Review of surface propagation studies in Moore's Bay, and other calculations

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CCAPP
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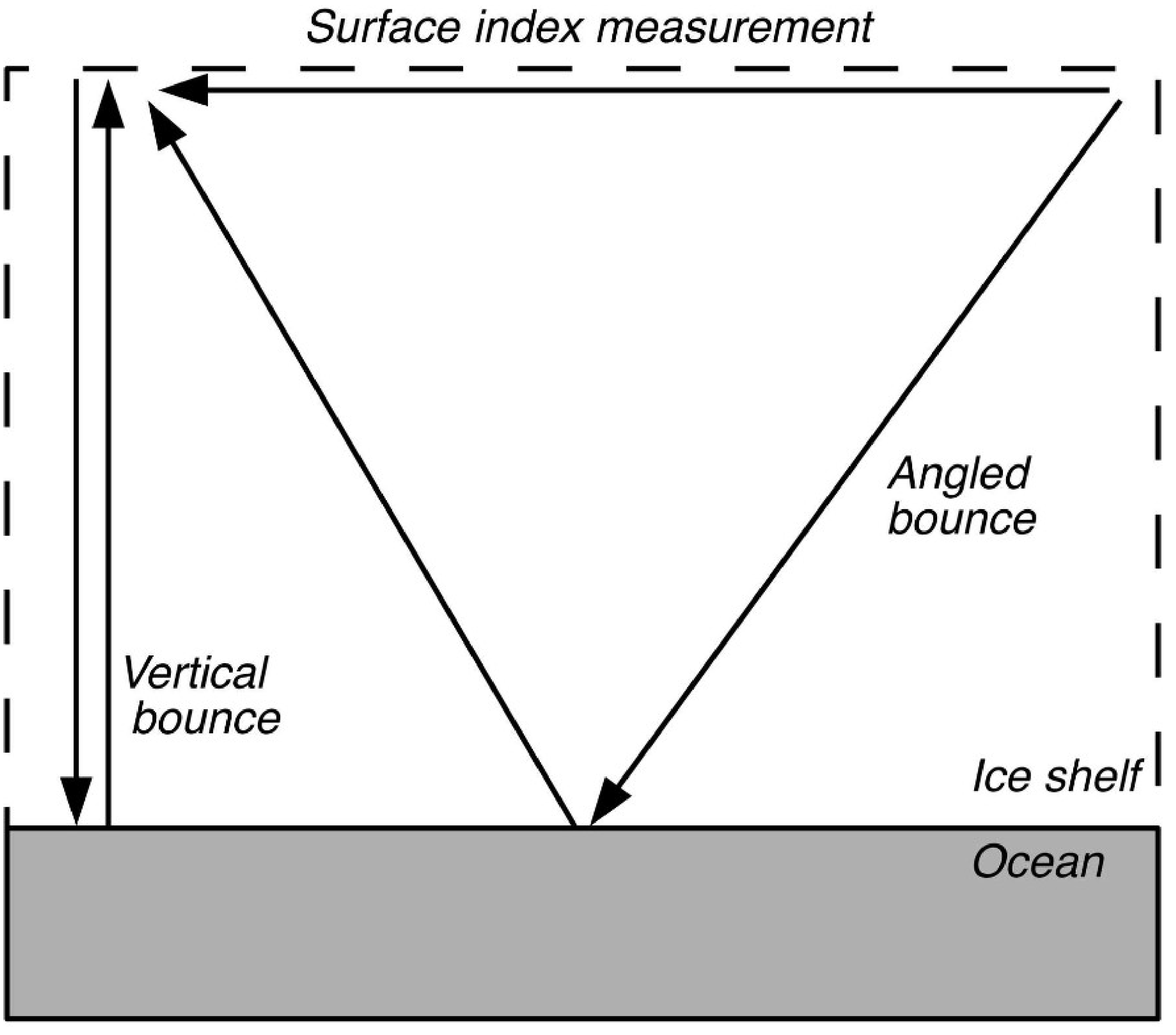
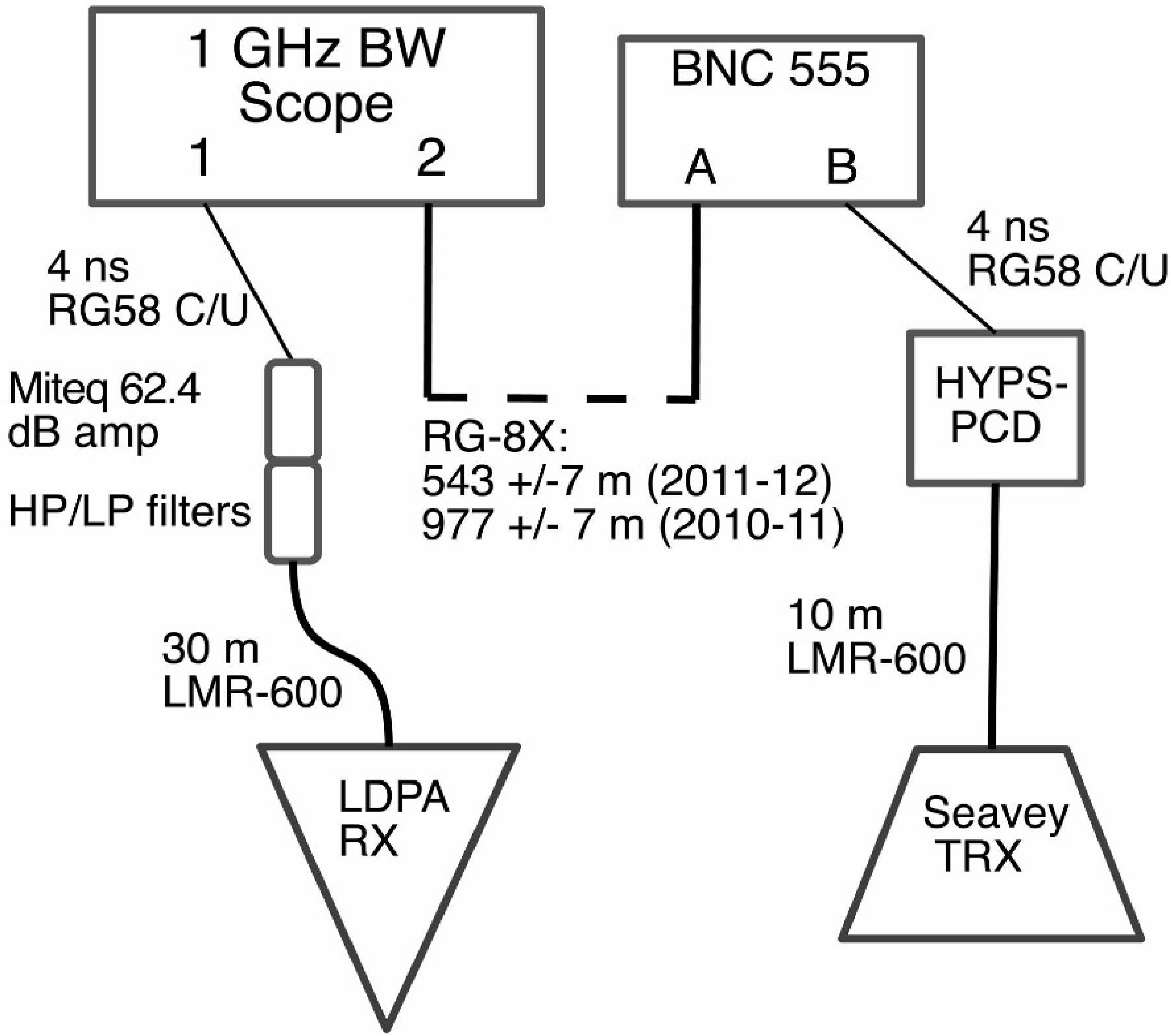
Outline

