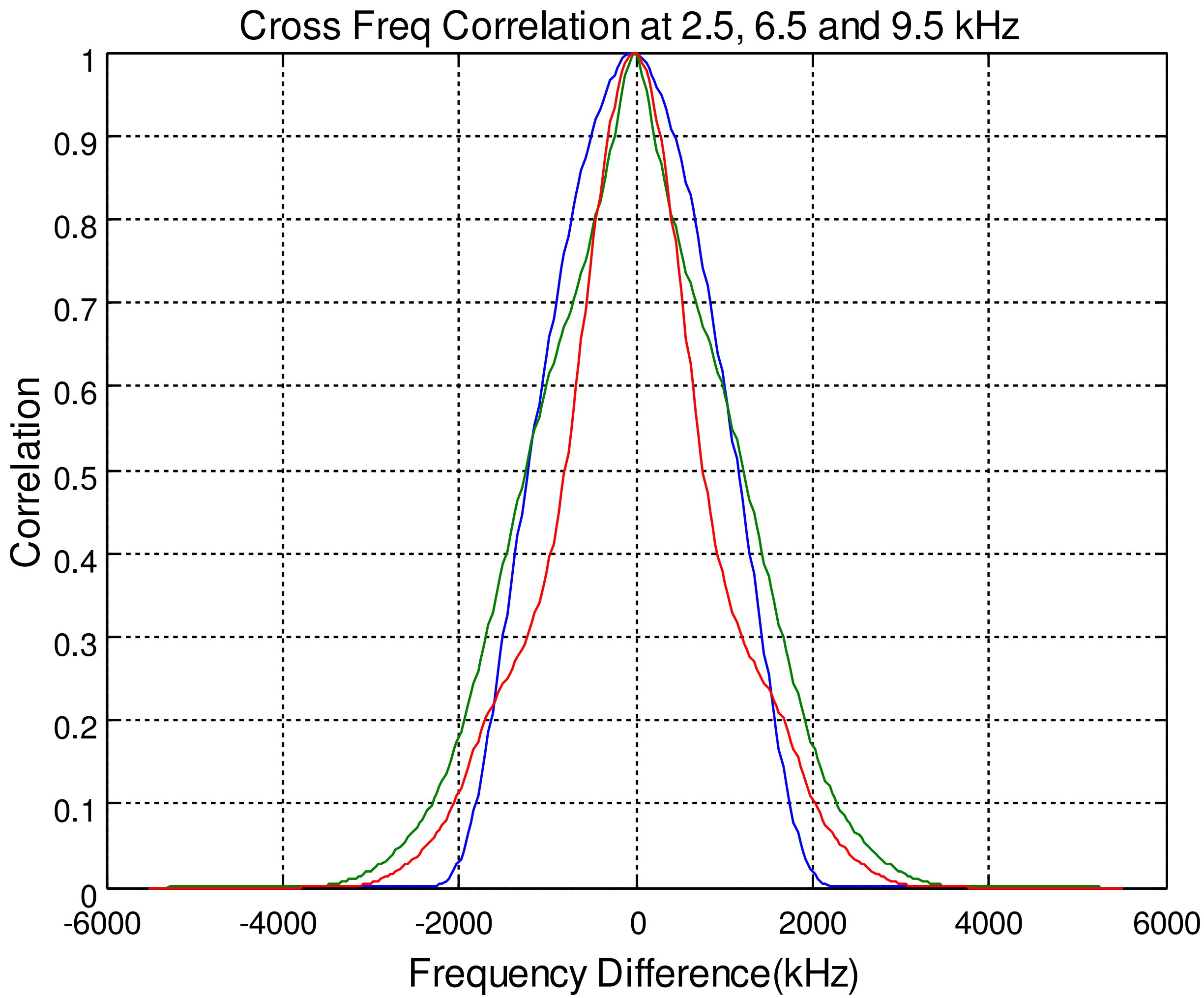


Ping-to-ping un-normalized decorrelation shows zero-crossing time = 1.5 minutes
Decollation is dominated by an amplitude scaling,
s(t) = a(t) <s(t)>, hence focusing is a main cause of fluctuation

Blue: Normal decorrelation, C(l) = Int P_j(t)P_(j+l) dt
Pink: Projecting to mean,
C(l) = Int P_j(t)P_m(t) dt IntP_(j+l)P_m(t) dt/Int(P_m(t)P_m(t) dt



In order to estimate scintillation index for single frequency, we found that intensity cross-frequency correlation > 1 kHz. In the paper, 33 Hz bins were used.