- Explanation of an experiment conducted in Moore's Bay, 2011-12
  - Motivation
  - Setup
  - Results
- Theoretical calculations (Fermat's principle)
- Reading: “Radio surf in polar ice: A new method of ultrahigh energy neutrino detection.” J. Ralston, Phys. Rev. D **71** 011503 (2005)

Moore's Bay Surface Propagation Experiment



Moore's Bay Surface Propagation Experiment



Moore's Bay Surface Propagation Experiment

Component	Delay (ns)
RG-58	4.0
10 m LMR-600	38
20 m LMR-600	76
RG-8X	2134
PCD	10

$$\Delta = \Delta t_{\mathrm{prop}} - \Delta t_{sys} = n \Delta x / c - \Delta t_{sys}$$

$$n = c \left(\Delta + \Delta t_{sys} \right) / \Delta x$$

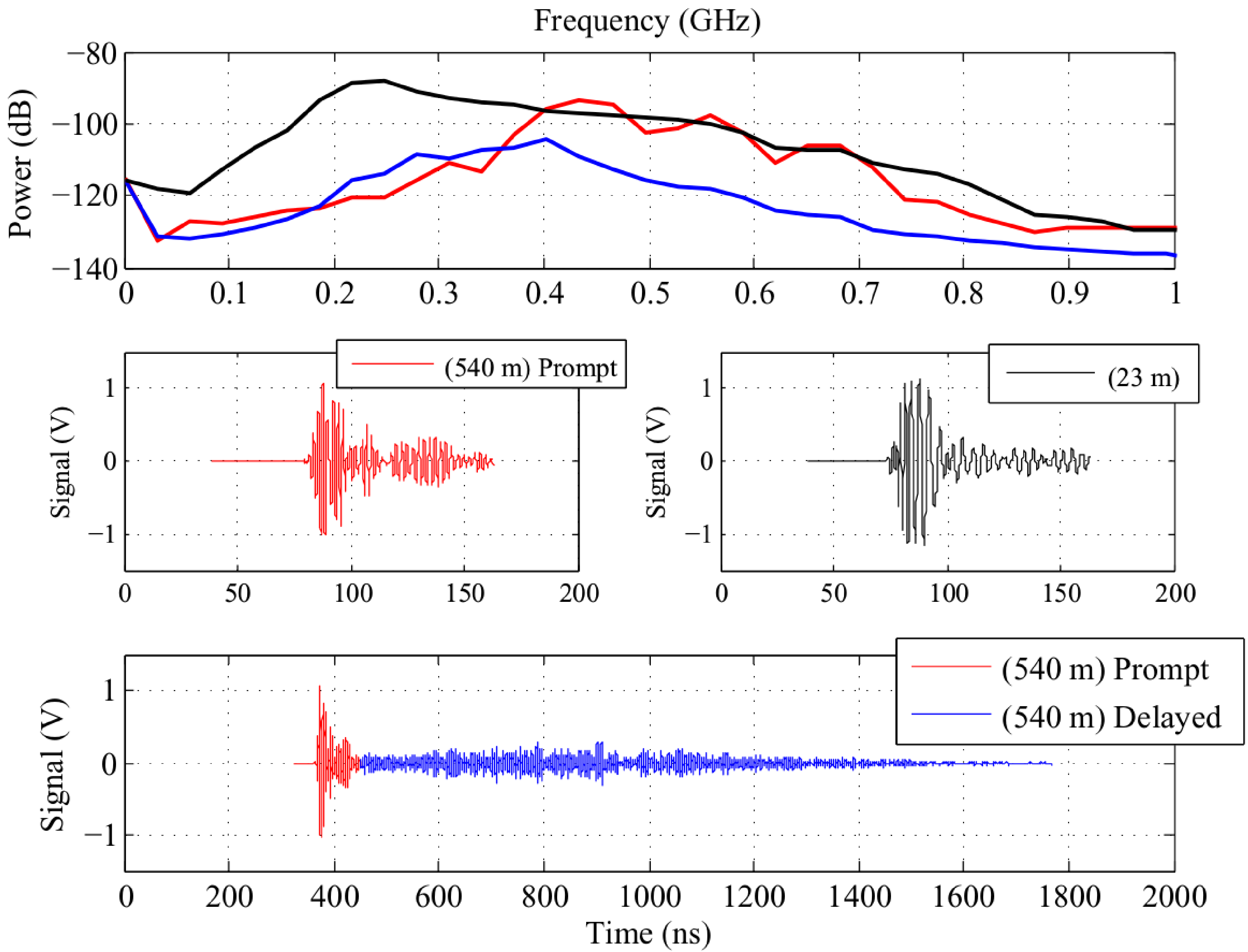
$$\sigma_n = \frac{c}{\Delta_x} \sqrt{\sigma_\Delta^2 + \sigma_T^2 + \left(\frac{\sigma_x}{x} \right)^2 \left(\Delta + \Delta t_{sys} \right)^2}$$

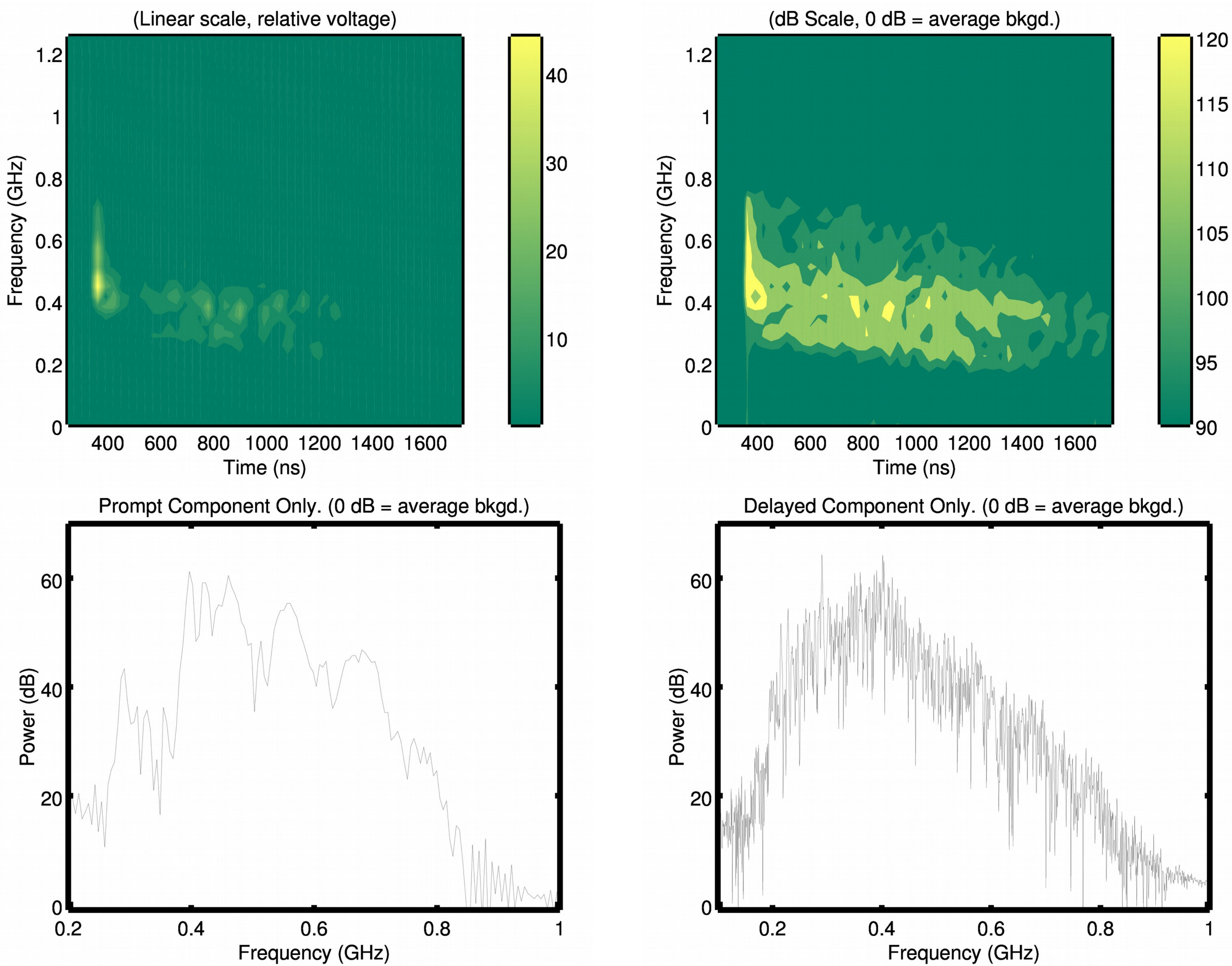
Results: Δ = 360+/-10 ns, Δt_{sys} = 1964 ns