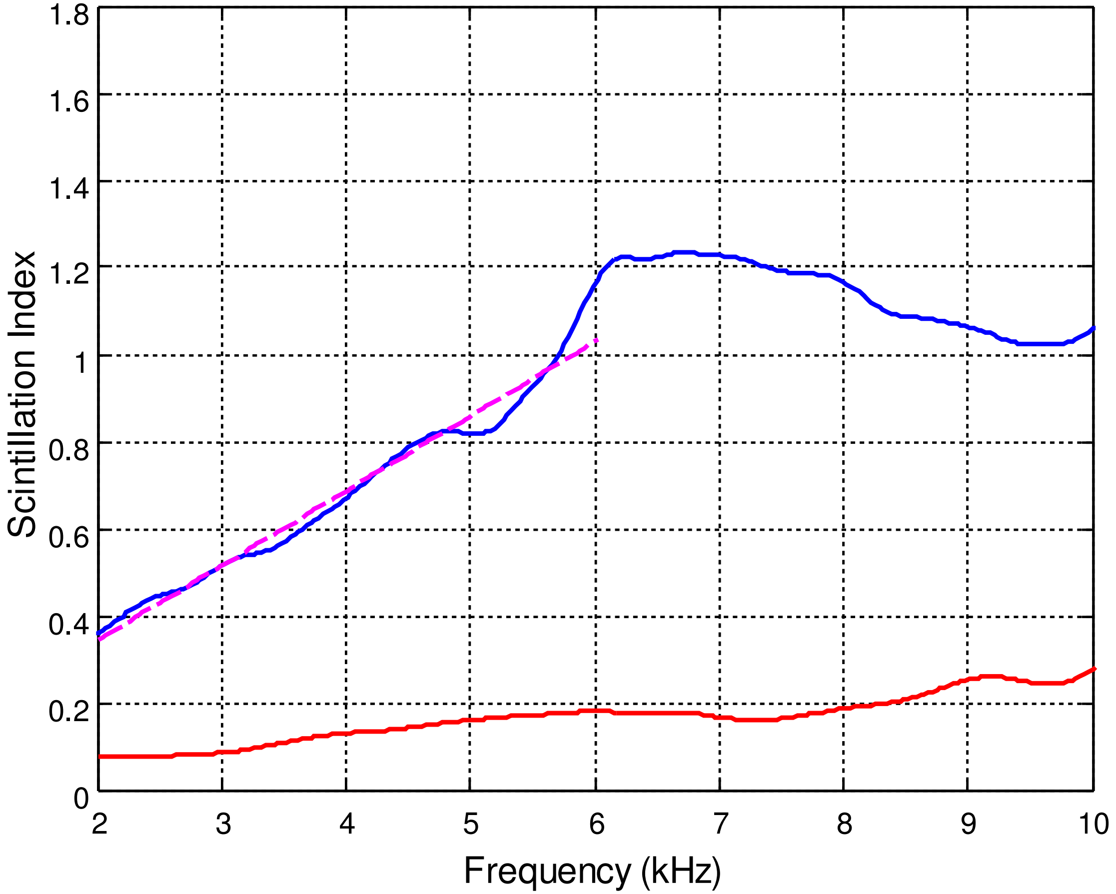
Scintillation index: $\langle I^2\rangle/\langle I\rangle^2 - 1$