n = 1.29+/-0.02

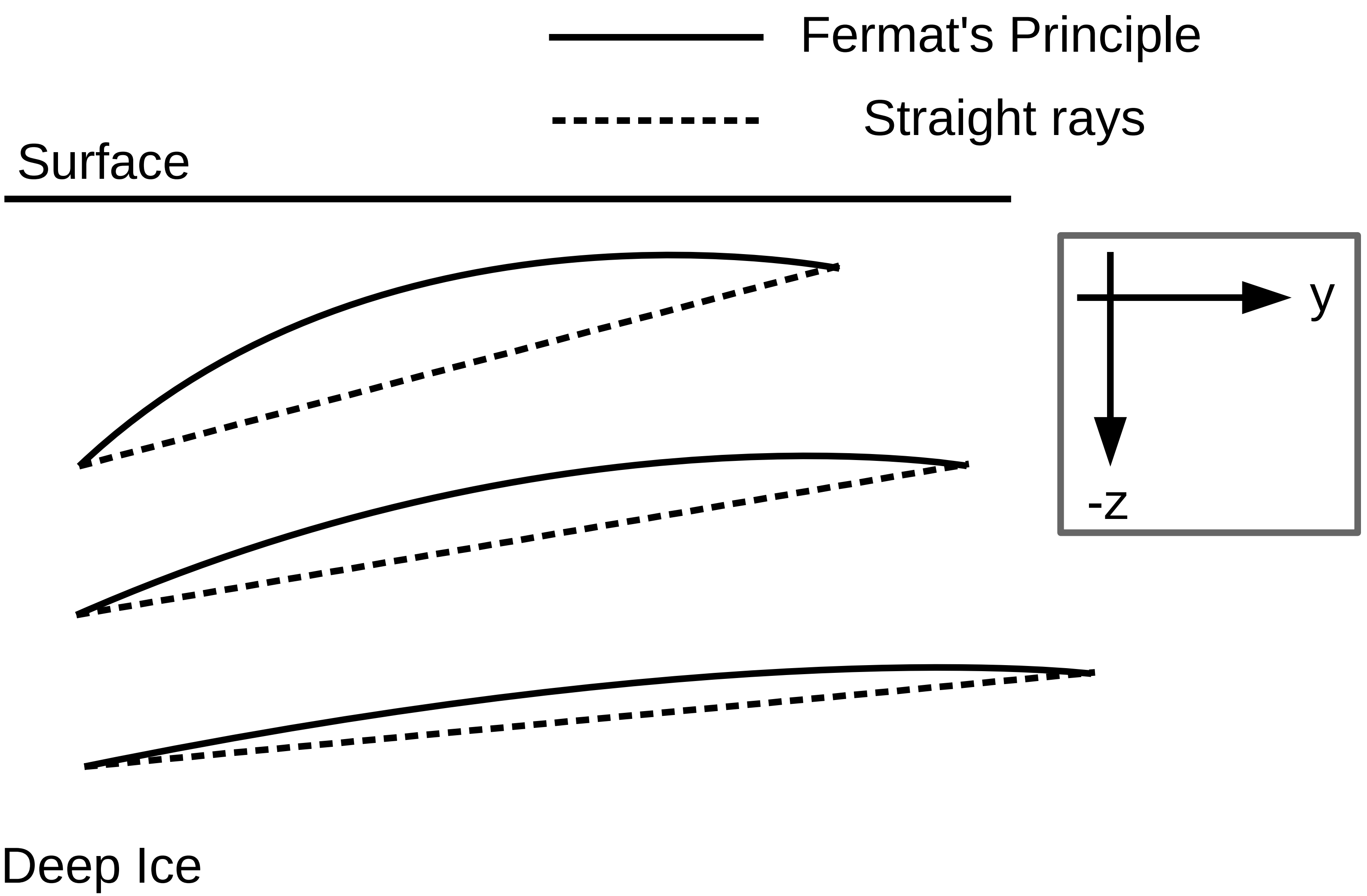
(No one source of error dominates).