Transition under-over-saturation vs. frequency

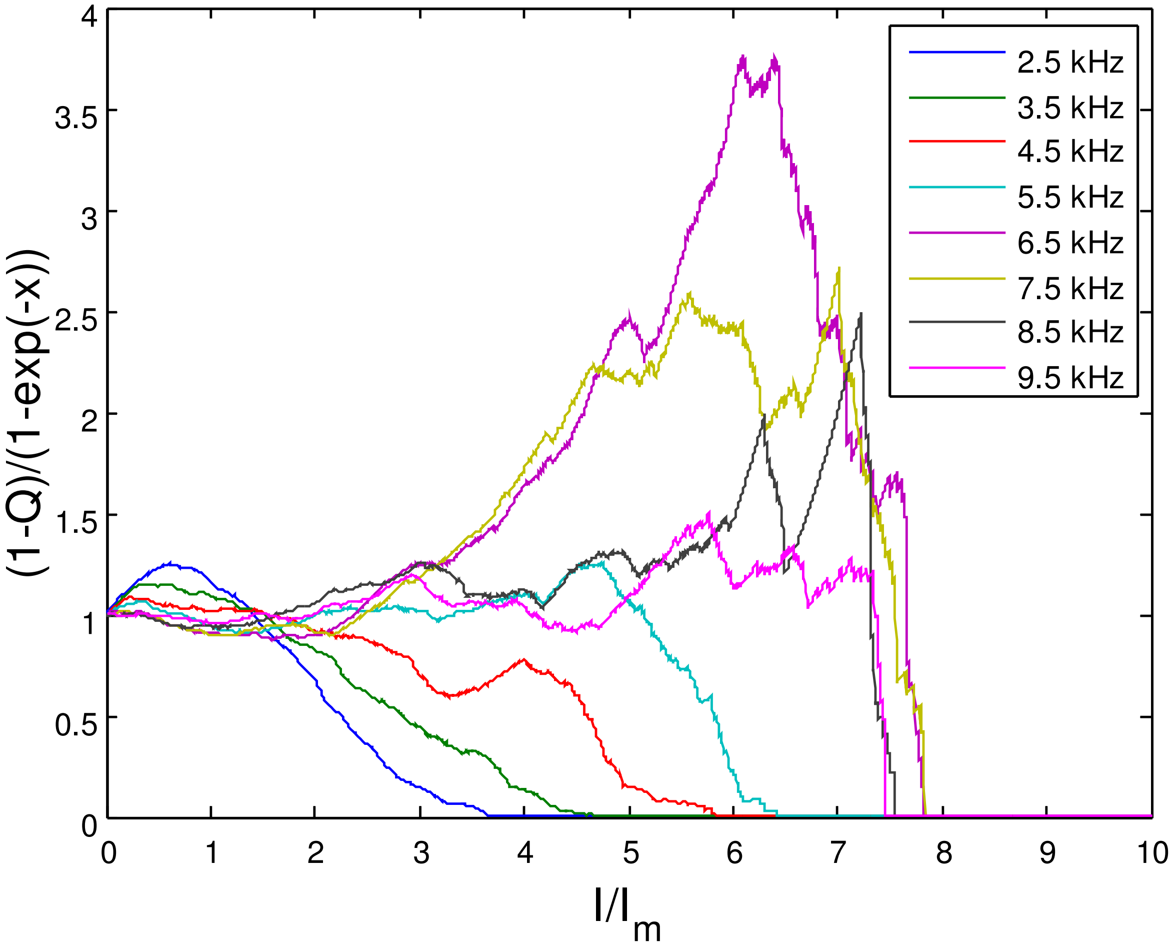
Blue: from ochosen path