Data Acquired

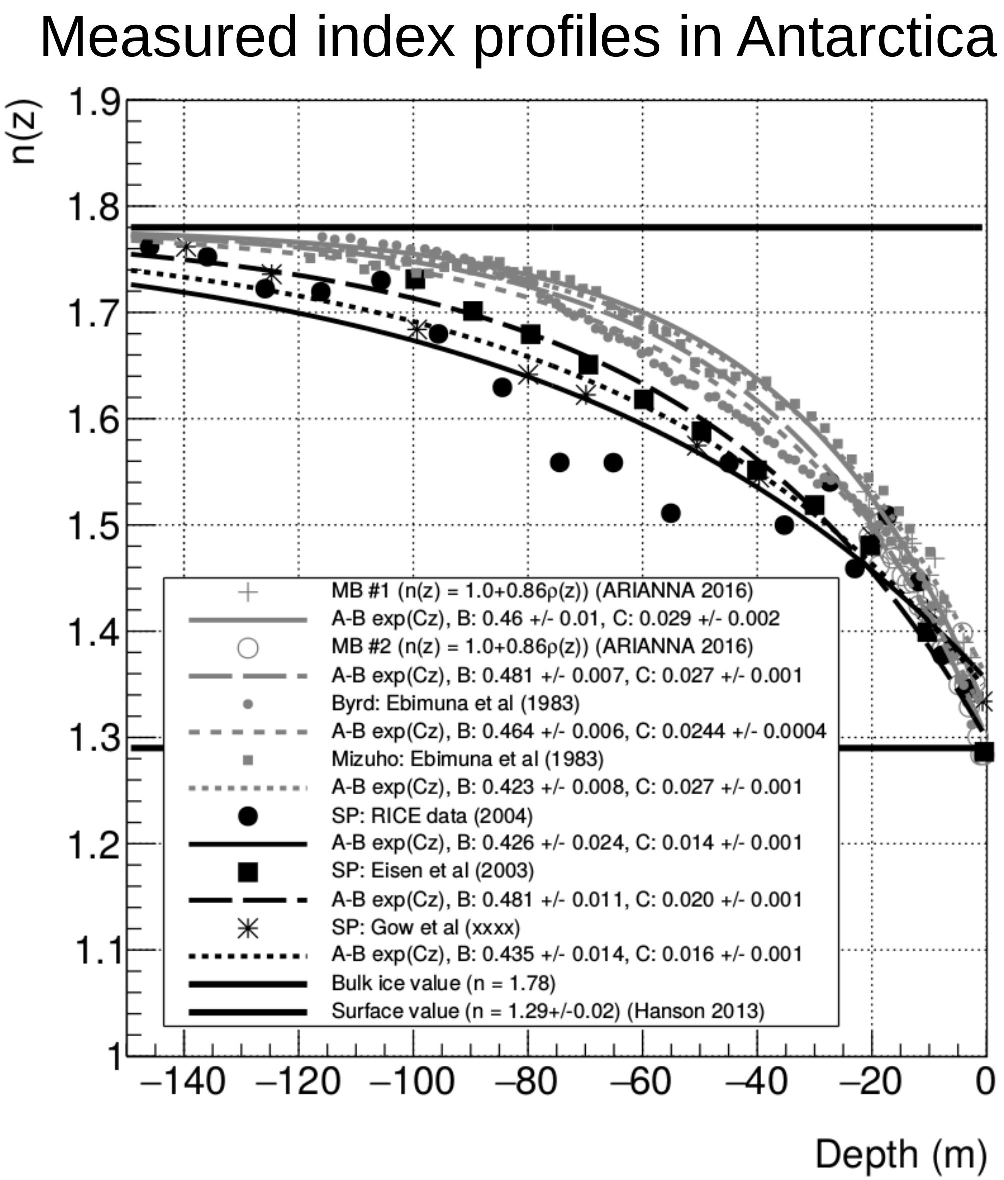



(Linear scale, relative voltage)
Frequency (GHz)
Time (ns)
(dB Scale, 0 dB = average bkgd.)
Frequency (GHz)
Time (ns)
Prompt Component Only. (0 dB = average bkgd.)
Power (dB)
Frequency (GHz)
Delayed Component Only. (0 dB = average bkgd.)
Power (dB)
Frequency (GHz)