Red: 550 single bottom bounce for reference

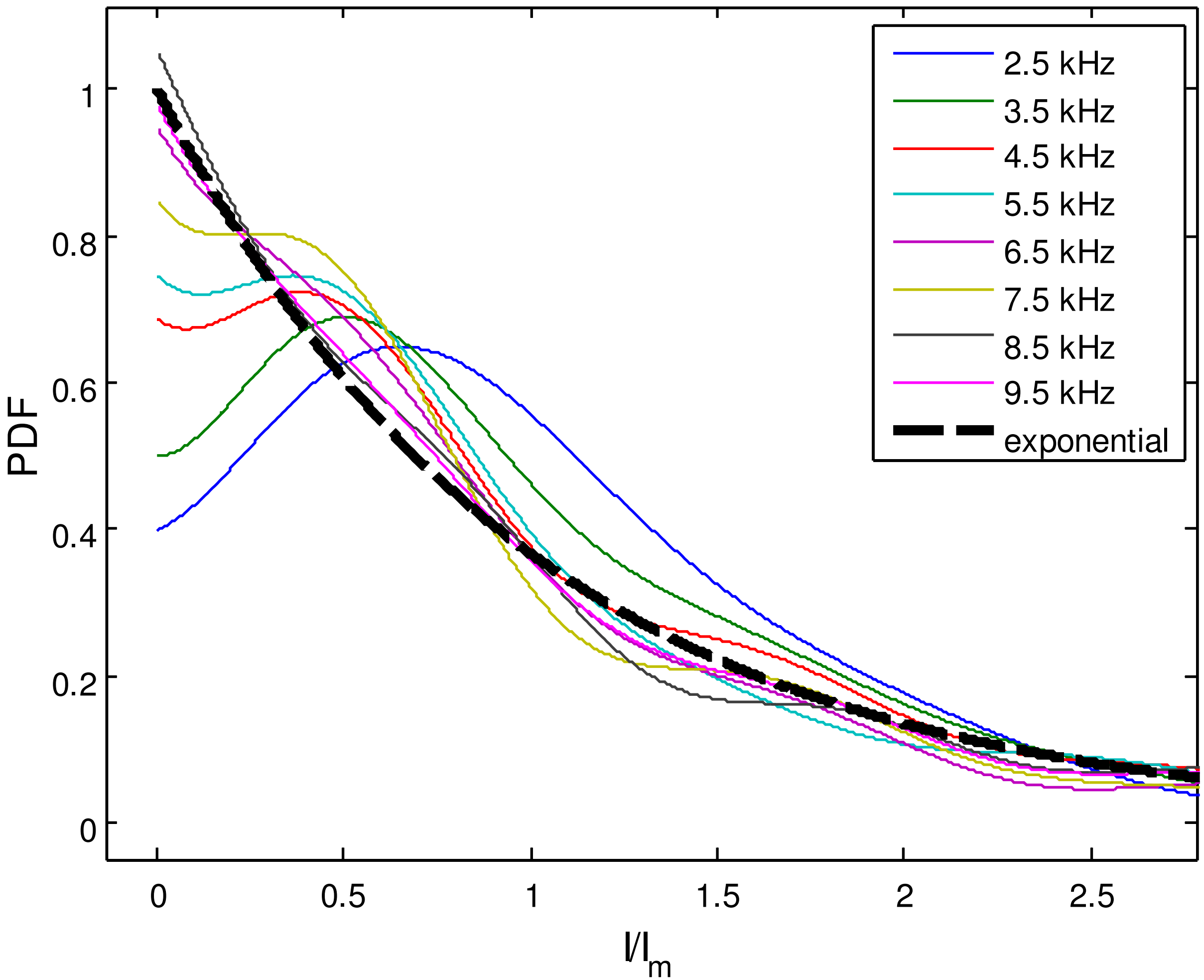
Pink: straight line fit to estimate slope



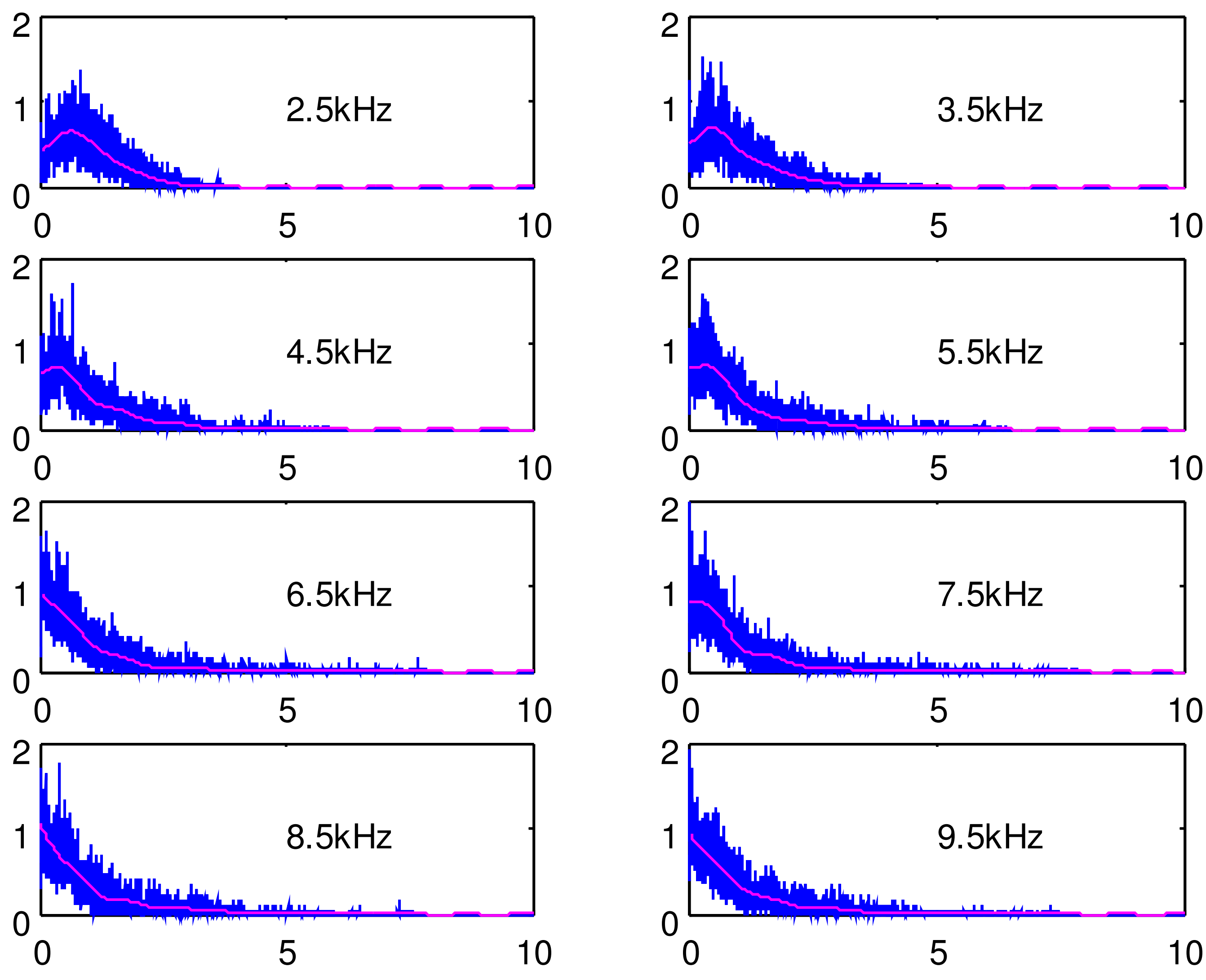
De-trended CDF shows that at low frequency, the distribution is more Gaussian, at mid-band, over saturated, and at highest band (9.5 kHz), it reaches saturation (a constant of 1)



Intensity PDFs vs. frequency show the same clear trend



PDF vs. histograms for consistency check



Recap:

- Mid-frequency propagation in shallow water has distinct fluctuations as compared to low-frequency.
- Single path analysis yields definitive arrival statistics.
- IW is thought to be responsible for the strong fluctuatiion
- 1st order: “coherent mean”: Signals are not fast changing.
- 2nd order: Intensity has strong fluctuation, including deep fades observed previously.
- 2nd order: temporal decorrelation time is about 2 minutes – implication to internal waves structure.
- 2nd order: Fluctuation is dominated by amplitude scaling: $s(t) = a(t) \langle s(t) \rangle$
- 4th order: High cross-frequency correlation – single freq scintillation can be estimated.
- 4th order: Frequency-dependent scintillation index trending toward saturation.

Conclusions and Implications:

2. Single path arrival, *not multi-arrival interference*, fluctuates.
3. Statistics are physically consistent with a picture of ray focusing by upper-turning points seen in deep ocean, but much, much stronger.
4. There is so far no, but need to develop quantitative link between an ocean model and mid-frequency statistics.
5. Counter-measures to uncertainty could be found though combined effort in ocean and acoustic models.
6. Acoustic communications in the mid-frequency band could be impacted by the fluctuations and fading observed.

Note to myself:

- Eventually, waveguide fluctuations have to be dealt with, but the first step is to understand identifiable ray paths.
- Navy concern: fluctuation, fading and lack of coherence, including angular gain.
- Large-scale fluctuation is important for phase fluctuation, and small-scale for intensity fluctuation (?).
- Ocean has anisotropic fluctuations: very different scales on the horizontal and vertical.
- Using rudimentary arguments (ray optics), intensity fluctuation phenomenon, such as saturation, can be qualitatively understood as due to beam focusing.
- $SI = <(I-Im)^2>/Im^2 = <I^2>/Im^2 - 1$
- Implication to low-frequency fluctuation – weak fluctuation region, hence inversion.
- If I is Gaussian, than statistical saturation is easy to see. But our data show that the PDF is not at all Gaussian. Where does the large number of “sources” come from? This is a mystery and a challenge.
- Scintillation due to surface waves has been studied by Thorsos.

References

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