Theoretical Calculations (see report on Dropbox)



Theoretical Calculations (see report on Dropbox)



Theoretical Calculations (see report on Dropbox)

Ref./Location	$A = n_{ice}$	B	n_s	C (m^{-1})	z_0 (m)
MB#1/Moore's Bay	1.78	0.46 ± 0.01	1.32 ± 0.01	0.029 ± 0.002	34.5 ± 2
MB#2/Moore's Bay	1.78	0.481 ± 0.007	1.299 ± 0.007	0.027 ± 0.001	37 ± 1
Ebimuna (1983)/Byrd	1.78	0.464 ± 0.006	1.316 ± 0.006	0.0244 ± 0.0004	41 ± 1
Ebimuna (1983)/Mizuho	1.78	0.423 ± 0.008	1.357 ± 0.006	0.027 ± 0.001	37 ± 1
RICE (2004)/South Pole	1.78	0.43 ± 0.02	1.35 ± 0.02	0.014 ± 0.001	71 ± 5
Eisen (2003)/South Pole	1.78	0.48 ± 0.01	1.3 ± 0.01	0.020 ± 0.001	50 ± 2.5
Gow (xxxx)/South Pole	1.78	0.435 ± 0.01	1.345 ± 0.01	0.016 ± 0.001	62.5 ± 4

Table 1: The fit parameters for the curves shown in Fig. 1. The function fit to the data is $n(z) = n_{ice} - \Delta n \exp(Cz)$. The differential equation derived in the first section requires $n_{ice} = 1.78$ and $B = \Delta n = n_{ice} - n(0)$ as boundary conditions.

Theoretical Calculations (see report on Dropbox)

$$\delta S = 0 \tag{19}$$

$$\delta \int_A^B n(z)(1+\dot{y}^2)^{1/2} dx dy dz = \int_A^B L(z,\dot{y}) dx dy dz = 0 \tag{20}$$

$$\boxed{\dot{u} = z_0^{-1} \left(\frac{\Delta n e^{z/z_0}}{n_{ice} - \Delta n e^{z/z_0}} \right) (u^3 + u)} \tag{24}$$

Definitions:
1) Derivatives are with respect to z
2) u = dy/dz
3) ***z_0 is the same from n(z)***

Limiting Cases:
a) Deep ice: ***straight lines***
b) Surface, ~horizontal: ***quadratic***
c) Shallow: ***quadratic***

$|z| \gg z_0,\ z < 0$:

$$\dot{u} = 0$$

$$z(y) = -\frac{1}{2z_0}\left(\frac{n_{ice} - n_s}{n_s}\right)(y - y_1)^2 + z_1$$

$$z(y) = -\frac{1}{2}\frac{Q_1}{z_0}(y - y_1)^2 - \frac{Q_0}{Q_1} z_0$$

Wait for it...If z_0 is the quadratic curvature, and that number is measured to be larger for Moore's Bay, ***paths should be bent MORE in Moore's Bay.***

They are not, apparently. Or, at least some portion of the wave is not.

So although my analytic model of ray-tracing is fast, simple, and based on Fermat's principle, it's not entirely correct.

Conclusions

- Explanation of an experiment conducted in Moore's Bay, 2011-12
  - Motivation – **Looking for surface propagation**
  - Setup – **540 meter baseline**
  - Results – **Prompt and Delayed Components propagated along surface**
- Theoretical calculations: Fermat's principle tells us that if there is a solution between two points, the fastest path between them for firn is roughly quadratic.
- Reading: "Radio surf in polar ice: A new method of ultrahigh energy neutrino detection." J. Ralston, Phys. Rev. D **71** 011503 (2005)